PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

National Library
of Canada

Acquisitions and
Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale
du Canada

Direction des acquisitions et
des services bibliographiques

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file / Votre référence

Our file / Notre référence

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents.

COMPUTER-ASSISTED LEARNING IN CONTROL SYSTEMS EDUCATION

by

RACHEL JUDITH WELCH. B.Eng.

A thesis submitted to
the Faculty of Graduate Studies and Research,
in partial fulfilment of
the requirements for the degree of
Master of Engineering

**Department of Mechanical and Aerospace Engineering
Ottawa-Carleton Institute
for Mechanical and Aerospace Engineering**

Carleton University
Ottawa, Ontario
August 21, 1995

©1995. Rachel Welch

National Library
of Canada

Acquisitions and
Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale
du Canada

Direction des acquisitions et
des services bibliographiques

395 rue Wellington
Ottawa (Ontario)
K1A 0N4

Author's irrevocable licence

Author's irrevocable licence

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-612-08970-3

Name NACHEB JUDITH NELLEH

Dissertation Abstracts International is arranged by broad, general subject categories. Please select the one subject which most nearly describes the content of your dissertation. Enter the corresponding four-digit code in the spaces provided.

MECHANICAL ENGINEERING

SUBJECT TERM

0548

U·M·I

SUBJECT CODE

Subject Categories

THE HUMANITIES AND SOCIAL SCIENCES

COMMUNICATIONS AND THE ARTS

Architecture 0729
Art History 0377
Cinema 0900
Dance 0378
Fine Arts 0357
Information Science 0723
Journalism 0391
Library Science 0399
Mass Communications 0708
Music 0413
Speech Communication 0459
Theater 0465

EDUCATION

General 0515
Administration 0514
Adult and Continuing 0516
Agricultural 0517
Art 0273
Bilingual and Multicultural 0282
Business 0688
Community College 0275
Curriculum and Instruction 0727
Early Childhood 0518
Elementary 0524
Finance 0277
Guidance and Counseling 0519
Health 0680
Higher 0745
History of 0520
Home Economics 0278
Industrial 0521
Language and Literature 0279
Mathematics 0280
Music 0522
Philosophy of 0998
Physical 0523

Psychology 0525
Reading 0535
Religious 0527
Sciences 0714
Secondary 0533
Social Sciences 0534
Sociology of 0340
Special 0529
Teacher Training 0530
Technology 0710
Tests and Measurements 0288
Vocational 0747

LANGUAGE, LITERATURE AND LINGUISTICS

Language 0679
General 0289
Ancient 0290
Linguistics 0291
Modern 0401
Literature 0294
General 0295
Classical 0297
Comparative 0298
Medieval 0316
Modern 0591
African 0305
American 0352
Asian 0355
Canadian (English) 0593
Canadian (French) 0311
English 0312
Germanic 0315
Latin American 0313
Middle Eastern 0314
Romance 0370
Slavic and East European 0372

PHILOSOPHY, RELIGION AND THEOLOGY

Philosophy 0422
Religion 0318
General 0321
Biblical Studies 0319
Clergy 0320
History of 0322
Philosophy of 0469
Theology 0323

SOCIAL SCIENCES

American Studies 0324
Anthropology 0326
Archaeology 0327
Cultural 0310
Physical 0272
Business Administration 0770
General 0454
Accounting 0338
Banking 0385
Management 0501
Marketing 0503
Canadian Studies 0505
Economics 0508
General 0509
Agricultural 0510
Commerce-Business 0511
Finance 0358
History 0366
Labor 0351
Theory 0578
Folklore 0460
Geography 0383
Gerontology 0386
History 0537
General 0537

Ancient 0579
Medieval 0581
Modern 0582
Black 0328
African 0331
Asia, Australia and Oceania 0332
Canadian 0334
European 0335
Latin American 0336
Middle Eastern 0333
United States 0337
History of Science 0585
Law 0398
Political Science 0615
General 0616
International Law and 0617
Relations 0617
Public Administration 0814
Recreation 0452
Social Work 0626
Sociology 0627
General 0938
Criminology and Penology 0631
Demography 0628
Ethnic and Racial Studies 0629
Individual and Family 0630
Studies 0700
Industrial and Labor 0344
Relations 0709
Public and Social Welfare 0999
Social Structure and 0453
Development 0537
Theory and Methods 0538
Transportation 0539
Urban and Regional Planning 0540
Women's Studies 0541

THE SCIENCES AND ENGINEERING

BIOLOGICAL SCIENCES

Agriculture 0473
General 0285
Agronomy 0475
Animal Culture and 0476
Nutrition 0359
Animal Pathology 0478
Food Science and 0479
Technology 0480
Forestry and Wildlife 0817
Plant Culture 0777
Plant Pathology 0746
Plant Physiology 0306
Range Management 0287
Wood Technology 0308
Biology 0309
General 0379
Anatomy 0329
Biosciatics 0353
Botany 0369
Cell 0793
Ecology 0410
Entomology 0307
Genetics 0317
Limnology 0416
Microbiology 0433
Molecular 0821
Neuroscience 0778
Oceanography 0472
Physiology 0786
Radiation 0760
Veterinary Science 0786
Zoology 0760
Biophysics 0786
General 0760
Medical 0786

EARTH SCIENCES

Biogeochemistry 0425
Geochemistry 0996

Geodesy 0370
Geology 0372
Geophysics 0373
Hydrology 0388
Mineralogy 0411
Paleobotany 0345
Paleoecology 0426
Paleontology 0418
Paleozoology 0985
Palmatology 0427
Physical Geography 0368
Physical Oceanography 0415

HEALTH AND ENVIRONMENTAL SCIENCES

Environmental Sciences 0768
Health Sciences 0566
General 0300
Audiology 0992
Chemotherapy 0567
Dentistry 0350
Education 0769
Hospital Management 0758
Human Development 0982
Immunology 0564
Medicine and Surgery 0347
Mental Health 0569
Nursing 0570
Nutrition 0380
Obstetrics and Gynecology 0354
Occupational Health and 0381
Therapy 0571
Ophthalmology 0419
Pathology 0572
Pharmacology 0382
Pharmacy 0573
Physical Therapy 0574
Public Health 0575
Radiology 0575
Recreation 0575

Speech Pathology 0460
Toxicology 0383
Home Economics 0386

PHYSICAL SCIENCES

Pure Sciences 0485
Chemistry 0749
General 0486
Agricultural 0487
Analytical 0488
Biochemistry 0738
Inorganic 0490
Nuclear 0491
Organic 0494
Pharmaceutical 0495
Physical 0754
Polymer 0405
Radiation 0605
Mathematics 0986
Physics 0606
General 0608
Acoustics 0748
Astronomy and 0607
Astrophysics 0798
Atmospheric Science 0759
Atomic 0609
Electronics and Electricity 0610
Elementary Particles and 0752
High Energy 0756
Fluid and Plasma 0611
Molecular 0463
Nuclear 0346
Optics 0984
Radiation 0346
Solid State 0984
Statistics 0346
Applied Sciences 0984
Applied Mechanics 0346
Computer Science 0984

Engineering 0537
General 0538
Aerospace 0539
Agricultural 0540
Automotive 0541
Biomedical 0542
Chemical 0543
Civil 0544
Electronics and Electrical 0348
Heat and Thermodynamics 0545
Hydraulic 0546
Industrial 0547
Marine 0794
Materials Science 0548
Mechanical 0743
Metallurgy 0551
Mining 0552
Nuclear 0549
Packaging 0765
Petroleum 0554
Sanitary and Municipal 0790
System Science 0428
Technology 0796
Operations Research 0795
Plastics Technology 0994
Textile Technology 0994

PSYCHOLOGY

General 0621
Behavioral 0384
Clinical 0622
Developmental 0620
Experimental 0623
Industrial 0624
Personality 0625
Physiological 0989
Psychobiology 0349
Psychometrics 0632
Social 0451

The undersigned hereby recommend to
the Faculty of Graduate Studies and Research
acceptance of the thesis.

**COMPUTER-ASSISTED LEARNING IN CONTROL SYSTEMS
EDUCATION**

submitted by

Rachel Judith Welch. B.Eng.

in partial fulfilment of the requirements
for the degree of Master of Engineering

Dr. K.R. Goheen
Thesis Supervisor

Dr. R. Bell
Chair, Department of Mechanical and Aerospace Engineering
Ottawa-Carleton Institute for Mechanical and Aerospace Engineering

Carleton University
August 21, 1995

ABSTRACT

This thesis examines the use of courseware to teach control systems material to engineering students. Following research into the state of computer-assisted learning in engineering education, courseware teaching frequency response material was developed and tested by undergraduate students. Academic results and attitudes of the students were examined and compared to those of a control group. It was found that there was little difference in the academic results and attitudes of students in the computer group and students in the lecture group. In addition, the effectiveness of the courseware was not related to students' previous computer experience. A cost analysis performed indicated that in most cases the use of courseware to teach control systems would be more costly than traditional lectures. It was recommended that the use of computer-assisted learning to teach engineering courses be considered, but only with careful cost management.

ACKNOWLEDGMENTS

The author wishes to thank Dr. K.R. Goheen for his guidance and support during the preparation of this thesis. Thanks are extended to Dr. W. Thorngate for invaluable insights and assistance. The author would also like to thank the friends, family and colleagues who have supported her.

This thesis is dedicated with love to my parents, who taught me to enjoy learning.

TABLE OF CONTENTS

	PAGE
Abstract	iii
Acknowledgments	iv
Table of Contents	v
List of Tables	viii
List of Figures	ix
List of Appendices	x
1 Introduction	1
1.1 Background	1
1.2 Scope of Work	3
2 Literature Review	5
2.1 Introduction	5
2.2 Computer-Assisted Learning and Courseware	5
2.3 CAL in Engineering Education	8
2.4 CAL Issues - Computer	10
2.5 CAL Issues - Teaching and Learning	13
2.6 Other CAL Issues	17

TABLE OF CONTENTS

	PAGE
2.7 Development Process	19
2.8 Social Science Issues	20
2.9 Evaluation	21
2.10 Results of Published Studies	23
2.11 Summary	25
3 Process	26
3.1 Introduction	26
3.2 General Procedure	26
3.3 Testing Procedure	32
3.4 Summary	33
4. Results and Analysis	34
4.1 Introduction	34
4.2 Data	34
4.3 Data Analysis	36
4.4 Results	40
4.4.1 t-Tests Showing Significance	45
4.4.2 Correlations Showing Significance	47
4.4.3 Notable Cases of Statistical Non-Significance	52

TABLE OF CONTENTS

	PAGE
4.4.4 Student Comments	57
4.5 Cost Analysis	60
4.5.1 One-Year Model	65
4.5.2 Five-Year Model	65
4.5.3 Cost Variances	67
4.5.4 Alternative Models	72
4.6 Summary	73
5 Conclusions and Recommendations	75
5.1 Conclusions	75
5.3 Recommendations	78
6. References	79
Appendices	89

LIST OF TABLES

TABLE	DESCRIPTION	PAGE
1	Academic Results for Participating Students	35
2	Averages and Distributions for Data Sets	28
3	Significant t-Test Results	41
4	Significant Correlations	42
5	Notable Non-Significant Results	43
6	Responses to Question 15 b	58
7	Responses to Question 15 c	59
8	Responses to Question 18	61
9	Responses to Question 20	62
10	Cost Comparison for Basic Model	66

LIST OF FIGURES

FIGURE	DESCRIPTION	PAGE
1	Cost Variation with Number of Students	68
2	Cost Variation with Development Cost	69
3	Cost Variation with Computer Use Rate	71

LIST OF APPENDICES

APPENDIX	DESCRIPTION	PAGE
A.1	Sample Screens from Frequency Response Courseware	89
A.2	86.352 Course Material	97
	A.2.1 Course Outline	98
	A.2.2 Midterm Examination	100
	A.2.3 Final Examination	103
A.3	Assessment Materials	107
	A.3.1 Post-Experiment Test	108
	A.3.2 Post-Experiment Questionnaire	109
A.4	Experimental Data	112
	A.4.1 Spreadsheet of Experimental Data	113
	A.4.2 Student Comments	121
A.5	Statistical Analysis	125
	A.5.1 First Stage Analysis	126
	A.5.2 Results of t-Tests for Significance	140
	A.5.3 Results of Tests for Significant Correlations	141
	A.5.4 Critical Correlation Coefficients	145
	A.5.5 Normalization of Academic Data	146
A.6	Cost Analysis	150
	A.6.1 Cost Analysis for Basic Model	151
	A.6.2 Cost Analysis for Varying Parameters	152
A.7	Software	156
	A.7.1 Asymetrix Multimedia ToolBook	157
	A.7.2 MATLAB	158
	A.7.3 LView	159
	A.7.4 StatView	160

1. INTRODUCTION

1.1 Background

The use of computers in the office, in the home, and in educational institutions continues to increase as computers become faster, cheaper and more reliable. In addition, computers are taking on more and more substantial roles, including that of teacher or tutor. The use of computer-assisted learning (CAL) in higher education has grown. CAL includes everything from students using a spreadsheet to arrange and process data to a lecturer using electronic slides and simulation software in the classroom. The extent of CAL use varies widely from faculty to faculty, in great part due to the differences in the subject matter as well as the attitudes of faculty and students.

In engineering education, computers are used for everything from the management of student records to the simulation of complex phenomena. The use of CAL to teach in engineering faculties is, however, less widespread than in other areas of education. More often, computers are used by students for the laboratory portion of a course only, where they serve to reinforce some of the concepts previously taught. The exceptions to this are, of course, courses where the subject matter involves computers directly, such as software engineering courses or courses teaching numerical methods.

Like most types of CAL, courseware is rarely used in engineering faculties. Courseware is a computer-based instruction tool which is designed to teach certain concepts. Most modern courseware uses multimedia techniques to teach material. Users proceed through the material at their own pace, and can often adapt the manner

or the order in which topics are learned to suit their learning style. Courseware is used more and more often in education, both at the pre-university level and in higher education. Very little engineering courseware exists, however, which is unusual for a discipline which has otherwise embraced computing technology.

Additionally, while some research has been conducted into CAL use in engineering education, very little has been published. That which has been published focuses more often on the CAL development and technology than on the use and evaluation of CAL tools in the classroom. There is a lack of studies examining the outcome of teaching engineering using courseware rather than through lectures. This is both a result of the fact that courseware use in engineering is not widespread and a cause, as faculties of engineering are unlikely to start using courseware without knowing how it will affect students.

One of the subject areas best-suited to be a testing ground for CAL in engineering education is control systems. This is in great part due to the highly-mathematical nature of the material and the need for numerical graphical representations. Use of computer technology in the practice of control engineering is widespread. However, the effects of using CAL to teach control systems material have not been determined. Limited studies have been published, but these tend to focus on the development of the CAL tools rather than on their effectiveness. None of these have compared the academic results and attitudes of students using CAL to learn the material to students attending lectures.

This thesis examines the impact of using CAL to teach frequency response material to undergraduate engineering students. The purpose of the experiment was to determine whether there was any difference in terms of the academic results or the resulting attitudes between students learning material from courseware and those

learning from lectures. It is hoped that the results of this study will help determine whether courseware can be effectively used to teach engineering.

1.2 Scope of Work

This thesis discusses the development, use and evaluation of control systems engineering courseware. The purpose of the experiment was to determine the differences in academic results and attitudes between students learning from courseware and those attending lectures.

The need for research in this area is discussed in this chapter, and supported by the literature review in Chapter 2. The structure of the experiment was developed based on published research into CAL implementation, CAL issues and social science research guidelines, in addition to consultation with faculty from both the Department of Psychology and the Department of Mechanical and Aerospace Engineering. The papers studied and relevant findings are described in Chapter 2.

Chapter 3 describes the procedure of the experiment. The chapter begins with a description of the concept definition stage, the background research conducted and the selection of the tools to be used. This is followed by a report of the software development process as well as the latter stages of the experimental design, including the preparation of the test and questionnaire. The testing procedure is discussed in detail. Finally, the types of analysis applied to the data are described.

The analysis and its results are discussed in Chapter 4. This includes the nature of the data analysed, the statistical methods used to determine the results, and a discussion of the outcomes. The results discussed are both academic results and

student attitudes. In addition, a cost analysis was conducted with the goal of determining the difference in cost between the use of courseware and the use of traditional teaching methods. The results of the cost analysis are also included in Chapter 4.

In Chapter 5, the conclusions reached based on the analysis are listed. These include specific findings and more general conclusions about CAL use in engineering education. In addition to the conclusions, recommendations based on the findings of the experiment are included in this chapter.

2. LITERATURE REVIEW

2.1 Introduction

This section discusses the current published literature relating to this thesis. The literature examined includes papers from the last twenty years and from a wide range of journals which have some bearing on the subject matter. These include general CAL papers, papers specific to engineering education, and papers relating to the psychology of teaching and learning.

The first papers discussed are those that discuss Computer-Assisted Learning (CAL) in general terms and help develop the context for the more specific information that follows. Sections discussing CAL in engineering education and issues in CAL implementation follow. A discussion of published papers describing aspects of the development process is also included. The social science issues impacting CAL use are briefly discussed. The last two sections describe the published evaluation methods and issues and the results of the CAL studies examined.

2.2 Computer-Assisted Learning and Courseware

Computer-assisted learning (CAL) is not a new concept, but its use has greatly increased as computing technology has become more powerful and more accessible. According to Barker (1987), "CAL is the general term used to describe virtually any learning activity that is promoted by a computer or in which a computer is involved". This includes anything from students using a spreadsheet to arrange and process data to a lecturer using electronic slides and simulation software in the classroom. The

term "computer-assisted instruction", or CAI, is sometimes used interchangeably with CAL (Brown and Cutlip, 1987).

CAL has been broken down into different types of learning-related computer tools including computer-managed learning, computer-based training, courseware, intelligent tutoring systems and computer-based education. While some of these terms describe very similar activities, the emphasis is often different.

Computer-managed learning (CML) describes a role for the computer where it is for "...the management of learning rather than instruction... the computer is used mainly to monitor, report and recommend" (Barker, 1987). There are programs that exist for this purpose alone, but much of CML takes place as a component of a larger CAL package.

Computer-based training (CBT) and computer-based education (CBE) represent two halves of CAL, separated according to the context of the learning. CBE assumes the application of the technology to education, whether pre-elementary, elementary, secondary or post-secondary. CBT places the technology in a training context - from driver's education courses to job training programs (Barker, 1987).

Just as CAL is separated into CBE and CBT according to the context of the learning, it is separated into interactive and passive CAL by considering the level of student involvement. An example of passive CAL might be a computer-assisted lecture, where "...the computer [is used] as a learning/teaching aid - but there is not involvement by the student'. Interactive CAL involves the student, and "...promotes active learning in which there are high degrees of participation and involvement by the student... the student's behaviour (and responses to instructional material) can be used to help determine the most appropriate pathway through the body of knowledge

for each individual student" (Barker, 1987). Examples of interactive CAL include courseware where the student chooses his or her own path through the material, and intelligent tutoring systems.

An intelligent tutoring system (ITS) has been described by Barker (1994) as "...a software program that uses artificial intelligence (AI) techniques to help people learn". Here, the instructional material is tailored to meet the requirements and level of understanding of the student. Antao et al (1992) described ITSs as "...the new generation of computer-aided training systems that integrate course material, simulation models, and diagnostic capabilities within a unified framework". While ITSs are recognized as both innovative and effective, they require significant resources for development.

Demerdash et al (1993), defined courseware as "...computer-based instruction that attempts to package lessons and complete courses that are independently accessed by students". Barker (1987) defined the essential components of courseware as "(1) a set of instructional strategies, (2) their associated domain-dependent subject matter, and (3) the storage media to which each of the (1) and (2) are committed". While not as sophisticated as ITSs, courseware has the advantage of requiring fewer resources to produce and use. Since it is also structurally more simple, it can be made to be more robust, less platform-dependent and more easily updated.

2.3 CAL in Engineering Education

Although CAL has been in use in engineering education for sometime, that use is not widespread. Furthermore, in comparison to the literature describing CAL applications in other disciplines, little has been published for engineering. Those studies which have been published tend to focus on the development of the CAL systems instead of the evaluation, and the result is that there is little information on the outcome of using CAL for engineering disciplines

As early as the 1970s, computers were being used to teach control systems. Broome and Woolvet (1976) described one such application, “[a] program... which permits interactive control system design, suitable for use by students either to run tutorial exercises as a back up to lecture material, or to integrate with laboratory work”. The program was written in FORTRAN IV for 8K computers such as the Honeywell H316.

The use of computer for control systems education has since then become widespread. According to a survey of control systems curricula by Feliachi (1994), “[s]oftware packages of a wide variety are being used by most schools. The most popular packages (in frequency of usage) are MATLAB, MATRIX-X, ACSL, DESIRE, and CC”. These packages are typically used in conjunction with the traditional lecture format. Feliachi did not identify any software packages being used to teach the material rather than to reinforce the material taught in the lectures.

These programs are part of the third and fourth layers of four described by Schaufelberger (1990) as making up the body of control systems teaching software

Each layer represents a different type of computer application, and stacked together they provide the complete teaching/learning environment. The layers are:

- (1) "specialized training programs"
- (2) "minitools for small tasks such as drawing the graph of a function"
- (3) "tools such as MATLAB or simulation environments for solving small to medium problems"
- (4) "full grown commercial tools (professional MATLAB, CTRL_C, ACSL, SIMNON, Mathematica, etc.)"

Some specific-application packages which make up the second layer of Schaufelberger's structure exist, including a circuit design and testing program (Hodgson, 1992), multimedia development tools (Abbanat et al, 1994), a linear control systems design program (Broome and Woolvet, 1976), a package for PID design and tuning (Wong et al, 1990), and a digital control simulator (Marcos et al, 1991).

What seems to be most lacking is the first layer - the development and evaluation of specialized training courseware. This is surprising because, while it is recognized that some subjects are more suited to learning with CAL than others (Outang et al, 1993), several researchers have identified CAL tools for engineering as having a large potential for success. According to Antao et al (1992), who examined the teaching of simulation in engineering education, "...computer-aided instructional aids can expedite the teaching process and provide individualized instruction". Aminmansour (1993) identified several advantages to using multimedia technologies in engineering education, including the increased involvement of the users (student), the user control of speed and direction, the capacity for individualized and self-paced hands-on learning, and high levels of comprehension and retention.

Because of the relatively small body of literature describing CAL applications in engineering, it is necessary to go beyond engineering to find discussions the issues concerning CAL development, application and evaluation

2.4 CAL Issues - Computer

Some of the issues in CAL use being researched have more to deal with the characteristics of computer use than with the impact of CAL on teaching and learning. While these issues arise whenever computers are used, whether for education of elsewhere, they can have a significant impact on the design of CAL systems in particular. Barker (1994) noted that “[a]pproximately every two years the computing power of microcomputers doubles. This astounding rate of growth in computing power has held since the early 1980s and shows no signs of abating. Conservative predictions indicate that by the year 2010, the typical microcomputer will be 1000 times faster than today”. It is unquestionable that this incredible increase in computing power has and will have an effect on engineering education

One of the issues is how using the computer as a tool actually alters what is being taught. The computer has changed engineering education in two ways (Demerdash et al, 1993) - by changing the content of engineering courses, and by changing the presentation. According to Demerdash et al, changes to the presentation result from the fact that “computing power can be used to present materials in ways that foster insight”. Changes to content are “appropriate since techniques that would require prohibitive effort if done by hand have now become manageable with the computer as a tool. Sometimes the changes are subtle - familiar problems are solved using new methods or more accurate models. Sometimes the changes are more profound - new disciplines, such as computer control, emerge. Further, reducing the computational

burden associated with analysis makes it possible to incorporate more design in the curriculum”

Perhaps the most important and oft-cited issue is that of the high level of trust placed in computer output. Latour and Woolgar (1979) examined the aspects of what they called inscription devices, of which the computer is one. They noted that “... inscriptions are seen as direct indicators of the substance under study. A second consequence, however, is the tendency to think of the inscriptions in terms of confirmation, or evidence for or against, particular ideas, concepts, or theories. There thus occurs a transformation of the simple end product of inscription into the terms of the mythology which informs participants’ activities”.

Gal (1992) noted that this “taking [of] the computer’s response for granted” is particularly significant in the area of CAL. “Users are not usually aware of or do not know the steps involved in programming the computer. They are also unaware of how their input is interpreted to graphic or textualized representation”. Gal investigated this phenomenon in the context of a computer expert system for civil engineering bridge design, and found that students trusted the computer’s response even if it conflicted with their understanding.

Another computer issue in CAL applications involves the hardware and software platform. This is particularly true in engineering applications, where UNIX machines are in common use. The question, investigated by researchers including Cvetkovic et al (1994), is whether the programs should be based on PCs, UNIX machines, or Macintosh computers. Macintosh computers are best suited to multimedia applications, but few engineering departments have substantial numbers of them. Furthermore, few of the engineering tools which might be connected to the CAL are available for the Macintosh. Large UNIX machines are in most engineering

departments, and are often the machines on which future work would be performed. Most of the multimedia development tools, however, are designed for PCs or Macs. PCs are fairly common in engineering departments, as well as in many homes, but lack the ease of development and use of the Macintosh computers. Cvetkovic et al "...considered availability, user friendliness, and the high desirability of being able to give students a package on a single high-density floppy disc," and concluded that the personal computer was the most appropriate platform for engineering CAL tools. Marcos et al (1991) concurred, also noting that "[t]he economic benefits of PC-based software are clear".

As noted above, computing power is rapidly increasing. This means that the kinds of computing environments available to users are also changing, and as such the possibilities for CAL will change. Barker (1994) writes that "[i]nformation technologies... are advancing and converging to produce intelligent multimedia virtual classrooms [which] will empower students and faculty to work together, share knowledge, and instantly access vast amounts of information". In the meantime, however, there are limitations to the speed and size of CAL programs. The most significant of these, according to Chen (1994) "...is the compression/decompression problem" - there is often an obvious and frustrating delay while images and video are readied for viewing. An associated problem is file size, since the "most rich" forms of computer output require large data files, even when highly compressed.

These computing issues are closely connected to many of the teaching and learning issues surrounding CAL, particularly when the psychological response of individuals is being assessed.

2.5 CAL Issues - Teaching and Learning

The use of CAL systems also raises issues relating to teaching and learning. For example, the psychology of learning and the ethics of classroom experimentation are issues which must be considered in CAL development and use. There is some crossover between such issues and those described in the section above. For example, the result of the use of inscription devices (described in the previous section) is both a computer issue and a learning issue. According to Petruk (1992), "[w]hat is quickly evolving is a learner-centred paradigm of the teaching-learning process," due to the changes to the education industry, including the effects of the information explosion, the advent of digital electronics and microcomputers, and a post-industrial, global economy,

Chun and Plass (1994) examined the extrapolation of standard psychology of learning to multimedia CAL, and stated that "in order for understanding and learning to take place, a reader must first activate prior knowledge, must then reorganize these existing knowledge structures or schemata, and can then link them to the new material to be learned". This suggests that while the manifestations of the presented material may be different, they must stimulate the student's thinking process in the same way that do effective traditional methods. Outang et al (1993) concluded that this was facilitated by a strong student-computer bond - students who had grown up with computers were better prepared to learn from them.

The required stimulation of the learning process had prompted research, including that by Antao et al (1992) into the nature of the CAL systems required to communicate knowledge. Janniro (1993) found that CAL was "most effective when systematically designed and the course content is pedagogically sound". He also noted that learning through CBI could be improved by "integrating instructional

visuals founded on information-processing learning theories, and including screen design strategies to enhance the transfer of information”

Ellis (1992) suggested that “[s]ince it is the learner who does the essential work, if the learner is given good learning tools and resources, and the incentive to use them, learning *can* happen without teaching”. Several researchers disagree with this statement, for reasons having to do with the different types of learning required for different subjects, and the various learning styles of students

Outang et al (1993) found that some subjects were better suited to CAL applications than others, and that this had to do with the nature of the learning required.

Aminmansour (1993) noted that engineering education was a particularly good learning application for multimedia technologies, because of the increased user-involvement, direction and pacing. Even Ellis admitted that “[i]n many areas of learning it is a decided advantage to have an experienced teacher to interpret, reason, explain, analyse, synthesize and so on, to the student’s benefit”. In the case of Rodgeron and Anderson (1992), who examined the use of tools such as MATLAB in control systems education, “neither researcher believes that the time for talk and chalk is past but both believe in making full use of the modern aids, as they become available, in conjunction with talk and chalk”.

Amongst the ways in which it is suggested that CAL facilitates learning in engineering is that it can, according to Hodgson (1992), “reinforce the traditional lecture/laboratory methods of teaching by reducing the extent of repetitive note-taking in lectures and unproductive laboratory experiments”. Rodgeron and Anderson (1992) found that one of the main benefits of using computers in teaching and learning was that “the requirement to understand fundamentals remains, but the maths is now easily implementable”.

In contrast, Driessel and Lehmann (1992) suggested that many engineering topics were difficult to teach using CAL because of the high level of innovation in the field. They noted that information was often unstable and time-dependent, distributed and inconsistent. While increasing computer power can improve the speed of many activities, the input and organization of new information is still a human activity, and may not be done quickly enough to stay abreast of changing technologies.

Even in the case of a subject which is well-taught with the aid of CAL technologies, some students will fare better with CAL than others. According to Baird and Silvern (1992), "[e]ach learner may bring individual cognitive styles, learning transfer skills, and motivation to both the learning and assessment forms". Allinson (1992) found that some students "showed a preference for a more linear and structured presentation of the information and navigated the screens at a slower rate," while others "demonstrated more active use, especially for their initial period of system use, showed greater use of the *self-determined* hypertext linkages as a navigational strategy, and appeared to be more actively searching the material". Allinson suggests that the first group consists of those students who are "high reproducing" in their approach to study, attempting to memorize all of the material. The second group are the "high meaning" students, who focus on understanding all of the material rather than remembering it.

The differences in learner outcomes can be separated, according to Brown and Cutlip (1987), into "academic outcomes" and "affective outcomes". The academic outcomes are those related to the amount learned by the student as a result of using the CAL technologies (e.g. final course grades). The affective outcomes relate to the changes in the student's attitudes and perceptions as a result of participation in CAL projects (e.g. changes in feeling towards computers). The researchers noted that in

some studies “two systems of instruction were compared and found to be equivalent in the academic outcomes, but different in affective outcomes”

Fyock and Sutphin (1995) found that some students require “direct interaction with a classroom instructor and other students” For these students, it is particularly important to complement the CAL activities with teacher-student interaction Furthermore, as noted by Barker (1987), these students benefit from the use of interactive CAL techniques, where “help is given at the time it is needed and when the student will benefit from it - not in a post-learning phase where its impact may be lost”.

The requirement for feedback is also noted by Croy et al (1994), who gave some students feedback through instructor-student meetings, and others through computer-supplied feedback. “The results showed that there was some advantage to instructor-supplied feedback as opposed to computer-supplied feedback during the most difficult phase of the course with respect to exam performance, class responsiveness, and students attitudes towards the instructor and other students”. The type of feedback did not seem to affect students attitudes towards the course or towards computers.

Some researchers, including Fyock and Sutphin (1995), have noted gender differences in CAL use From the results described, these seem to be differences in the students’ feelings towards the material and the teaching methods, rather than in the amounts learned or the course results. Similar effects are difficult to assess for engineering disciplines, as the ratio of female students to male is very small Most courses do not have enough female students to produce a statistically significant result.

The novelty factor is also an issue, as discussed by several authors, including Outang et al (1993). The difficulty here is that students using CAL may show improved results over traditional methods, not because of the technology itself, but because the students enjoy the novelty of using the new system, and the feeling of being singled-out for such a project. Outang et al recognized this, but suggested that students' "novelty using CAI should be motivated and further explored," rather than minimized. The difficulty, as suggested by Neale and Liebert (1980), is that this effect makes it more difficult to assess the true effectiveness of CAL.

2.6 Other CAL Issues

In addition to the issues described above, there are other considerations affecting the implementation of CAL systems in engineering classrooms. Not the least of these considerations is the often significant resistance to new technologies from lecturers and administrators. Ellis (1992) described this problem, stating that "the history of computer assisted learning... is littered with projects which have failed to win general acceptance by academic staff, and which have failed to deliver on promises of better and/or cheaper education. As a result, senior management in educational institutions has a healthy scepticism towards such enterprises".

However, Ellis does express confidence that cost-effective and academically-effective systems can and are produced, and suggests that in those instances, "capital can be invested effectively, generating gains in productivity". Rodgers and Anderson (1992) found that as instructors they were "more efficient in their teaching, tutorial and laboratory work". However, Clark and Craig (1991) suggested that there was some question as to the economic benefits of CAL, and suggested that research be focused "on economic questions such as the cost of delivering instruction and the

speed with which media permit the achievement of present learning or performance standard”.

According to Ellis (1992), the principal barriers to full instructor participation are inertia, inaccurate perceptions about CAL, computer-phobia and a perceived threat to employment. In addition, promotion criteria for instructors are based on research rather than emphasis on teaching-related activities. Several researchers, including Hodgson (1991), countered some of these concerns. Petruk (1992) emphasized the need of changes to the role of instructors, saying “change we must, for both our economic and our intellectual survival depend on it”.

Another of the potential spin-off benefits of CAL involves the additional skills gained by CAL-using students. Cvetkovic et al (1994) found that “the encouragement of self-learning and stimulation of... students’ research potential” were benefits in addition to those directly related to the course. Maurer (1992) also wrote of the “enrichment of our sensory and communicative possibilities” through exposure to multimedia computing technologies.

Barker (1994) suggests that while there is some resistance at this time, the technologies will go ahead. According to Barker, “[t]he benefits of a virtual classroom will be so appealing to the students, faculty, and society-as-a-whole that universities who ignore this technology revolution will risk extinction. In other words, schools that act now will achieve significant competitive advantages over institutions that will wait. Anticipating, experimenting, and developing the technologies that enable virtual classrooms will carry untold benefits for those willing to invest the money, resources, and time”.

2.7 Development Process

The most significant phase in CAL courseware implementation is the concept and material development and design, rather than the actual programming. Goos et al (1989) found that "about one third of the total development time [is used] for the basic design, another third for documentation, and only one third for programming". The time spent varies according to the size and nature of the material, the type of CAL being created, and the type of attention paid to various issues and factors.

One of the difficulties, described by Abbanat et al (1994) is that "[t]he development process for a courseware module is highly nonlinear". The researchers separated the different software programs needed into categories according to their functions (e.g. authoring software, simulation software, etc.). Mayer et al (1993) noted that "[s]ophisticated interactive courseware makes heavy use of various media... and supports a variety of metaphors"

Barker (1987) noted that for learning and training, whether in the case of CAL or traditional lectures, the same basic characteristics and rationale apply, and thus the same general development process. Barker also emphasizes the importance of a pre-stage in the development process, where "a list must be made of the educational objectives that are to be realised and a plan formulated of the ways in which they are to be achieved - using the available resources and within the confines of a pre-specified budget". This is echoed by Bork (1991) who suggests that one of critical features of curriculum material development is overall management, including ensuring that the materials can be provided at reasonable cost.

Most researchers are in general agreement as to the nature of the development process. Makedon (1994) identified the steps in the process as being the definition of

requirements, the search for software tools, the research of content and the orchestration of the media, programming, integration, evaluation and stepwise refinement, and finally product distribution. Abbanat et al (1994) went into more detail about the earlier stages of the process - "[o]nce an engineering topic has been chosen for implementation, the developer will... first simulate a problem or situation that is the engineering focus, then transform output from the simulation into an appropriate... form, generate [animation], audio and text components, define the navigational topology and finally integrate everything using an authoring package"

2.8 Social Science Issues

While most of the literature published about CAL focuses on the development of the material and technology rather than on the assessment of CAL, those research projects which aimed to evaluate some aspect of CAL tended to fall into two groups. In the first group, the CAL project was assessed through observation or informal means. In the second group, the evaluation was conducted by applying the general principles of social science research. This was done in the hopes of making the results as valid and reliable as possible.

There have been many papers and books published on behavioural research. Two examples are Neale and Liebert (1980) and Rosnow and Rosenthal (1993). Each of these references discusses research issues ranging from observational methods to statistical analysis.

There are ethical issues to be considered when designing the experiment. The American Psychological Association (1982) has developed a code of research ethics. These detail the responsibilities of the researcher towards the participants. For

example, the ninth principle states that "[w]here research procedures may result in undesirable consequences for the participant, the investigator has the responsibility to detect and remove or correct these consequences including, where relevant, long-term after effects".

2.9 Evaluation

As noted above, few of the papers discussing CAL in engineering education discussed in any depth the evaluation of the programs. For example, Wong et al (1990) based their results on observation and information contact, rather than on any structured evaluation. Hofer and Roggiro (1990) postulate that "evaluations are more easily controlled in a laboratory environment. This is no doubt why very few performance based, summative training evaluations are being performed in applied domains," such as engineering. Another reason given is that "[e]valuations require considerable discipline and cooperation from all the parties involved, including students, instructors, managers and evaluators".

Chun and Plass (1994) conducted a three-part evaluation of their non-engineering multimedia courseware, by assessing usability, tracking learned behaviour and assessing the program effectiveness. This evaluation coverage can provide a good assessment of the program effectiveness, but the logistical aspects of the evaluation vary from study to study. Sometimes students are merely observed, sometimes they are tested on the material learned, and sometimes they are asked to complete questionnaires or participate in interviews.

Baird and Silvern (1992) called into question the viability of testing, and decided to assess its effectiveness as an evaluation tool. They found that the mode of testing

used has little effect on the results. In other words, a paper test is a reasonable means of testing CAL students, just as a computer test will not skew the results for traditionally-taught students. The researchers concluded that, for the material their non-engineering CAL application taught, "mixing computer study with paper-and-pencil testing does not bias the outcome of the test" Clark and Craig (1991), however, noted that the instructional methods, such as interactivity, might influence evaluation results more than the technology.

One of the questions debated by researchers surrounds the involvement of students in the evaluation process. Reiser and Kegelman (1994), in a comprehensive review of current evaluation methods, found that "[v]ery few models suggest that students serve as evaluators," and recommended that "students should be observed as they use a software program, and conclusions about the quality of the program should be based, in part, upon what the evaluators observe". In addition to recording students reactions and observations while using the program, the researchers recommended that "evaluators should assess how much students have learned as a result of using a particular program".

The actual composition of the evaluation program varies from study to study. To evaluate a non-engineering CAL application, Janniro (1993) compared the results of 14 students learning via CAL to a 15-student classroom control group learning the same material. The results for the two groups were compared statistically using such tools as a two-tail t-test for significance. The focus here was heavily on the academic outcomes rather than the affective outcomes.

Similarly, Brown and Cutlip (1987) investigate the results of teaching FORTRAN programming to engineering students by comparing the results of an 18-student courseware group to a 22-student lecture group. Here, both academic and affective

outcomes were considered, using both a test and an attitude questionnaire. Hofer and Roggiro (1990) also combined questionnaire data with performance measures to evaluate the use of CAL to teach technical material, and found that it was a reasonable means of evaluation while difficult to implement and manage.

2.10 Results of Published Studies

The published results of CAL use are generally positive. However, as discussed in the section above, many of these results are based on observation rather than on any kind of structured testing. The trend amongst those results based on structured evaluations seems to be that the academic outcomes were similar to or better than those achieved using the traditional lecture format, but that there were different affective outcomes, such as reduced study time or changes in student attitudes.

According to Outang et al (1993), in their study of pre-university CAL use, CAL had a positive effect on the test subjects' academic achievement. The evaluation methods used are not discussed in the published information. Janniro (1993) used a combination of pre-testing and post-testing of CAL and control groups, and found that a group of students using CAL "achieved significantly higher posttest scores," and "also required less than half of the scheduled instructional time compared to those students in the classroom group". He concluded that CAL "appears to be most effective when systematically developed and the course content is pedagogically sound", and recommended that developers apply information-processing learning theories and screen design strategies to improve CAL.

Aminmansour (1993) found that CAL contributed to better comprehension and retention in civil engineering students. Here again, the methods used to arrive at this conclusion are not discussed. Hodgson (1992) found that it was “evident from the way students take to this self-learning environment... that workstation learning will become an ever more important and powerful tool in engineering education”.

Similarly, Plank et al (1990) found positive results when using CAL in engineering, but base these results on experience rather than on an evaluation.

Brown and Cutlip (1987) compared the results of engineering students learning FORTRAN through CAL to those in a classroom control group, and found that the evaluation “failed to yield a significant difference between the two groups”

However, they also found that “the experiences of the students in the CBE group resulted in an increasingly negative attitude about the instructional use of computers”

Some authors, including Rodgerson and Anderson (1992), found that, in addition to positive student results, they were “more efficient in their teaching, tutorial and laboratory work” through the use of computer tools. Hodgson (1992) concurred, stating that “[s]taff are relieved of unproductive supervision, allowing more time for personal student tutoring and counseling”. However, Plank et al (1990) found that CAL “did not necessarily give relief to the teacher, but simply made the task of teaching individual topics more varied”.

There have also been conclusions reached about certain aspects of CAL technology. For example, Chun and Plass (1994) examined the use of multimedia components in CAL, and found that “users felt overwhelmingly that seeing a photograph or movie helped reinforce learning but that the text and audio links were not as helpful,” and concluded on that basis that “visual types of links of information may be preferable to textual links”.

Baird and Silvern (1992) suggested that the differences in CAL results are due to “variance in (a) teaching styles and applications on the computer, (b) types of supplementary materials used in computer learning, (c) prerequisite activities, and (d) prior knowledge of the learner”. Clark and Craig (1991) stated that “the measured learning gains in studies of the instructional uses of multiple media are most likely due to instructional methods”. They also recommended that future research concentrate in this area, examining “the effects of instructional methods for different types of students”.

2.11 Summary

This chapter reviewed some of the current published literature relating to CAL use in engineering. The papers discussed come from a variety of sources, referenced in Section 6. The literature appears to support the usefulness and the relevance of the experiment on which this thesis is based.

The literature examined included general CAL papers, papers specific to engineering education, and papers relating to the psychology of teaching and learning. These were papers from the last twenty years and from a wide range of journals which have some bearing on the subject matter. Papers describing CAL in general terms were used to help develop the context for the more specific information, including information on CAL in engineering education, on issues in CAL implementation, on aspects of the development process, on the social science issues impacting CAL use, on published evaluation methods and issues, and on the results of the CAL studies examined.

3 PROCESS

3.1 Introduction

This section discusses the procedure used for this project. Subsection 3.2 describes the general procedure, from the conception of the thesis to the final analysis.

Subsection 3.3 details the procedure followed for the execution of the experiment portion of the project.

The first step in the general procedure was the definition of the concept of using CAL to teach Feedback Control Systems. This included research into the technologies to be used and the development of the outline of the experiment. The tools to be used in the software development were selected, and the courseware design and programming was begun. During the course of the software development, some obstacles were encountered and overcome. In parallel to the software development, the design of the experiment was refined and the test and questionnaire to be used to evaluate the software were developed. The experiment itself was conducted over a two-week period in the Winter Term. This was followed by the evaluation process. The results and analysis are discussed in the next chapter.

3.2 General Procedure

In early 1994, the concept of applying CAL technologies to control systems education by developing multimedia courseware was proposed and accepted as a thesis topic.

The thesis would examine the effects of the use of this technology on the control

systems students and their ability to learn the required material. In addition, the cost-effectiveness of this method of learning would be examined.

The thesis was begun in earnest in the summer of 1994. In order to fully develop the concept of the experiment, research into the current state of computer-assisted learning (CAL), and more specifically that of multimedia technology in engineering education, was conducted. In addition to these publications, papers discussing the application of social science issues (behavioural research, psychology of learning, etc.) to CAL were also studied. Based on the publications examined (see Literature Review), the outline of the experiment was developed. The reading of relevant literature was continued during the course of the experiment.

It was found that there was a shortage of published studies describing the application of CAL to control systems education, and to engineering education in general. In particular, few published studies included a structured evaluation of CAL and the results of its use.

The initial plan for the project was developed. The intention was to prepare courseware for the entire 86.352 Feedback Control of Dynamic Systems course. This is a mandatory course of all undergraduate students in the Department of Mechanical and Aerospace Engineering at Carleton University, and is similar in structure to the feedback controls course offered in most faculties of engineering. The course outline for 86.352 is included in Appendix A.2. The students in the class are primarily in their third year of a four-year Bachelor of Engineering program.

The courseware was to be used in the Winter term of 1995 by some portion of the 86.352 class, replacing the regular lectures.

Before the development of the courseware could begin, it was necessary to select and procure where necessary the hardware and software tools to be used both for the development and the experiment itself. The computing facilities under the jurisdiction of the Chair of the Department of Mechanical and Aerospace Engineering and the Dean of the Faculty of Engineering contained IBM-compatible personal computers, UNIX-based computers (Sun Microsystems, Silicon Graphics, etc.), as well as a few Apple Macintosh computers. It was felt that the most appropriate platform for the control systems courseware would be the IBM-compatible 486-xx computers. Two suitable networked facilities existed, one belonging to the Faculty of Engineering and one to the Department.

Once the decision to use PC-based software was made, the investigation of suitable software packages was begun. After some research, Asymetrix Multimedia ToolBook (Appendix A.7) was selected as the authoring software. This was based on the software features, as well as the relatively low price, compatibility with other software packages, unlimited run-time license and upgrade capability. In addition to ToolBook, MATLAB (Appendix A.7) was determined to be a necessary tool for the courseware. A third tool, Lview (Appendix A.7), was selected because of its image processing and formatting capabilities.

A 486-66 computer was prepared and dedicated to this purpose. It was augmented by a CD-ROM drive loaned to the project by the Dean of Engineering's computer support staff. The computer was also set up to emulate when necessary a local-area network such as that on which the courseware would eventually be run. ToolBook, MATLAB, Lview and other helper applications were installed and configured.

The initial phase of learning to use the ToolBook software took place in the fall of 1994, and proved to take longer than was expected. Some of the requirements of the

project, particularly where connections to external programs were concerned, seemed to be outside the realm of the usual expectations of ToolBook. In addition to learning to use the software, it was necessary to become familiar with the accompanying object scripting language OpenScript.

The learning process continued during the courseware development, and the final courseware was therefore the result of several programming iterations.

The content to be taught by the courseware was based on the textbook (Franklin et al., 1994) and lecture notes (Goheen, 1994) for 86.352. This was done to ensure the completeness of the software, compatibility with the lecture material and the integrity of comparisons to the lecture format. The style and presentation were altered to suit the medium, and multimedia components were designed to be incorporated.

As the initial intention was to develop courseware for the entire 86.352 curriculum, programming was begun with that purpose. Shortly before the end of the fall term, however, with the advice of Warren Thorngate, a professor from the Department of Psychology at Carleton University (Thorngate, 1994a), the plan was altered. Based on Dr Thorngate's experience with CAL design, implementation and evaluation, it was felt that it would be more valid to replace a shorter portion of the course with electronic courseware for the purposes of the experiment.

The decision was made to begin programming anew, with the goal being the development of courseware for the Frequency Response portion of the course. The experiment would thus last about two weeks instead of the full term. This material was chosen because it was well-suited in length, position in the course, and relative independence from the other course material. In addition, the material was appropriate for teaching with CAL.

The requirement thus became to develop the multimedia courseware for a two-week portion of the course, and to complete this development in the early part of the winter term, so that it could be tested and corrected before use later in that term.

In conjunction with the software development, work was conducted to ensure that the final product would work well with MATLAB and be network-compatible. This was done both by using the development PC to simulate the network and by testing an early prototype of the program on the Dean of Engineering's network.

In addition to those activities discussed above, the first outlines of the experiment itself were developed with the assistance of Warren Thorngate (Thorngate, 1994b). This was to ensure that the experiment would be conducted according to the accepted procedures for social science research (ethics, validity of results, etc.) These consultations continued during the course of the experiment and afterwards.

The programming of the courseware continued during the early part of the winter term of 1995, in parallel with the final stages of the experimental design, as described in section 3.2. The participating students were selected, and informed of their selection and the terms of participation.

Once the programming was complete, it was tested both on the network and off. The off-network testing was to look for errors in the program. The on-network testing was to verify that it would run properly in the laboratory. Some errors in the program were found at this stage and corrected before the final implementation. Once the final version was ready, it was put on the network with the assistance of Warren Hik and Gordon Young, who manage the Dean of Engineering's computing facilities. Several sample screens are included in Appendix A.1.

The frequency response test and questionnaire to be given to the students at the end of the experiment were designed and reviewed by the lecturer (for content) and the professor from the Department of Psychology (for structure and phrasing).

The experiment was run over a two-week period. During this time, the lecture group had approximately six hours of classroom instruction. The computer group covered the same material, with some students taking more time and others less. Ten days after the end of the material, the participating students were tested as described in section 3.2.

The tests were corrected without the corrector knowing either the identity of the student, whether the student was in the computer or lecture group, or the nature of the student's responses to the questionnaire. The tests and test results were returned to the lecturer for distribution. The recorded results of the test and questionnaire were compiled into a spreadsheet (Appendix A.4) so that they could be analysed. The spreadsheet identified students by a record number only. In addition to the test and questionnaire results, midterm examination, exam and final grades were included as data. It should be noted that tutorial assistance was made available after the test to those students in the computer group who requested it.

Different methods of analysis were applied to the data to test for correlations or other possible significance. This was done with the assistance of the Department of Psychology (Thorngate, 1995). The results were compared to those of other published studies, where possible.

3.3 Testing Procedure

The students in 86.352 were advised of the nature of the experiment and of the process. Volunteers were requested, and more than eighty students responded positively. Of the volunteers, forty were selected at random to take part in the experiment, and these divided equally into two groups. The limitation on the number of participants was made because of the size of the computer lab in which the courseware would be used.

The recruitment of volunteers and the selection took place before the course midterm examination so that the results of the midterm examination could not bias the process, and so that the students were not self-selecting from those who did poorly on the midterm examination. Those selected were only told that they would be part of the experiment, and were not advised as to whether they were in the computer group or the lecture group.

The students in the computer group were advised in the lecture immediately preceding the start of the experiment that they should be reporting to the computer laboratory for the next lecture period. While the courseware remained on the network at all times so that students requiring extra time could use it, the courseware sessions were run at the same time as the lectures to minimize cross-over by members of either group. During these sessions, students were given assistance with the courseware when needed, but assistance with the actual course material was avoided as much as possible. In addition to the courseware, the computer group were given printed versions of the text in the courseware as a study aid.

Both groups wrote a one-hour test (Appendix A.3) on the material. Those who did better on the test than they had on the midterm examination had the test counted for a

portion of the value of the midterm examination. The midterm examination was worth thirty-five percent of the overall course mark. In the cases where the test mark exceeded the midterm examination mark, the test was used for fifteen percent of the course grade and the midterm examination for twenty percent. Prior to the start of the test, the students were asked to complete a questionnaire (Appendix A.3) which aimed to assess such factors as familiarity with computers, learning style and feelings about the courseware.

3.4 Summary

This section described the steps followed for this project. The main section discussed the overall process followed for this project, including the concept development, the selection of software and hardware tools, the development of the experimental procedure, the software design and programming, the execution of the experiment and the analysis of the data. Subsection 3.3 describes the experimental procedure in greater detail.

The concept of using CAL to teach Feedback Control Systems was developed, and a basic process was determined. The tools to be used in the software development were selected. The courseware was designed and developed over several months. During this time, several obstacles were encountered and overcome. The design of the experiment was refined and the test and questionnaire to be used to evaluate the software were developed. The experiment was conducted over a two-week period in the Winter Term, and the results were analysed during the Summer Term.

4. Results and Analysis

4.1 Introduction

The purpose of this chapter is to describe the results of the experiment, including the types of analyses used to arrive at these results. The results include those obtained from the test and questionnaire data and from additional academic data.

The data considered in this experiment included academic data such as the test results, the midterm examination and final examination grades, the overall course grade, and the cumulative grade point averages of the students. Additional student information was obtained from the students' responses to the pre-test questionnaire.

Statistical techniques were used to find significant relationships amongst the sets of data. The significant relationships are discussed below, as are those cases of interest because no relationship was found when one was expected. In addition, a cost comparison of the computer course model and the lecture cost model is included in subsection 4.5.

4.2 Data

As seen in Appendix A.4 and summarized in Table 1, test data were retrieved for all participating students, as well as midterm examination, final examination and final grade data. The test is included in Appendix A.3, and the midterm examination and final examination are included in Appendices A.2. Data from the midterm examination (which took place before the start of the experiment), the final

Table 1. Academic Results for Participating Students

record	test %	midterm %	exam %	grade
101	66.67	37.14	59	D+
102	53.33	45.71	49	D-
103	86.67	54.29	55	C-
104	86.67	45.71	71	B-
105	80.00		76	A-
106	80.00		77	A-
107	26.67	34.29	40	FNS
108	80.00	60.00	53	C-
109	46.67	74.29	52	C-
110	86.67	40.00	78	B+
111	73.33	68.57	29	F
112	60.00	85.71	55	C+
113	60.00	57.14	45	D-
114	66.67	42.86	74	B-
115	93.33	85.71	92	A+
116	46.67	48.57	63	C-
117	73.33	45.71	84	A-
118	73.33	31.43	49	D-
119	86.67	40.00	29	F
120	60.00	48.57		ABS
121	53.33	60.00	52	D+
122	86.67	40.00	50	D+
123	60.00	54.29	63	C
124	53.33	82.86	70	B+
125	86.67	25.71	43	D-
126	60.00	48.57	62	C-
127	26.67	62.86	52	D+
128	73.33	90.00	64	B-
129	80.00	62.86	49	D+
130	60.00	40.00	44	D-
131	46.67	80.00	90	A+
132	46.67	68.57	47	D+

record: record number for participant

test %: test result for participant

midterm %: midterm examination result for participant

exam %: final examination result for participant

grade overall course letter grade for participant

examination and the overall course grade were referenced by record number only such that the students' privacy was protected. Test data were obtained directly from the tests themselves, which were graded without knowledge of the identity of the student, their group or their responses to the questionnaire. As well, the cumulative grade point averages of the participating students were obtained so that the normalization of other marks was possible.

Additionally, questionnaire data were compiled from participants' responses. These data were compiled, sorted and referenced to the appropriate record numbers after all test grades had been entered. The questionnaire responses were given voluntarily by the participants. In addition to the note printed on the questionnaire (Appendix A 3), the voluntary nature of the questionnaire was emphasised orally to the students on more than one occasion. Once the responses were obtained, they were coded into discrete values wherever possible to facilitate analysis. Comments, which for obvious reasons could not be coded, are included in Tables 6,7,8 and 9, and Appendix A.4, and are discussed in section 4.4.4. The coded responses were combined onto a single spreadsheet with the academic data, included in Appendix A.4.

4.3 Data Analysis

As a first stage of the analysis, some approximate comparisons were made to see if there were any immediately obvious relationships between data sets. The resulting graphs are included as Appendix A.5. Upon examination of these graphs, the only immediately obvious correlation was between knowledge of computers and enjoyment of computers, a result which might have been anticipated.

As can be seen by the spreadsheet included as Appendix A.4, there are forty-five sets of data, and thus 990 possible comparisons. While it would be possible to generate all of these possible comparisons, it was not advisable as it would have increased the chance of finding what appears to be a correlation when it is, in fact, just a chance effect. Instead, a shortlist of 165 comparisons was compiled.

Each of the comparisons in that list was examined for significance. In each case, the probability of the null hypothesis was calculated. The null hypothesis suggests that there is no relation between the two variables being tested. The probability of the null hypothesis is the chance that the apparent result is due to chance rather than to a relation between variables. For any apparent relationship there will always be a possibility that the null hypothesis is true, and thus it is necessary to choose a probability below which the null hypothesis can be rejected. A common value in behavioural research, and the value used in this analysis, is 0.05. That is, if the probability of the null hypothesis for any given set of results was less than 0.05, the null hypothesis was rejected and the results was assumed to be due to a relationship between the variables.

Two types of tests were employed to analyze the data and to find significance. The first is the t-test, used when one of the two values being compared is on a continuum and the other is always one of two discrete values. For example, this type of test was used to compare the test marks (a continuum) to the students' degree program (always either mechanical or aerospace engineering). The t-test calculates the average value for each of the two groups, then considers the number of data points and the spread of these to determine if the result is significant. Twenty-one t-tests were performed, using StatView (Appendix A.7), and the results of these can be seen in Appendix A.5. For t-tests, StatView provides the probability of the null hypothesis directly.

Table 2. Averages and Distributions for Data Sets

category	all students	comp. only	lecture only
A record number	n/a	n/a	n/a
B age	22.2	22.1	22.3
C gender (m or f)	all m	all m	all m
D year at university	84.4 % 3rd	81.3 % 3rd	87.5 % 3rd
	15.6 % 4th	18.7 % 4th	12.5 % 4th
	0 % blank	0 % blank	0 % blank
E specialization	59.4 % mech	63.5 % mech	56.3 % mech
	37.5 % aero	37.5 % aero	37.5 % aero
	3.1 % blank	0 % blank	6.2 % blank
F lecture or computer group (l or c)	50 % each	all computer	all lecture
G years using computers for academic work	5.4	5.1	5.7
H % engineering knowledge from lectures	13.4	11.8	15
I % engineering knowledge from lecture notes	16.3	13.8	18.6
J % engineering knowledge from computer tutorials	2.7	3.5	1.9
K % engineering knowledge from textbook	18.8	13.9	23.1
L % engineering knowledge from study with others	10.2	10.2	10.1
M % engineering knowledge from studying alone	17.4	18.3	16.4
N % engineering knowledge from problems etc.	22.7	28.6	17.2
O % engineering knowledge from labs	7.6	7	8.3
P % engineering knowledge from other sources	4.8	6.3	2.5
Q knowledgeable about comp. (0 none - 9 v much)	5.4	5	5.8
R enjoy working with comp (0 none - 9 v. much)	6.2	5.6	6.7
S times used computers for tutorials or training	4.4	2.8	6.2
T ease of course material (0 easy - 9 difficult)	6	5.4	6.6
U hours spent listening to lectures in last 2 weeks	3.6	0.9	5.8
V hours spend using FR software in last 2 wks	2.9	5.3	0
W computer group - looked at lecture notes	n/a	12.5 % yes	n/a
	n/a	87.5 % no	n/a
	n/a	0 % blank	n/a
X lecture group - used computer lab (yes or no)	n/a	n/a	6.3 % yes
	n/a	n/a	93.7 % no
	n/a	n/a	0 % blank
Y tried to learn material in additional ways	84.4 % yes	81.3 % yes	87.5 % yes
	12.5 % no	12.5 % no	12.5 % no
	3.1 % blank	6.2 % blank	0 % blank
Z studied class notes (yes or no)	34.4 % yes	0 % y	68.8 % yes
	18.8 % no	31.3 % no	6.3 % no
	46.8 % blank	68.7 % blank	24.9 % blank
AA studied computer printouts (yes or no)	18.8 % yes	31.2 % yes	6.3 % yes
	18.8 % no	12.5 % no	25.0 % no

Table 2. Averages and Distributions for Data Sets (con'd)

category	all students	comp. only	lecture only
	62.4 % blank	56.3 % blank	68.7 % blank
AB studied textbook (yes or no)	81.3 % yes	81.3 % yes	81.3 % yes
	3.1 % no	0 % no	6.3 % no
	15.6 % blank	18.7 % blank	12.4 % blank
AC did assigned problems (yes or no)	65.6 % yes	62.5 % yes	68.8 % yes
	12.5 % no	6.3 % no	12.5 % no
	21.9 % blank	31.2 % blank	18.7 % blank
AD other additional study			
AE hours spent trying to learn the material	5.1	4.3	5.8
AF comp group - like software (0 none - 9 v. much)	n/a	6	n/a
AG comp group - what liked most about program	n/a		n/a
AH comp group - what liked least about program	n/a		n/a
AI comp group - learn from program (0 none - 9 all)	n/a	5.3	n/a
AJ comp group - problem learning to use software	n/a	0 % yes	n/a
	n/a	100 % no	n/a
	n/a	0 % blank	n/a
AK comp group - specify problem	n/a		n/a
AL comp group - suggest for improving program	n/a		n/a
AM preference (0 computer - 9 lectures)	5.7	6.1	5.3
AN comments			
A0 test Q1 (out of 5)	3.7	3.9	3.4
AP test Q2 (out of 10)	6.3	5.8	6.8
AQ test total (out of 15)	9.9	9.6	10.3
AR test percent	66.3	64.2	68.3
AS midterm mark (out of 35)	19.3	18.7	19.9
AT midterm percent	55.1	53.3	56.8
AU exam Q2 (out of 25)	13.4	13.3	13.4
AV exam Q3 (out of 25)	13.3	11.9	14.5
AW exam total percent	58.6	57.2	59.9
AX final letter grade			
AY final grade #	4.7	4.5	5

The second type of test used was the correlation test. Here both sets of data being compared are continua, and the test seeks to find out how the values relate to each other. For example, a correlation test is used to see whether test marks (a continuum) increase or decrease with changes in attitudes towards computers (another continuum). The correlation test fits a line or a higher order function to the data points, then calculates a correlation coefficient which describes how closely the points lie to the line. When the absolute value of the correlation coefficient is close to one, the points lie close to the line. The coefficient is positive when one value increases with the other, and negative when one increases as the other decreases. One hundred and forty-four correlation tests were conducted using StatView, and the results of these are found in Appendix A.5. StatView provides the correlation coefficient, but does not give the probability of the correlation being the result of chance rather than of some true relationship. These probabilities were determined using the table included in Appendix A.5, using the correlation coefficient and the number of degrees of freedom, calculated according to the formula given in Appendix A.5.

4.4 Results

Tables 3 and 4 list the t-tests and correlations that showed significance (where the probability of the null hypothesis was less than 0.05). Table 5 lists other comparisons which may be considered interesting because they did not show a significant relationship between variables when one might be expected. The comparisons listed in these three tables are discussed here.

Table 3. Significant t-Test Results

X 1st column	Y 2nd column	t t-test result	v degrees of freedom	p probability of null hypothesis
degree program	ease of course	2.895	29	0.0071
degree program	exam %	-2.221	28	0.0346
degree program	grade #	-2.401	28	0.0232
group (comp. or lecture)	ease of course	-2.559	30	0.0158

Table 4. Significant Correlations

X 1st column	Y 2nd column	r correlation coefficient	c record count	v degrees of freedom
years using comp.	knowledge of comp.	0.538	32	30
years using comp.	enjoyment of comp.	0.402	32	30
knowledge of comp.	enjoyment of comp.	0.721	32	30
ease of course	additional hours	0.463	27	25
ease of course	midterm %	-0.401	30	28
c-amount of FR	l/c preference	0.584	16	14
c-amount of FR	exam Q2	0.614	13	11
test %	exam Q3	0.432	24	22
midterm %	grade #	0.494	29	27
exam %	grade #	0.952	31	29
total hours	ease of course	0.365	32	30
total hours	test Q1	0.420	32	30
c only -total hours	test %	0.508	16	14

Table 5. Notable Non-Significant Results

X 1st column	Y 2nd column
group (comp. or lecture)	hours spent
group (comp. or lecture)	additional hours
group (comp. or lecture)	total hours
group (comp. or lecture)	test Q1
group (comp. or lecture)	test Q2
group (comp. or lecture)	test %
group (comp. or lecture)	exam Q2
group (comp. or lecture)	exam Q3
group (comp. or lecture)	exam %
group (comp. or lecture)	grade #
group (comp. or lecture)	l/c preference
enjoyment of comp.	test %
enjoyment of comp.	exam %
enjoyment of comp.	grade #
enjoyment of comp.	c-liking of software
enjoyment of comp.	c-amount of FR
enjoyment of comp.	l/c preference
knowledge of comp.	test %
knowledge of comp.	exam %
knowledge of comp.	grade #
knowledge of comp.	c-liking of software
knowledge of comp.	c-amount of FR
knowledge of comp.	l/c preference
years using comp.	c-liking of software
years using comp.	c-amount of FR
c only -enjoy. of comp.	test %
c only -enjoy. of comp.	exam %
c only -enjoy. of comp.	grade #
c only -enjoy. of comp.	liking of software
c only -enjoy. of comp.	l/c preference
c only -know. of comp.	test %
c only -know. of comp.	exam %
c only -know. of comp.	grade #
c only -know. of comp.	liking of software
c only -know. of comp.	l/c preference
c only -yrs using comp.	test %
c only -yrs using comp.	exam %
c only -yrs using comp.	grade #

Table 5. Notable Non-Significant Results (con'd)

X 1st column	Y 2nd column
c only -yrs using comp.	liking of software
c only -yrs using comp.	amount of FR
c only -yrs using comp.	l/c preference
c-liking of software	test %
c-liking of software	exam %
c-liking of software	grade #
c-liking of software	c-amount of FR
c-liking of software	l/c preference
c-amount of FR	test %
c-amount of FR	exam %
c-amount of FR	grade #
% from lectures	l/c preference
c only -% lectures	liking of software
c only -% lectures	l/c preference
c only -% lectures	test %
c only -% lectures	exam %
c only -% lectures	grade #
ease of course	test %
ease of course	exam %
ease of course	grade #
total hours	test %
total hours	exam %
total hours	grade #
total hours	l/c preference
hours spent	c-liking of software
hours spent	c-amount of FR

Several sets of data were included for the purpose of comparing the profiles of the computer and lecture groups. These include basic information such as the age and gender of the students, as well as their responses to questions about their study habits and their experience with computers. This was done so that there could be reasonable certainty that any differences between the results for the two groups were due to the experiment rather than due to pre-existing differences. There were no statistically significant differences between the two groups for any of the aspects considered. The averages of the data values for all students, and for the computer and lecture groups separately, are found in Table 2.

4.4.1 t-Tests Showing Significance

4.4.1.1 Difference in t-Test Results by Degree Program

Three sets of t-test results demonstrated an appreciable difference between the mechanical engineering students and the aerospace engineering students, as can be seen in Table 3. The aerospace engineering students rated the course material as easier in response to the question:

11. How easy or difficult is the material in Feedback Control Systems?

extremely easy 0 1 2 3 4 5 6 7 8 9 extremely difficult

and scored better on the final examination and final grade. It is noteworthy, however, that they fared no better on the midterm examination or the post-experiment test.

This difference in results between degree programs may be due to the nature of the students in each program. For example, entrance marks are on average higher for aerospace students than for mechanical students. Also, the two groups are self-selecting, and it may be that students with an affinity for material such as that taught in 86.352 also tend to enter aerospace engineering rather than mechanical engineering. It is also possible that the presence in the sample of three fourth-year electronics stream aerospace engineering students had an effect on the results, as these students have an additional year of engineering courses including some with similar content to 86.352.

4.4.1.2 Difference in Rating of Ease of Course Material by Group

There was a significant difference between the ratings for the ease of the 86.352 course material by the computer group students and the lecture group students. The lecture group students rated the course material as being more difficult than did the computer group students. This is despite there being no significant difference in the test, examination or final grades of the two groups, and no significant difference in composition.

It may be that the computer tutorial software made the material easier to learn, or perhaps that it made the students more comfortable with the material, and thus brought them to believe that the material was easier than it was. The latter is more likely, as the computer group students spent an equivalent amount of time learning the material and fared approximately the same in testing as the lecture group students, despite rating the material as easier.

4.4.2 Correlations Showing Significance

4.4.2.1 Correlations Involving Computer Experience

The results of the statistical analysis showed correlations relating computer experience to knowledge and enjoyment of computers, as can be seen in Table 4. Good correlations were found to exist between the years of computer use for academic work and the students' self-rating of computer knowledge, as well as between the years of computer use and the students' enjoyment of working with computers. A very strong correlation was noted between the students' knowledge of computers and how much they enjoyed working with them. The four questions used to evaluate these factors were:

6. How many years have you been using computers for academic work?

8. How knowledgeable are you about computers?

complete novice 0 1 2 3 4 5 6 7 8 9 expert

9. How much do you enjoy working with computers?

not at all 0 1 2 3 4 5 6 7 8 9 very much

10. How many times have you used computers for tutorials or training (e.g. in engineering courses, first aid courses, for summer jobs, for learning software, etc.)?

None of these correlations are surprising. It is reasonable to expect that the length of time a student has been using computers would be closely tied to how well they know them and how much they enjoy working with them. It is also not surprising that students would be more knowledgeable about computers if they enjoy working with them, and vice versa.

4.4.2.2 Correlations Related to the Ease of the Course Material

The students' rating of the ease of the 86.352 course material was found to be related to both the amount of study hours devoted to learning the frequency response material and the midterm examination grades. In the first instance, the students who found the course material more difficult also spent more time outside of the lecture and tutorial time learning the material. This is also true of the total time spent including lecture and tutorial time. The questions used to determine the amount of time spent in each case were:

- 12.a In the past couple of weeks, how many hours did you spend listening to the lectures about Frequency Response? (maximum 7 hours)
- 12.b In the past couple of weeks, how many hours did you spend using the computer software about Frequency Response?

14.a In addition to attending the lectures or using the computer programs, did you try to learn the Frequency Response material in any other way? yes no

14.c If yes, how many hours did you spend trying to learn this material?

Similarly, it was found that the more difficult the students judged the material to be, the lower their scores on the midterm examination. This is true only of the midterm examination. There was no similar effect for the test, the final examination, or the final grade.

It is difficult in this case to separate cause from effect. It may be that students who did poorly on the midterm examination rated the course material as being more difficult, or that students who find the material difficult did less well on the midterm examination. Similarly, it may be that students who found the material difficult compensated through additional study, or that students who studied the material in depth determined that the material was more difficult than it seemed to students who studied less.

4.4.2.3 Correlations with the Amount of Frequency Response Taught by the Software

One of the questions on the questionnaire

16. How much about the Frequency Response part of the course do you think you learned by using this program?

nothing 0 1 2 3 4 5 6 7 8 9 everything

asks the computer group students to assess how much of the frequency response component of the course was taught by the tutorial. The result has a significant correlation with the students response to their preference of computer tutorials or lectures.

19. Given the choice, how much would you prefer to learn other engineering topics using the computer or using traditional lectures?

much prefer computer 0 1 2 3 4 5 6 7 8 9 much prefer lectures

According to the data, the more students felt the tutorials taught them, the more they preferred lectures over future tutorials. This result seems counter-intuitive, as one might expect that students who felt they were taught all of the necessary material through the tutorials would lean towards tutorials for future use. It is possible that instead of one of these factors being the result of the other they are both the results of some third factor.

There was also a correlation between the amount of frequency response the computer group learned through the tutorial software and their performance on one of the final examination questions. Question 2 of the final examination was one of two questions relating to frequency response. Students who felt that they were taught a large amount of frequency response material by the tutorials did better on that question than those who felt they learned less from the tutorials. Since this effect was not

apparent for the other frequency response examination question or for any of the other marks, it is difficult to say why it is true in this case.

4.4.2.4 Comparisons Between Sets of Marks

There were correlations between some of the sets of marks used as data. Two of these are obvious and easy to explain. These are the high correlations between midterm examination grade and final grade, and between final examination grade and final grade. These are due to the fact that the midterm examination and final examination marks contribute linearly to the final grade, and thus a higher score on either of these exams will result in a higher final grade.

More interesting, perhaps, is that the experimental test result was a good indicator of performance on Question 3 of the final examination. Those students who did better on the test also fared well on the examination question. Question 3 is the second of two final examination questions relating to the material taught during the period of the experiment. The same result was not noted for the other question. It may be that Question 3 was closer in structure or in content to the test questions than was the other question.

4.4.2.5 Correlations Involving the Total Hours Spent

As discussed above, the total hours spent learning the material was related to how easy or difficult the students found the course material. The total hours spent are similarly related to the students' marks on the first question of the experimental test, and in the case of the computer group, to the overall test grade. These results make sense, but what is difficult to determine is why there were only significant

correlations in these cases. For example, it seems logical that the more time spent learning the material, the better students would do on the test. Why, then, would this be true only of the computer group and not of the lecture group? It may be that the results show the effects of other factors in the process, such as teaching methods or individual learning styles.

4.4.3 Notable Cases of Statistical Non-Significance

In some cases, the fact there was no relationship between two sets of data was in itself of interest. This is particularly true when a correlation was expected or considered a strong possibility.

4.4.3.1 Group Non-Significance

Some of the t-tests comparing results for the computer group to those of the lecture group yielded no significant differences when differences were expected. The two groups spent the same amount of time learning the material. This is true not only of the total hours, but also when comparing study hours alone, or comparing lecture hours to hours of computer use. The groups did not differ in any significant way in marks, including the test marks, examination marks and overall grades. This was also true when the final grades and test marks for the students were normalized with respect to the cumulative grade point averages of the students, as can be seen in Appendix A.5. Both groups scored on average slightly higher on the post-experiment test, and moderately lower on the overall course grade than their cumulative grade point averages. Finally, it is notable that the two groups gave similar responses when asked whether they would prefer lectures or computer tutorials in the future.

These results are significant because they seem to indicate that there was very little difference in major outcomes according to whether the students in the sample attended lectures or used the computer tutorials. The only significant difference noted, described above, was that the computer group rated the course material as being easier than did the lecture group.

4.4.3.2 Non-Correlations Relating to Experience with Computers

One of the most interesting results was that the students' experience of computers had very little effect on their experiences with the tutorial software. There were no significant correlations between students' knowledge of computers or enjoyment of computers and their grades on the test, examination or overall course. Furthermore, these factors appeared to have no relation to their like or dislike of the tutorial software, their estimates of how much of the material was taught by the tutorials or their lecture/tutorial preference.

This result was not only found in the overall population, but also in the computer group alone. The number of years of experience students had using computers for academic work did not appear to be related to the amount of time spent learning the material, the students' attitudes towards the software, the amount of frequency response material taught by the software, the students' lecture/computer preference or any of their grades. Also, no correlations were evident when the computer group students' knowledge, enjoyment of computers and previous times using computers for tutorials were compared to these same sets of outcome data.

These results are interesting because one of the common questions about CAL is whether its effectiveness is biased towards those students who are most comfortable with computer use. This result indicates that this may not be the case, that students

can learn well from CAL whether or not they are very familiar with computers or enjoy working with them. It is important to note, however, that the students participating in this experiment were all engineering students, as such the spectrum of computer experience is smaller and weighted towards the high end.

4.4.3.3 Non-Correlations Involving Liking of Tutorial Software

Similarly to the above, it was interesting to note that the computer group students' attitudes towards the tutorial software, as assessed by the question:

15.a In general, how much did you like the computer program that taught
Frequency Response?

not at all 0 1 2 3 4 5 6 7 8 9 very much

had little apparent impact on their marks, on the amount of the material they were able to learn from the software or on their lecture/computer preference. This is interesting, because it means that whether or not the students liked the tutorial software did not affect their learning.

4.4.3.4 Lack of Relationship Between Amount of Frequency Response Taught by Tutorials or Lecture/Computer Preference and Academic Outcomes

The amount of the frequency response material that the computer group students felt they were taught by the tutorial was not related to their academic results. Similarly, there seems to be no relationship between the students' preference of traditional lectures or computer tutorials to their marks. This is interesting because it

means that their preference for a mode of teaching may not be based on the marks they feel will result.

4.4.3.5 Non-Correlation Involving Percent of Learning from Lectures for the Computer Group Only

The amount of learning computer group students said that they usually obtained from lectures had no obvious impact on their liking of the software, their lecture/computer preference or their grades. In other words, students who said that a high percentage of their learning came from lectures, in response to the question:

7. How much of your knowledge of engineering do you think you learn in the following ways:

lecture	_____ %
lecture notes	_____ %
computer tutorials	_____ %
textbook	_____ %
studying with other students	_____ %
studying alone	_____ %
problems and exercises	_____ %
labs	_____ %
other _____	_____ %

tared no worse and no better when they were members of the computer group.

4.4.3.6 Lack of Relationship Between Marks and Rated Ease of Course

Apart from the exception of the midterm examination mark, discussed above, students' rating of the ease of the 86.352 course material seems to have no relation to their marks on the test, the examination, or the overall course. This could mean that students tend to compensate with additional effort when a course is more difficult, that they are not good at assessing the difficulty of the material, or that their assessment of difficulty is not directly related to their ability to learn the material.

4.4.3.7 Non-Correlations Involving Total Hours Spent Learning the Frequency Response Material

Interestingly, the total amount of time spent by students learning the material did not correlate with their midterm examination, final examination or final marks, or their lecture/computer preference. The exceptions were the marks on the first question of the experimental test, and in the case of the computer group, the overall experimental test mark. These were discussed above.

Additionally, in the case of the computer group, the total time spent was not related to their liking of the software or the amount of the material they felt it taught. This suggests that the students' appraisal of the software was not based solely on their own level of effort. It is perhaps more likely that it demonstrates that a student's study habits are in some part due to their overall learning style, rather than being an entirely course-dependent factor.

4.4.4 Student Comments

The questionnaire offered the participating students several opportunities to provide comments on the software and on CAL use in engineering. Four of these questions were directed to the computer group only, and were intended to offer them an opportunity to elaborate on their impressions of the software and to make suggestions for improvement.

The first opportunity for the computer group students to provide comments came when they were asked:

15.b What did you like most about the program?

Of the sixteen students in the computer group, thirteen responded. The comments provided are included in Table 6. Next, the same students were asked:

15.c What did you like least?

Twelve of the sixteen computer group students responded, and these responses are included in Table 7. The computer group students were also asked if they had any problem learning to use the tutorial software. In the case of a positive response, they were given the opportunity to elaborate on the problem:

17.b If yes, what was the problem?

No comments were provided by any of the computer group students. This was expected, as none of the students reported having any problem learning to use the tutorial software. The computer group students were also asked:

Table 6. Responses to Question 15 b**15.b What did you like most about the program?**

record	response
107	The instructions helped in guiding me through the tutorial Could learn at your own pace.
109	MATLAB, easy to go back and look at the old notes
110	That I could go & do the tutorial anytime I wanted
113	can see all the diagrams on screen
115	interactive, interface with MATLAB
119	Go at own pace, Don't need to take notes (since we were given them)
120	The bode plots and graphs were clearer to figure out because everything was step by step I also liked it because I could go at my own pace
122	can get through the material quickly
123	Ease of use!
125	Matlab examples
126	easy to use, simple egs
127	it was at my own pace
132	interactive

Table 7. Responses to Question 15 c**15.c What did you like least? *(about the program)***

record	response
109	No talk
110	Few mistakes; and the fact that when colleagues ask questions: the entire class doesn't hear it
113	it hard to understand how to draw the bode plot
119	Can't ask Prof questions
120	I wish you could be able to use the reverse button on the examples so we could read the previous page instead of having to press return & spool to the required page.
122	referring back when going through the examples
123	Too much like a book! Well written, but I could go to the library too.
124	not being able to ask a question when I had problems understanding a particular concept
125	Reading from a computer screen
126	Hard to concentrate and pay attention to what I'm reading
127	it was on a computer
132	not enough examples

18. Do you have any suggestions about improving the Frequency Response computer program?

and eight responded with the comments included in Table 8.

Finally, both the computer group and the lecture group were asked:

20. Do you have any comments about the use of computer-aided instruction in engineering?

Of the thirty-two participating students, twenty-one responded. The comments provided are included in Table 9.

The comments were generally positive. As there was a large variety of responses, and no remarkable trends, the comments are not discussed here at length.

4.5 Cost Analysis

A cost-comparison of the lecture and CAL methods for teaching 86.352 was carried out. The purpose of this comparison was to determine the difference in cost to the university. Only the difference in cost is considered. Those areas where the two methods of instruction have the same cost or produce the same revenue are not considered. Two models were used. The first of these is based on a single year of course delivery. The second assumes a five-year period. The figures used for the lecture model are based on a cost analysis of Carleton University's itv program (Goheen and Brown, 1995).

Table 8. Responses to Question 18

18. Do you have any suggestions about improving the Frequency Response computer program?

record	response
110	not the program
113	try to improve the procedure of plotting the graph
115	ability to scroll backwards through windows
120	I think more difficult & complex examples would help too The ones presented were rather straight forward.
122	correct the typo's & more diagrams
124	more examples in step by step detail, less reliance on switching back and forth to MATLAB
125	correct errors, make it easier to move back 1 page at a time in examples
132	It was a very good program, just add some more examples.

Table 9. Responses to Question 20

20. Do you have any comments about the use of computer-aided instruction in engineering?

record	response
102	No experience with "computer-aided" just used computers as tool, would like to try integrating computer so can "work at own pace"
106	Computer learning is effective if the system is user friendly enough
108	Good. But the computers that we use are too old. The U should upgrade the computer to at least 486 level. Even in high school, we are not using 286
109	some courses should have at least limited hours of classes
110	I strongly not recommend computer-aided instruction in engineering if they are to be given independent of the lectures. The lecture is crucial
111	Software should be included in text book.
112	I think computer tutorials should be available for all lecture courses in engineering that the student may persue at his/her leisure. It should expand upon, explain in a different manner, the material covered in the lecture
113	it easy to give every student to understand, but hard to ask question if the problem has occurred
115	could be made available along with lectures as extra resource for students
116	If you aren't familiar with computers in general you start at a disadvantage
120	I think tutorials should be in computer form, along with TAs present I don't think it should replace instruction, however.
121	computer aided instruction should be an optional condition for the student to the lectures already being attended
122	No
123	it is useful for some students more than others.
124	computers can't answer questions or explain concepts, or give personal experiences relating to the concept
125	benefit: repeat problem areas and go at your own pace
126	Personally I learn from the textbook so the computer (or lectures) is not very helpfull
127	use it as well as the regular lectures
130	Some is good, but I don't know to what extent since I never tried
131	It would be difficult to get answers to questions you may have This is important in learning
132	Since much of this section was review from 94.260 (360 now) I am not sure how much I learnt from the tutorial. Therefore my test result may not indicate how much I learnt from the tutorial Despite this the computer program was fairly well done.

The comparison initially assumes that there are one hundred students in the course. This parameter was later varied, as discussed in section 4.5.3 to determine the effect of having more or fewer students. A maximum number of one hundred students per section was assumed. These students pay the same fees whether they are in the lecture group or the computer group, and are also identical where use of university services such as the library are concerned. The printing and publication costs for course handouts are assumed to be the same. Furthermore, outside of the actual course computer laboratory time for the computer model, they use computer facilities equally. They are assumed to spend the same amount on books, food and parking. The course time for both groups is three hours per week. For the computer model, they are assumed to be divided into two equal groups of fifty students.

It is assumed that a professor earns \$80,000 per annum, plus fifteen percent benefits. Professors spend fifty percent of their time lecturing. For the lecture model, this represents two credits of courses per annum, or four half-credit courses. For the computer model, there is still a need for the direction of a professor. It is assumed that a professor will supervise six credits of computer-based courses, or twelve half-credit courses.

The computer laboratory contains fifty computers. These are assumed to cost one thousand dollars each per annum, including hardware, system software and all peripherals. The cost includes shared facilities such as printers and network servers. Computer management and maintenance personnel are assumed to cost \$35,000 per annum per three hundred computers. This is an estimated average of salaries, benefits and other costs of employment of senior computer personnel, junior personnel, and student employees.

It is assumed that a single teaching assistant works with both halves of the computer group. There is no teaching assistant for the lecture model. The teaching assistant is assumed to cost \$3300 per term.

The computer software is assumed to take one half-year to program. The programmer is initially assumed to cost the university a total of \$25,000 per annum. This is intended to represent an average between a professional programmer and an externally-funded graduate student. This cost was also varied, as can be seen in section 4.5.3, to consider the effect on the cost differential. For the five-year model, it is assumed that two weeks per year are required for updating the software. It is assumed that the cost of content development by the professor is equal to the time the professor spends developing content for the lecture model.

It is assumed that in the lecture room, there is one student per fifteen square feet of space (Goheen and Brown, 1995). Computer laboratories in the Faculty of Engineering average approximately twenty square feet of space per student. The rooms are available for use fifty-seven hours per week (twelve hours per day Monday to Thursday, nine hours on Friday), but the lecture room has a sixty percent net utilization rate, meaning that each seat is in use on average for only sixty percent of the available time (Ibid., 1995), and the computer lab has an eighty percent net utilization rate. This means that the classroom is 1500 square feet, and is used for this course 8.77 percent of the time. The computer laboratory is 1000 square feet, and is used for the course 13.16 percent of the time. The capital cost of the classroom is assumed to be thirty dollars per square foot per annum, including building and furniture costs (Ibid., 1995). The capital cost of the computer laboratory is assumed equal, but with the addition of the computer capital described above. Maintenance, including cleaning, electricity and heat, is assumed to cost eight dollars per square foot per annum for the classroom (Ibid., 1995), and ten dollars per square

foot per annum for the computer laboratory due to additional electricity and connectivity costs. The classroom is assumed to have audio and video equipment costing five thousand dollars per annum.

4.5.1 One-Year Model

According to the assumptions above, as can be seen in Table 10 and in the spreadsheet in Appendix A.6, the computer model would cost approximately \$15,000 more than the traditional lecture format for the one-year case. The one-year model assumes that all of the development cost is borne in the first year. Because of that assumption, the annual cost differential for the one-year model is higher than for the five-year model or for any other longer term model.

4.5.2 Five-Year Model

For the five-year case, the development cost is distributed over a five year period. For those five years, the computer model would cost a total of about \$30,000 more than the lecture model, or \$6,000 per year. This result is shown in Table 10 and in Appendix A.6. The cost differential is smaller than the one-year model because the development cost is only substantial in one of the five years. The differential would be further reduced by considering an even longer model, but based on the current set of assumptions, would never disappear completely.

Table 10. Cost Comparison for Basic Model

Item	L100	C100
One-Year Model		
professor cost	11500	3833
TA cost		3300
development cost		12500
room capital (room and furniture)	3947	3948
room maintenance	1052	1316
classroom AV	439	
computer lab capital (software and hardware)		6580
computer personnel		768
Total	16938	32245
Differential	-15307	15307
Percent	-90.37	47.47
Five-Year Model		
lecturer cost	57500	19165
TA cost		16500
development cost		16346
room capital (room and furniture)	19735	19740
room maintenance	5260	6580
classroom AV	2195	
computer lab capital (software and hardware)		32900
computer personnel		3840
Total	84690	115071
Differential	-30381	30381
Percent	-35.87	26.40

4.5.3 Cost Variances

The costs of the one-year and five-year lecture and computer models vary when the parameters on which the calculations are based are varied. In order to see the extent of these variations, the costs were re-computed and plotted against the changing parameter. This was done for the number of students, for the development cost, and for the computer use rate.

The variation of cost versus the number of students can be seen in Figure 1 and in Appendix A.6. The cost of the computer model is always above that of the lecture model. It grows more rapidly as the number of students is increased because the per-student cost increment of the computer model is greater. The step which can be seen in all four curves represents the point where two sections are required. For the purposes of this calculation, it was assumed that the largest possible section size was one hundred students. It is notable that the computer cost is closest to the lecture cost when the number of students per section is lowest (at the lowest number of students and immediately after the jump to two sections) because the cost of adding another section to the lecture model is greater than that of adding another section to the computer model.

The cost variation with respect to changes in the development cost can be seen in Figure 2 and Appendix A.6. Here the first year development cost was varied, and the five-year development cost was calculated based on the first year cost with the addition of two weeks per year of the programmer cost. The minimal development cost might represent a case where the software is purchased rather than developed, and the purchase cost is borne by students much as the cost of a textbook. The upper-end cost represents the cost of having the software developed in-house over a full year by a professional programmer. Alternative models in the mid-range include

Figure 1. Cost Variation with Number of Students

Figure 2. Cost Variation with Development Cost

decreased development time, development by graduate students, development with the assistance of external funding, development costs offset by sales to other institutions and external purchase of software. When the development costs is minimized, the cost of the lecture and computer models are very close, although the cost of the computer model is slightly higher. As the development cost is increased, the lecture model cost remains unchanged, and the cost differential grows.

The change in cost relative to the computer use rate is shown in Figure 3 and in Appendix A.6. The computer use rate is the fraction of the net use time of the computer facilities for which they are used by the course. As discussed above, the course is assumed to use the computer facilities for six hours per week (two sections of students for three hours each). The net use time is calculated by finding the total number of hours for which the computer facilities are available per week and multiplying it by a net utilization rate. The base assumption was that the computer laboratory was available for fifty-seven hours per week, and that it was used for eighty percent of that time. This meant that the course would be using the computer facilities for 45.6 percent of the total time that they are used. This rate was varied from 8.5 percent to twenty-five percent. The low rate might represent a model where the computer is used on weekends as well as during the week. The high rate might represent a case where the computer lab is under-utilized by other groups. When the computer use rate is low, the cost of the computer model is close to that of the lecture model. When the use rate is high, the cost differential is much greater.

None of these variations alone caused the cost of the computer model to fall below that of the lecture model, but a combination of them could. For example, if the class size were 125 students, the computer use rate ten percent and the first-year development (or purchase cost) five thousand dollars, then the cost of the computer model is below that of the lecture model for a five year period.

Figure 3. Cost Variation with Computer Use Rate

4.5.4 Alternative Models

The results of the cost analysis will vary according to the assumptions on which the analysis is based. These changes can be minor or significant depending on which assumption is affected.

One change which would have a significant effect not only on the cost of the computer model but also on the nature of the model would be to use purchased software instead of developing the software in-house. While this may not currently be possible, educational publishers and other universities are starting to produce high-quality CAL packages, and it is likely that an excellent control systems CAL package will be available in the near future. Such a purchase would affect the development and maintenance components of the cost analysis, and might also impact the teaching assistant and professor requirements. It is also possible that a package could be purchased by students just as they purchase textbooks.

If the software is to be developed in-house, some of the cost of the software development could be recovered by selling it to a publisher or to other institutions. A significant investment would be required for the initial development, but if the software were properly developed it could provide income to offset the costs of the course.

Another change which would significantly affect the cost of the computer model would be to encourage students to use the tutorial software at home. This would decrease the number of computers required to run the course, and thus the overall cost. Similarly, the number of computers required would be reduced if it is assumed that there exist currently computer labs which are not being used to the fullest

possible extent possible. Increasing their use would therefore distribute the cost of the laboratory and equipment over a greater number of courses, thus reducing the cost to the other courses. The computer use rate for the control systems course and for the other courses would be reduced.

4.6 Summary

This section described the data collected from the experiment and the analysis performed on the data, and the results of the analysis. The data collected included questionnaire responses, test marks, examination and final grades and cost data. The types of analyses performed on the data included statistical analyses and a cost analysis.

Several interesting relationships were noted. From the results of the t-tests for significance, it was found that the aerospace engineering students obtained higher grades on the final exam and on the overall course. Also, there was a significant difference in results for the rating of the ease of the course material by the computer group and the lecture group. The lecture group rated the frequency response material as more difficult than did the computer group.

There were some significant correlations found in the analysis. The students' years of computer experience, their enjoyment of working with computers and their knowledge of computers were all closely related. The ease of the course material as rated by the students was closely related to the amount of time spent studying the frequency response material, and to the midterm grades. The amount of frequency response material the computer group students thought they had been taught by the software was inversely related to their preference for future software tutorials.

over lectures. Some of the sets of grades considered were closely related. The amount of time spent studying the material was found to be related both to the rated ease of the course material and to some of the grades.

Additionally, some of the results discussed in the section above were included because no relationship was found where one might have been expected. One of the most interesting of these cases is that, except for the rating of the ease of the course material, there were no significant t-test results for comparisons between the computer and lecture groups. Also, there were no significant correlations related to students' experience with, knowledge of or enjoyment of computers, except amongst these factors themselves. The computer group students' stated amount of learning from lectures was not related to their performance on the test or in the course, to their liking of the software or to their lecture/computer preference. The students' rating of the ease of the course material was only related to their midterm examination grade and not to any other grades. The amount of time students spent learning the material was not related to their major grades or to their preference for lectures or computer tutorials. The amount of time the computer group students spent learning the material was not related to their liking of the material or the amount they felt it taught.

The cost analysis suggested that the computer tutorial model developed would cost the university more to provide than the lecture model. This cost differential was reduced by considering a longer period of employment of the model. It could also be reduced, and in fact reversed, by changes in some of the other assumptions, such as the number of students in the class and the development cost. The cost differential was altered by changing the assumptions used to develop the models, but in most cases the computer model was more costly than the lecture model.

5. Conclusions and Recommendations

5.1 Conclusions

1. The use of CAL instead of traditional lectures was equally effective in terms of academic results.
2. The effects on students' attitudes were minimal. The only significant affective result was that the students using CAL instead of attending traditional lectures found the material easier to learn than did the lecture students, although the grades obtained were similar.
3. The results indicate that the effectiveness of CAL is not biased towards those students who are most comfortable with computer use, and that students can learn well from CAL whether or not they are very familiar with computers or enjoy working with them. It is important to note, however, that the students participating in this experiment were all engineering students; as such the spectrum of computer experience is smaller and weighted towards the high end.
4. The cost analysis suggested that the computer tutorial model developed would cost the university more to provide than the lecture model. This cost differential was reduced by considering a longer period of employment of the model. The resulting cost differential is altered by changing the assumptions used to develop the models, but in most cases the computer tutorial model was more expensive.

5. Additionally, based on the experimental results:

- a. The participating aerospace engineering students rated the course material as easier than did the mechanical engineering students, and scored better on the final exam and overall course grade.**
- b. Students' self-rating of computer knowledge, years of computer use and enjoyment of working with computers are very strongly related**
- c. Students who found the course material more difficult also spent more time outside of the lecture and tutorial time learning the material.**
- d. The more students felt the tutorials taught them, the more they preferred lectures over future tutorials.**
- e. The total hours spent learning the material was related to how easy or difficult the students found the course material. Those students who found the material more difficult spent more time learning it**
- f. The students' experience of computers had very little effect on their experiences with the tutorial software.**
- g. The computer group students' like or dislike of the tutorial software did not affect their learning.**
- h. The amount of frequency response material the students felt was taught by the software did not affect the academic outcomes.**

- i. There is no relationship between the students' preference of traditional lectures or computer tutorials to their marks. This is interesting because it means that their preference for a mode of teaching may not be based on the marks they feel will result.
- j. Students who said that a high percentage of their learning came from lectures fared no worse and no better when they were members of the computer group.
- k. Students' rating of the ease of the 86.352 course material had no relation to their marks on the test, the examination, or the overall course.
- l. The total amount of time spent by students learning the material did not correlate with their midterm and final examination marks or their lecture/computer preference.
- m. The total time spent by the computer group learning the material was not related to their attitudes toward the software or to the amount of the material they felt it taught.

5.3 Recommendations

1. The use of CAL to teach engineering courses should be considered, but considerable attention must be paid to controlling the cost.
2. Further research is required before the impact of CAL use on all types of students and all subject matter can be properly assessed. This study only examined the effects of CAL use on undergraduate engineering students studying frequency response. Similar results would likely be obtained for other subjects and participant groups, but it is possible that altered outcomes would result if the material and the student profiles were greatly different.

6. REFERENCES

- Abbanat, R.
Gramoll, K.
Craig, J. (1994). Use of Multimedia Development Software for Engineering Courseware. In T. Ottmann and I. Tomek (Eds.), *Educational Multimedia and Hypermedia, 1994: Proceedings of ED-MEDIA 94 - World Conference on Educational Multimedia and Hypermedia* (pp. 625). Charlottesville, Virginia: Association for the Advancement of Computing in Education.
- Allinson, L. (1992). Learning Styles and Computer-Based Learning Environments. I. Tomek (Ed.), *Lecture Notes in Computer Science: Computer Assisted Learning - 4th International Conference, ICCAL '92* (pp. 61-73). Berlin, Germany: Springer-Verlag.
- American Psychological Association (1982). *Ethical principles in the conduct of research with human participants*. Washington, District of Columbia: American Psychological Association.

- Aminmansour, A. (1993). Multimedia: A Revolutionary Tool to Enhance Teaching and Learning of Structural Steel Design. In H Maurer (Ed.), *Educational Multimedia and Hypermedia, 1993: Proceedings of ED-MEDIA 93 - World Conference on Educational Multimedia and Hypermedia* (pp. 11-16). Charlottesville, Virginia: Association for the Advancement of Computing in Education.
- Antao, B.A.A. (1992). Building Intelligent Tutorial Systems for Teaching Simulation in Engineering Education. *IEEE Transactions on Education* (Vol. 35, No. 1, pp. 50-55). New York, New York: IEEE.
- Brodersen, A.J.
- Bourne, J.R.
- Cantwell, J.R.
- Baird, W.E. (1992). Computer Learning and Appropriate Testing: A First Step in Validity Assessment. D.W. Spuck and W. C. Bozeman (Eds.), *Journal of Research on Computing in Education* (Vol. 25, No. 1, pp. 18-27). Eugene, Oregon: International Society for Technology in Education.
- Silvern, S.B.
- Barker, D.I. (1994). A Technological Revolution in Higher Education. T.T Liao and D.C. Miller (Eds.), *Journal of Educational Technology Systems* (Vol. 23, No. 2, pp. 155-168). Amityville, New York: Baywood Publishing Company.
- Barker, P.G. (1987). *Author Languages for CAL*. London, United Kingdom: Macmillan Education.

- Bork, A. (1991). Learning in the Twenty-First Century Interactive Multimedia Technology M. Giardina (Ed.), *Interactive Multimedia Learning Environments - Human Factors and Technical Considerations on Design Issues* (pp. 2-17). Berlin, Germany: Springer-Verlag.
- Broome, D.R.
Woolvet, G.A. (1976). Mini-Computer Implementation of Interactive Programs for Teaching Linear Control Systems Analysis. *The International Journal of Mechanical Engineering Education* (Vol. 4, No. 1, pp. 25-36). London, United Kingdom: Institution of Mechanical Engineers, University of Manchester Institute of Science and Technology, Mechanical Engineering Publications Limited.
- Brown, S.W.
Cutlip, M.B. (1987). Computer-Based Education in College: A Study of Cognitive and Affective Outcomes. *Proceedings of the International Conference on Computer-Assisted Learning in Post-Secondary Education* (pp. 71-76). Calgary, Alberta: The University of Calgary.
- Chen, L.L. (1994). Digital Multimedia Instruction - Past, Present and Future. T.T. Liao and D.C. Miller (Eds.), *Journal of Educational Technology Systems* (Vol. 23, No. 2, pp. 169-175). Amityville, New York: Baywood Publishing Company.

- Chun, D.M.
Plass, J.L. (1994). Assessing the Effectiveness of Multimedia in Language Learning Software. In T. Ottmann and I. Tomek (Eds), *Educational Multimedia and Hypermedia, 1994: Proceedings of ED-MEDIA 94 - World Conference on Educational Multimedia and Hypermedia* (pp. 135-140). Charlottesville, Virginia: Association for the Advancement of Computing in Education.
- Clark, R.E.
Craig, T.G. (1991). Research and Theory on Multi-Media Learning Effects M. Giardina (Ed.), *Interactive Multimedia Learning Environments - Human Factors and Technical Considerations on Design Issues* (pp. 19-29) Berlin, Germany: Springer-Verlag.
- Croy, M.J.
Cook, J.R.
Green, M.G. (1994). Human-Supplied Versus Computer-Supplied Feedback: An Empirical and Pragmatic Study. D.W. Spuck and W. C Bozeman (Eds.), *Journal of Research on Computing in Education* (Vol. 26, No. 2, pp. 185-204) Eugene, Oregon International Society for Technology in Education
- Cvetkovic, S.R.
Seebold, R.J.A
Bateson, K.N.
Okretic, V.K. (1994). CAL Programs Developed in Advanced Programming Environments for Teaching Electrical Engineering. *IEEE Transactions on Education* (Vol. 37, No. 2, pp. 221). New York, New York: IEEE.

- Demerdash, N.A.O. (1993). Impact of Academic Computing on Teaching Electrical Engineering at Clarkson University. *IEEE Transactions on Education* (Vol. 36, No. 1, pp. 94-101). New York, New York: IEEE.
- Gallagher, R.H.
- Schilling, R.J.
- Svoboda, J.A.
- Diessel, T. (1992). An ITS for Engineering Domains - Concept, Design and Application. I. Tomek (Ed.), *Lecture Notes in Computer Science: Computer Assisted Learning - 4th International Conference, ICCAL '92* (pp. 161-173). Berlin, Germany: Springer-Verlag.
- Lehmann, A.
- Ellis, H.D. (1992). Application Report: Low-cost, High-volume Exploitation of Computer Technology in Education. *Journal of Computer-Based Instruction* (Vol. 19, No. 3, pp. 73-76). Columbus, Ohio: Association for the Development of Computer-Based Instructional Systems.
- Feliachi, A. (1994). Control Systems Curriculum National Survey. *IEEE Transactions on Education* (Vol. 37, No. 3, pp. 257-263). New York, New York: IEEE.
- Franklin, G.F. (1994). *Feedback Control of Dynamic Systems*, 3rd Ed. Reading, Massachusetts: Addison-Wesley Publishing Company.
- Powell, J.D.
- Emami-Naeini, A.

- Fyock, J.J.
Sutphin, H.D. (1995). Students' Perceptions of the Effectiveness of Two-Way Interactive Television. In M.M. Thompson (Ed.), *DEOS - The Distance Education Online Symposium - DEOSNEWS* (Vol. 5, No. 4). University Park, Pennsylvania: The American Center for the Study of Distance Education (ACSDE), The American Journal of Distance Education (AJDE), The Pennsylvania State University, College of Education.
- Gal, S. (1992). Computers and Design Activities: Their Mediating Role in Engineering Education. In E. Barrett (Ed.), *Sociomedia - Multimedia, Hypermedia, and the Social Construction of Knowledge: Technical Communication and Information Systems* (pp. 433-467). Cambridge, Massachusetts: MIT Press.
- Goheen, K.R.
Brown, D. (1995). Financial Impact of Increasing itv Operations. Report for L.A. Copley, Vice-President (Academic), Carleton University.
- Goheen, K.R. (1994). 86.352 Course Notes. Carleton University
- Hodgson, J.M. (1992) A Workstation Self-Learning Programme. *International Journal of Electrical Engineering Education* (Vol. 24, pp. 357-373). Manchester, United Kingdom. Manchester University Press.

2 of/de 2

PM-1 3 1/2" x 4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

- Hofer, E.F.
Roggiero, F.T. (1990) Computer-Based Flight Training Evaluation. G. Goos, J. Hartmanis, D.H. Norrie and H.-W. Six (Eds.), *Lecture Notes in Computer Science: Computer Assisted Learning - 3rd International Conference, ICCAL '90* (pp. 309-319). Berlin, Germany: Springer-Verlag.
- Janniro, M.J. (1993). Effects of Computer-Based Instruction on Student Learning of Psychophysiological Detection of Deception Test Question Formulation. *Journal of Computer-Based Instruction* (pp. 58-62). Columbus, Ohio: Association for the Development of Computer-Based Instructional Systems.
- Latour, B.
Woolgar, S. (1979) *Laboratory Life: The Social Construction of Scientific Facts*. Beverly Hills, California: Sage Publications.
- Makedon, F. (1994). Issues and Obstacles with Multimedia Authoring. In I. Ottmann and I. Tomek (Eds.), *Educational Multimedia and Hypermedia, 1994: Proceedings of ED-MEDIA 94 - World Conference on Educational Multimedia and Hypermedia* (pp. 38-45). Charlottesville, Virginia: Association for the Advancement of Computing in Education.
- Marcos, M.
Wellstead, P.E.
Sandoval, J.M. (1991). A Real-Time Software Package for Teaching Digital Control. *International Journal of Electrical Engineering Education* (Vol. 28, No. 1, pp. 5-7). Manchester, United Kingdom: Manchester University Press.

- Maurer, H. (1992) Why Hypermedia Systems are Important. I Tomek (Ed). *Lecture Notes in Computer Science: Computer Assisted Learning - 4th International Conference, ICCAL '92* (pp. 1-15). Berlin, Germany: Springer-Verlag
- Mayer, S. (1993) NEAT An Integrated Authoring Environment Based upon ToolBook. In H. Maurer (Ed), *Educational Multimedia and Hypermedia, 1993: Proceedings of ED-MEDIA 93 - World Conference on Educational Multimedia and Hypermedia* (pp. 332-339) Charlottesville, Virginia: Association for the Advancement of Computing in Education.
- Muldner, T.
Unger, C. (1980). *Science and Behaviour - An Introduction to Methods of Research* Englewood Cliffs, New Jersey. Prentice Hall.
- Neale, J.M.
Liebert R M (1993) Meta-analysis. The Effectiveness of CAI in Elementary Education. In H. Maurer (Ed), *Educational Multimedia and Hypermedia, 1993: Proceedings of ED-MEDIA 93 - World Conference on Educational Multimedia and Hypermedia* (pp. 619) Charlottesville, Virginia: Association for the Advancement of Computing in Education
- Outang, J.
Gerlach, G.
Bieger, G.
Mikkelsen, V. (1992). Adjusting to the Paradigm Shift in Teaching and Learning or What do I do Now??? I Tomek (Ed). *Lecture Notes in Computer Science: Computer Assisted Learning - 4th International Conference, ICCAL '92* (pp. 34-38). Berlin, Germany: Springer-Verlag.

- Plank, R.J.
Burgess, I.W.
Brown, C.J. (1990). Teaching Software For Structural Engineering. G. Goos, J. Hartmanis, D.H. Norrie and H.-W. Six (Eds.), *Lecture Notes in Computer Science: Computer Assisted Learning - 3rd International Conference, ICCAL '89* (pp. 300-308). Berlin, Germany: Springer-Verlag.
- Reiser, R.A.
Kegelman, H.W. (1994). Evaluating Instructional Software: A Review and Critique of Current Methods. *Educational Technology Research and Development* (Vol. 42, No. 3, pp. 63-69). Washington, District of Columbia: Association for Educational Communications and Technology.
- Rodgerson, J.L.
Anderson, J.H. (1992). Teaching Systems and Control Using MATLAB. *International Journal of Electrical Engineering Education* (Vol. 29, pp. 235-242). Manchester, United Kingdom: Manchester University Press.
- Rohlf, F.J.
Soakal, R.R. (1981). TABLE 25: Critical values for correlation coefficients. *Statistical Tables* (2nd Ed.). New York, New York: W.H. Freeman.
- Rosnow, R.L.
Rosenthal R. (1993). *Beginning Behavioral Research - A Conceptual Primer*. New York, New York: Macmillan Publishing Company.

- Schaufelberger, W (1990) Design and Implementation of Software for Control Education *IEEE Transactions on Education* (Vol. 33, No. 3, pp. 291-297) New York, New York: IEEE.
- Schaufelberger, W (1989). Design and Implementation of Interactive Programs for Education in Engineering and Natural Sciences. G. Goos, J. Hartmanis and H. Maurer (Eds.), *Lecture Notes in Computer Science: Computer Assisted Learning - 2nd International Conference, ICCAL '89* (pp. 468-479) Berlin, Germany: Springer-Verlag
- Thorngate, W (1994a) Project Discussion Meeting Carleton University, Summer 1994
- Thorngate, W (1994b) Project Discussion Meeting Carleton University, Fall 1994.
- Thorngate, W (1995) Project Discussion Meeting Carleton University, Winter 1995
- Wong, Y -K (1990) Application of Learning Theory to a Computer Assisted Instruction Package *International Journal of Electrical Engineering Education* (Vol. 27, pp. 237-246). Manchester, United Kingdom: Manchester University Press.
- Chan, S P
- Cheung, S -K

APPENDIX A.1

Sample Screens from Frequency Response Courseware

FREQUENCY DOMAIN ANALYSIS

Feedback Control Systems 86.352

*To start, put the
mouse cursor arrow
over the button at
right and click the
left mouse button.*

START

A.1.1 Courseware Title Page

Note that the actual screen is in colour. In addition, some graphical items may be slightly displaced due to the printing process

MAIN MENU

To make a selection, either click on the button at right or on the toolbar button below. If you're not sure how to proceed, put your mouse cursor on the dark gray button next to "Getting Started", and click your left mouse button.

Topics

Getting Started

Search

Matlab

Note Pad

A.1.2 Courseware Main Menu Page

Note that the actual screen is in colour. In addition, some graphical items may be slightly displaced due to the printing process.

In summary then,

A - magnitude of input U

$M(\omega)$ - magnitude portion of transfer function G

$AM(\omega)$ - magnitude of output Y

$\phi(\omega)$ - phase between output and input

A.1.3 Sample Note Page

Note that the actual screen is in colour. In addition, some graphical items may be slightly displaced due to the printing process.

The convention is that for a system such as the one shown at right, the bandwidth is the frequency of u at which the output y is attenuated to a factor of 0.707 times the input.

The plot at right is a graphical depiction of the bandwidth for the closed loop transfer function of the system shown. Note that the amplitude ratio of 0.707 corresponds to -3 dB on the decibel scale. If unclear on the concept, click the button at right to see the correspondence between the amplitude ratio and decibel scales.

Note that the output follows the input pretty closely at lower excitation frequencies, but ceases to follow it at higher frequencies.

A.1.4 Sample Note Page

Note that the actual screen is in colour. In addition, some graphical items may be slightly displaced due to the printing process.

END OF SESSION 5

**click here for
exercises**

**click here to proceed to
the next session**

**click here to return to
the topics menu**

A.1.5 Sample Session End Page

Note that the actual screen is in colour. In addition, some graphical items may be slightly displaced due to the printing process.

EXAMPLE

$$M(\omega) = \frac{1}{\sqrt{\omega^2 + 100}}$$

$$f(\omega) = \tan^{-1} \frac{\omega}{10}$$

A is chosen large enough to mask noise, but small enough not to make the system non-linear.

An experiment is done by driving a mechanical system with a shaker. The response $y(t)$ is measured using a position sensor then that measurement and the sinusoidal input to the shaker are fed into a Dynamic Signal Analyser. At each frequency ω , we wait until the transients ("natural response") decay, then measure A , $A/M(\omega)$ and $f(\omega)$, where $M(\omega)$ and $f(\omega)$ are as shown at left. What is the forced response to $u(t) = 7 \sin(6t + 80^\circ)$?

Try the problem, then click below to see the solution.

A.1.6 Sample Example Page

Note that the actual screen is in colour. In addition, some graphical items may be slightly displaced due to the printing process.

EXERCISES

Suppose that for a practical control system we wish to use experimental data to find a transfer function which approximates the system

You can see the Bode plot of the experimental data by cutting and pasting the block at right into Matlab. Take a brief look at the this plot, the proceed to the next page.

```
mag2 = [1 0.3 0.096 0.035 0.017 0.012 0.01 0.01 0.01 0.0097
0.009 0.0076 0.005 0.003 0.002 0.001];
phase2 = [-168 -159 -142 -116 -82 -51 -30.5 -19.7 -16 -18.7 -27 -42
-58.5 -71.5 -80 -84.5];
w2 =[0.1 0.2 0.3 0.6 1.2 2.2 4 7.4 13.6 25.1 46.4 85.8 158.5 292.9
541.2 1000];
subplot(211),semilogx(w2,20*log10(mag2),'+w');
xlabel('Frequency (rad)'),ylabel('Gain (dB)');
title('Bode Plot')
subplot(212),semilogx(w2,phase2,'+w');
xlabel('Frequency (rad)'),ylabel('Phase (deg)');
```

next page

A.1.7 Sample Exercise Page

Note that the actual screen is in colour. In addition, some graphical items may be slightly displaced due to the printing process.

APPENDIX A.2

86.352 Course Material

A.2.1 Course Outline

A.2.2 Midterm Examination

A.2.3 Final Examination

CARLETON UNIVERSITY

Department of Mechanical and Aerospace Engineering

LECTURE OUTLINE

Engineering 86.352
Feedback Control Systems

Second Term
 Lectures - 3 hours/week

<u>WEEK</u>	<u>TOPIC</u>
1	Introduction to control. Aims and objectives. History of Automatic Control. Block diagrams. Software design tools.
2	Transfer functions. Steady-state analysis, stability, frequency and time responses.
3	Stability. BIBO, Lyapunov, Routh-Hurwitz criteria.
4,5,6	Root locus analysis and design techniques.
7,8,9	Frequency domain analysis and design techniques. Nyquist and Bode charts. Gain and phase margin.
10,11,12	Design. Performance evaluation. Methods of compensation.
13	Industrial applications of control theory. Programmable Logic Controllers, Ladder diagrams.

TEXT: Franklin G.F., Powell J.D. and Emami-Naeini A. "Feedback Control of Dynamic Systems", 3rd ed., Addison-Wesley, 1994.

EVALUATION:	Midterm	35%
	Final Examination	65%

Prepared by: K.R. Goheen,
 January, 1995

kgoheen@ccs.carleton.ca
 788-5697

If there is any student in this course who, because of disability, has need for special accommodation, please feel free to come and discuss this with me and/or contact the Paul Menton Centre for Persons with Disabilities (Room 500, UC, 788-6608, or TTY 788-3937).

ADDITIONAL REFERENCES

1) Books you might want to buy someday (but can survive without)

Automatic control, F.H. Raven, McGraw-Hill. Comprehensive on classical control. Uninspiring and rather old.

Feedback and control systems, Di Stefano et al., Schaum outline series. Good on classical, no modern, also a bit dated.

Digital control of dynamic systems, Franklin, Powell and Workman, Addison Wesley. Good introduction to digital control and treats many continuous time techniques described in course but in discrete time.

2) Good but pricey/out of print. Annoy the library.

Control, Takahashi, Rabins and Auslander, Wiley, 1972. Out of print but excellent on everything if you can get it.

Introduction to dynamic systems, D.G. Luenberger, Wiley, 1979. Fine book about dynamics with some control and many non-engineering applications.

3) Books on areas of control not covered by the most courses.

Introduction to random vibrations and spectral analysis, D.E. Newland, Longman. Not specifically about control but contains a lot of useful material for stochastic applications. Written by a Mechanical Engineer so not unnecessarily mathematical.

Self tuning and adaptive control, ed. C.J. Harris and S.A. Billings, Peter Peregrinus. A good selection of papers on the current state of the art in adaptive control.

Theory and practice of recursive identification, L. Ljung and T. Soderstrom. Everything you ever wanted to know about parameter estimation.

4) Journals

Most new work in control gets published in journals before it makes it into text books. Most of it is pretty incomprehensible and very mathematical, but try the following for a flavour:

International Journal of Control

IEEE Journal of Automatic Control

Automatica

Many applications papers never get into text books. Try the following for some idea of what you can do with the theory (other than impress other people). If you don't follow the math, just read the engineering:

AIEE Journal of Guidance and Control

ASME Journal of Dynamic Systems and Control

IEEE Control System Magazine

CARLETON UNIVERSITY

Department of Mechanical and Aerospace Engineering

Engineering 86.352
Feedback Control Systems

3 March 1995
1800-2000

MIDTERM EXAMINATION

Authorised Memoranda: open book. Calculators

Do all questions: marks as shown

1. A machine tool is designed to follow a desired path so that:

$$r(t) = (2 - t + 0.5t^2) u(t)$$

where $u(t)$ is the unit step function. The machine tool control system is shown in fig.1

Determine the steady-state error when $r(t)$ is the desired path as given and $D(s)=0$.

(5 marks)

Fig. 1

Engineering 86.352
Mid-term Exam
March 3, 1995

2. The block diagram of a closed-loop transfer function is shown in fig.2. Using Routh-Hurwitz techniques, find the maximum value K can assume before the system becomes unstable? When K is equal to this maximum value, the system oscillates. Determine the frequency of oscillation.

(10 marks)

Fig. 2

3. To meet current U.S. emissions standards for automobiles, hydrocarbon (HC) and carbon monoxide (CO) emissions are usually controlled by a catalytic converter in the automobile exhaust. Federal standards for nitrogen oxides (NO_x) emissions are met mainly by exhaust-gas recirculation (EGR) techniques. However, as NO_x emission standards were tightened from the current limit of 2.0 grams per mile to 1.0 gram per mile, these techniques were no longer sufficient. Although many schemes are under investigation for meeting the emissions standards for all three emissions, one of the most promising employs a three-way catalyst - for HC, CO and NO_x emissions - in conjunction with a closed-loop engine control as shown in fig.3. The exhaust gas sensor gives an indication of a rich or lean exhaust and compares it to a reference. The difference signal is processed by the controller and the output of the controller modulates the vacuum level in the carburetor to achieve the best air-fuel ratio for proper operation of the catalytic converter. The open-loop transfer function is represented by:

$$KG(s) = \frac{K(s+2)(s+7)}{s(s+5)(s+3)}$$

Engineering 86.352
Mid-term Exam
March 3, 1995

- a) Draw the root locus of the control system for $0 < K < \infty$. Note that two of the solutions for $a \frac{db}{ds} + b \frac{da}{ds}$ are $s = -1.816 \pm 1.314 j$
- b) Determine K for minimum damping of the oscillating poles.

(20 marks)

Fig. 3

CARLETON UNIVERSITY

**Final
EXAMINATION
April 1995****DURATION: 3 HOURS****No. of Students: 110****Department Name & Course Number: Mechanical & Aerospace Engineering 86.352A****Instructor(s) Professor K.R. Goheen****AUTHORIZED MEMORANDA****Open Book; Calculators**

Students **MUST** count the number of pages in this examination question paper **before** beginning to write, and report any discrepancy immediately to a proctor. This question paper has **6** pages.

This examination question paper **MAY** be taken from the examination room.

Attempt only 4 of the 5 questions; All questions of equal value

1. A closed-loop control system is shown in Fig. 1.
- The outer loop, by itself, is unstable. Find the relationship between k_1 and k_2 to put the system at the limit of stability.
 - If only velocity feedback is used ($k_2=0$), what value of k_1 is required at the stability limit?

Fig. 1

Engineering 86.352A
 Final Exam
 April 21, 1995

2. Draw a Bode plot of the transfer function $G(s) = x(s)/F(s)$ for the mechanical system shown in Fig. 2.

Fig. 2

3. An aircraft heading control system is shown in Fig. 3. Use frequency response methods to determine a suitable value of the "pilot gain" K . Why did you choose this gain?

Fig. 3

Engineering 86.352A
Final Exam
April 21, 1995

4. Without a feedback control system, most helicopters are unstable (Fig. 4). For helicopter dynamics:

$$G_p(s) = \frac{10(s+0.05)}{(s+0.5)((s-0.2)^2 + (0.4)^2)}$$

relating blade pitch angle to blade control, it is desired, using root-locus methods, to design a feedback PD compensator of the form:

$$H_c(s) = 1 + ks$$

- a) Show that the characteristic equation may be written as

$$1 + \frac{ks(10s + 0.5)}{(s + 0.06)(s + 0.02 \pm 3.16j)}$$

- b) Complete the root locus and choose a gain k for good response.

NOTE:

$$a \frac{db}{ds} - b \frac{da}{ds} = (s - 3.17)(s + 3.15)(s + 0.085)(s + 0.036)(-10)$$

- c) For your completed design, estimate the rise time and settling time to a step change in pilot input.

Fig. 4

Engineering 86.352A
 Final Exam
 April 21, 1995

5. Shown in Fig. 5 is a satellite attitude control system, where the moment of inertia of the satellite has been normalized to unity.
- Write the closed-loop transfer function $\theta(s)/\theta_r(s)$.
 - The system is commanded to assume an attitude of 10 degrees. After the transients die out, what will be the steady-state attitude value?
 - The closed-loop system is to respond to a step input with no overshoot. Find K_v as a function of K such that this specification is satisfied.
 - The system of part c) is to reach steady-state approximately 6 s after a command to change the attitude angle. Find the value of K that satisfies this specification.

Fig. 5

APPENDIX A.3

Assessment Materials

A.3.1 Post-Experiment Test

A.3.2 Post-Experiment Questionnaire

CARLETON UNIVERSITY**Department of Mechanical and Aerospace Engineering****Engineering 86.352
Feedback Control Systems****17 March 1995
1800-1930****TEST**Authorized Memoranda: open book, calculatorsDo all questions; marks as shown

- 1 Consider the unity-feedback system with the open-loop transfer function

$$G(s) = \frac{10}{s + 11}$$

Obtain the steady-state output of the system when it is subjected to the following input:

$$r(t) = 2 \cos (2t - 45^\circ)$$

(5 marks)

- 2 The figure below shows the block diagram of a space vehicle control system. Determine the gain K such that the phase margin is 50 degrees. What is the gain margin in this case?

(10 marks)

QUESTIONNAIRE

NAME: _____

STUDENT NUMBER: _____

On the next two pages is a set of questions designed to assess your experiences with the Frequency Response portion of Feedback Control Systems (86.352). Your responses to this questionnaire will be confidential, and will not affect your mark on the accompanying test. You are asked above for your name and student number. Please write these only on this sheet, and not anywhere on your midterm. The number code that you see in the bottom right corner of this page will be used to connect your test mark to your student number. Answering these questions is voluntary - if there are any that you prefer not to answer, you are not obliged to do so.

- 1 What is your age? _____
- 2 What is your gender? male female (please circle one response)
- 3 What year are you in at university? 1 2 3 4 Other _____ (please specify)
- 4 What is your specialization? _____
- 5 Were you in the lecture or the computer group? lecture computer
- 6 How many years have you been using computers for academic work? _____
- 7 How much of your knowledge of engineering do you think you learn in the following ways:
lecture	_____	%
lecture notes	_____	%
computer tutorials	_____	%
textbook	_____	%
studying with other students	_____	%
studying alone	_____	%
problems and exercises	_____	%
labs	_____	%
other _____	_____	%
- total: 100%
- 8 How knowledgeable are you about computers?
- complete novice 0 1 2 3 4 5 6 7 8 9 expert (please circle a number)
- 9 How much do you enjoying working with computers?
- not at all 0 1 2 3 4 5 6 7 8 9 very much
10. How many times have you used computers for tutorials or training (e.g. in engineering courses, first aid, courses, for summer jobs, for learning software, etc.)? _____
11. How easy or difficult is the course material in Feedback Control Systems?
- extremely easy 0 1 2 3 4 5 6 7 8 9 extremely difficult
- 12.a In the past couple of weeks, how many times did you spend listening to the lectures about Frequency Response? _____ (maximum 7 hours)
- 12.b In the past couple of weeks, how many hours did you spend using the computer software about Frequency Response? _____
- 13.a If you were in the computer group, did you look at the lecture notes? yes no
- 13.b If you were in the lecture group, did you use the computer lab? yes no

- 14.a In addition to attending the lectures or using the computer programs, did you try to learn the Frequency Response material in any other way? yes no
- 14.b If yes, how?
studied class notes	yes	no
studied computer printouts	yes	no
studied textbook	yes	no
did assigned problems	yes	no
other _____		
- 14.c If yes, how many hours did you spend trying to learn this material? _____

**Questions
15 - 18 are
for
students
who were
taught
Frequency
Response
by
computer.**

- 15.a In general, how much did you like the computer program that taught Frequency Response?
- not at all 0 1 2 3 4 5 6 7 8 9 very much
- 15.b What did you like most about the program? _____
- 15.c What did you like least? _____
16. How much about the Frequency Response part of the course do you think you learned by using the program?
- nothing 0 1 2 3 4 5 6 7 8 9 everything
- 17 a Did you have any problem learning how to use the software? yes no
- 17.b If yes, what was the problem? _____
18. Do you have any suggestions about improving the Frequency Response computer program? _____

These final questions are for all students.

19. Given the choice, how much would you prefer to learn other engineering topics using the computer or using traditional lectures?
- much prefer computer 0 1 2 3 4 5 6 7 8 9 much prefer lectures
20. Do you have any comments about the use of computer-aided instruction in engineering?
- _____
- _____

Thank you for completing this survey, and for participating in this project.

APPENDIX A.4

Experimental Data

A.4.1 Spreadsheet of Experimental Data

A.4.2 Student Comments

A.4.1 Spreadsheet of Experimental Data: Key to Spreadsheet Data

A record number
 B age
 C gender (m or f)
 D year at university
 E specialization
 F lecture or computer group (l or c)
 G years using computers for academic work
 H % engineering knowledge from lectures
 I % engineering knowledge from lecture notes
 J % engineering knowledge from computer tutorials
 K % engineering knowledge from textbook
 L % engineering knowledge from studying with other students
 M % engineering knowledge from studying alone
 N % engineering knowledge from problems and exercises
 O % engineering knowledge from labs
 P % engineering knowledge from other sources
 Q knowledgeable about computers (0 not at all - 9 very much)
 R enjoy working with computers (0 not at all - 9 very much)
 S times used computers for tutorials or training
 T ease of FCS course material (0 extremely easy - 9 extremely difficult)
 U hours spent listening to FR lectures in last two weeks
 V hours spend using FR software in last two weeks
 W computer group - looked at lecture notes (yes or no)
 X lecture group - used computer lab (yes or no)
 Y tried to learn material in additional ways (yes or no)
 Z studied class notes (yes or no)
 AA studied computer printouts (yes or no)
 AB studied textbook (yes or no)
 AC did assigned problems (yes or no)
 AD other additional study
 AE hours spent trying to learn the material
 AF comp group - like FR software (0 not at all - 9 very much)
 AG comp group - what liked most about program
 AH comp group - what liked least about program
 AI comp group - FR learning from program (0 nothing - 9 everything)
 AJ comp group - problem learning to use software (yes or no)
 AK comp group - specify problem
 AL comp group - suggestions for improving program
 AM preference (0 much prefer computer - 9 much prefer lectures)
 AN comments
 AO test Q1 (out of 5)
 AP test Q2 (out of 10)
 AQ test total (out of 15)
 AR test percent
 AS midterm mark (out of 35)
 AT midterm percent
 AU exam Q2 (out of 25)
 AV exam Q3 (out of 25)
 AW exam total percent
 AX final letter grade
 AY final grade #

A.4.1 Spreadsheet of Experimental Data: Sheet 1

	A	B	C	D	E	F	G	H
1	101	22 m		3 m	c		2	5
2	102	20 m		3 a			10	10
3	103	21 m		3 m			6	5
4	104			3			3	20
5	105	21 m		3 m	c		2	20
6	106	25 m		3 m			10	40
7	107	23 m		3 m	c		4	
8	108	21 m		3 a			4	
9	109	28 m		3 m	c		6	20
10	110	21 m		3 a	c		3	20
11	111	24 m		4 m			4	30
12	112	26 m		3 a			8	10
13	113	22 m		3 m	c		10	20
14	114	22 m		4 m			2	30
15	115	21 m		4 a	c		6	5
16	116	26 m		3 m			6	10
17	117	21 m		3 a			9	10
18	118	22 m		3 m			6	5
19	119	21 m		3 m	c		3	5
20	120	22 m		3 a	c		2	5
21	121	22 m		3 m			3	5
22	122	22 m		3 m	c		3	5
23	123	20 m		3 m	c		6	20
24	124	21 m		3 a	c		7	15
25	125	21 m		3 m	c		10	
26	126	24 m		4 a	c		4	10
27	127	22 m		3 m	c		5	10
28	128	22 m		3 m			3	20
29	129	21 m		3 a			8	10
30	130	22 m		3 m			3	10
31	131	20 m		3 a			6	10
32	132	22 m		4 a	c		8	5

A.4.1 Spreadsheet of Experimental Data: Sheet 2

	I	J	K	L	M	N	O	P
1	10	5	20	15	15	30	5	
2	20	25	20	25	10	25	10	
3	5	5	30	5	30	10	10	
4	25	0	5	0	30	10	10	
5	15	5	2	8	15	30	5	
6	25	10	10	4	1	5	5	
7								
8			50		20	30		
9	20	10	10	20	10	5	5	
10	10	3	17	0	30	15	5	
11	20		25	15		10		
12	10	0	50	0	15	15	0	
13	50	5	1	0	5	10	5	4
14	20		20	10	10	10		
15	10	0	10	0	14	60	1	
16	5	2	30	25	15	10	3	
17	10	1	15	5	14	30	15	
18	70	0	5			10	10	
19	5	5	5	15	20	40	5	
20	10		10	10	20	40	5	
21	15	0	5	25	25	20	5	
22	10	0	10	10	30	30	5	0
23			10	20	10	20	20	
24	10	0	10	0	0	60	5	
25			75	15	10			
26	10				50	30		
27	10	5	5	20	5	10	20	15
28			40		15		20	5
29	10	0	35	10	20	15		
30	5	0	25	25	15	18	2	0
31	20		5	5	10	40	10	
32	10	0	10	10	40	20	5	

A.4.1 Spreadsheet of Experimental Data: Sheet 3

	Q	R	S	T	U	V	W	X
1	4	6	4	4	5	4 y		
2	9	9	6	7	7	0		n
3	6	7	6	6	6			n
4	4	7		8	7	0		n
5	3	3	1	4	3	5 y		
6	8	9		7	7	0		n
7	2	2		5	0	6 n		
8	3	1		5	2	0 y		y
9	7	8		6		10 n		
10	7	8	5	6	0	7 n		
11	4	8	4	7	6	0		n
12	7	7	5	3	7	0		n
13	5	6	3	7	0	7 n		
14	6	6	0	7	6			n
15	5	5	3	5		7 n		
16	4	5	4	8	2	0		n
17	5	5	6	6	6	0		n
18	9	8	0	7	7	0		n
19	3	5	2	6	2	5 n		
20	2	1	1	5	1	8 n		
21	6	5	15	7	4	0		n
22	6	7		7		6 n		
23	5	7	5	6	0	6 n		
24	5	7	2	5	0	5 n		
25	6	7	3	8	1	2 n		
26	7	7	0	4	0	1.5 n		
27	6	3	4	5	0	4 n		
28	3	6	2	7	7	0		n
29	7	7	6	7	5	0		n
30	5	8		8	7	0		n
31	6	9	20	5	7			n
32	7	8	4	3	0	2 n		

A.4.1 Spreadsheet of Experimental Data: Sheet 4

	Y	Z	AA	AB	AC	AD	AE	AF
1	y			y	y		5	6
2	y	y		y	y		4	
3	y	y	n	y	y		3.5	
4	y	y		y	y		10	
5	n							6
6	y	y		y	y		5	
7	y			y	y			9
8	y	y		y	y	94 260 Sys	3	
9	y		y	y	y		3	9
10		n		y	y	summary o	0.5	2
11	y	y	y	y	y		10	
12	y	y	n	y	n		3	
13	n							5
14	y	y		y			2	
15	y			y	y		6	6
16	y	n	n	y	y		6	
17	y			y	y		8	
18	y	y		n	n		10	
19	y			y	y		8	5
20	y	n	y	y	y		7	7
21	y	y	n	y	y	sys & sim r	12	
22	y		y	y	y		8	7
23	y			y	y		3	4
24	y	n	n	y	y	n	4	4
25	y			y			7	7
26	y	n	y	y	n		2	6
27	y		y				2	4
28	n						1	
29	y	y		y	y		4	
30	y			y	y	talk to prof		
31	n							
32	y	n	n	y	n		1	9

A.4.1 Spreadsheet of Experimental Data: Sheet 5

	AG	AH	AI	AJ	AK	AL	AM	AN
1			4 n				5	
2							5	No experie
3							5	
4							5	
5			5 n				3	
6							5	Computer I
7	The instructions helped		5 n				4	
8							5	Good. But
9	MATLAB, e No tali		9 n				9	some cours
10	That I could Few mistak		8 n			not the pro	9	I strongly n
11							6	Software st
12							5	I think com
13	can see all it hard to u		6 n			try to imprc	5	it easy to g
14								
15	interactive, interface w		6 n			ability to sc	7	could be m
16							6	If you aren
17							6	
18							5	
19	Go at own Can't ask F		3 n				6	
20	The bode p I wish you c		6 n			I think more	6	I think tutor
21							5	computer a
22	can get thr referring ba		8 n			correct the	7	No
23	Ease of use Too much I		5 n				7	it is useful
24	not being a		4 n			more exam	9	computers
25	Matlab exa Reading fro		4 n			correct errc	4	benefit: rep
26	easy to use Hard to cor		2 n				4	Personally
27	it was at m it was on a		6 n				8	use it as w
28							5	
29							5	
30							5	Some is go
31							7	It would be
32	interactive not enough		3 n			It was a ve	5	Since much

A.4.1 Spreadsheet of Experimental Data: Sheet 6

	AO	AP	AQ	AR	AS	AT	AU	AV
1	4	6	10	66 67	13	37 14	15	10
2	3	5	8	53 33	16	45 71	3	16
3	5	8	13	86 67	19	54 29	13	20
4	5	8	13	86 67	16	45 71	25	
5	5	7	12	80 00				25
6	5	7	12	80 00			20	15
7	2	2	4	26 67	12	34 29	7	10
8	5	7	12	80 00	21	60 00	15	
9	5	2	7	46 67	26	74 29	20	7
10	5	8	13	86 67	14	40 00	20	18
11	5	6	11	73 33	24	68 57	1	10
12	1	8	9	60 00	30	85 71	7	13
13	5	4	9	60 00	20	57 14	10	10
14	3	7	10	66 67	15	42 86	17	22
15	5	9	14	93 33	30	85 71	25	24
16	1	6	7	46 67	17	48 57		5
17	5	6	11	73 33	16	45 71	25	20
18	5	6	11	73 33	11	31 43	20	20
19	5	8	13	86 67	14	40 00	7	0
20	5	4	9	60 00	17	48 57		
21	2	6	8	53 33	21	60 00	5	
22	5	8	13	86 67	14	40 00	15	
23	1	8	9	60 00	19	54 29	4	
24	5	3	8	53 33	29	82 86	10	
25	3	10	13	86 67	9	25 71	10	12
26	3	6	9	60 00	17	48 57		15
27	1	3	4	26 67	22	62 86	20	0
28	3	8	11	73 33	28	80 00	17	10
29	5	7	12	80 00	22	62 86	1	12
30	1	8	9	60 00	14	40 00	7	5
31	1	6	7	46 67	28	80 00	25	20
32	3	4	7	46 67	24	68 57	10	

A.4.1 Spreadsheet of Experimental Data: Sheet 7

	AW	AX	AY
1	59	D+	3
2	49	D-	1
3	55	C-	4
4	71	B-	7
5	76	A-	10
6	77	A-	10
7	40	FNS	0
8	53	C-	4
9	52	C-	4
10	78	B+	9
11	29	F	0
12	55	C+	6
13	45	D-	1
14	74	B-	7
15	92	A+	12
16	63	C-	4
17	84	A-	10
18	49	D-	1
19	29	F	0
20		ABS	
21	52	D+	3
22	50	D+	3
23	63	C	5
24	70	B+	9
25	43	D-	1
26	62	C-	4
27	52	D+	3
28	64	B-	7
29	49	D+	3
30	44	D-	1
31	90	A+	12
32	47	D+	3

A.4.2 Student Responses: Question 15.b

107	The instructions helped in guiding me through the tutorial	Could learn at your own pace.
109	MATLAB, easy to go back and look at the old notes	
110	That I could go & do the tutorial anytime I wanted	
113	can see all the diagrams on screen	
115	interactive, interface with MATLAB	
119	Go at own pace, Don't need to take notes (since we were given them)	
120	The bode plots and graphs were clearer to figure out because everything was step by step. I also liked it because I could go at my own pace	
122	can get through the material quickly	
123	Ease of use'	
125	Matlab examples	
126	easy to use, simple egs	
127	it was at my own pace	
132	interactive	

A.4.2 Student Responses: Question 15.c

109	No talk
110	Few mistakes; and the fact that when colleagues ask questions; the entire class doesn't hear it
113	it hard to understand how to draw the bode plot
119	Can't ask Prof questions
120	I wish you could be able to use the reverse button on the examples so we could read the previous page instead of having to press return & spool to the required page.
122	referring back when going through the examples
123	Too much like a book! Well written, but I could go to the library too
124	not being able to ask a question when I had problems understanding a particular concept
125	Reading from a computer screen
126	Hard to concentrate and pay attention to what I'm reading
127	it was on a computer
132	not enough examples

A.4.2 Student Responses: Question 18

110 not the program

113 try to improve the procedure of plotting the graph

115 ability to scroll backwards through windows

120 I think more difficult & complex examples would help too. The ones presented were rather straight forward

122 correct the typo's & more diagrams

124 more examples in step by step detail, less reliance on switching back and forth to MATLAB

125 correct errors, make it easier to move back 1 page at a time in examples

132 It was a very good program, just add some more examples

A.4.2 Student Responses: Question 20

- 102 No experience with "computer-aided" just used computers as tool, would like to try integrating computer so can "work at own pace"
- 106 Computer learning is effective if the system is user friendly enough
- 108 Good But the computers that we use are too old. The U should upgrade the computer to at least 486 level Even in high school, we are not using 286
- 109 some courses should have at least limited hours of classes
- 110 I strongly not recommend computer-aided instruction in engineering if they are to be given independent of the lectures The lecture is crucial.
- 111 Software should be included in text book
- 112 I think computer tutorials should be available for all lecture courses in engineering that the student may persue at his/her leisure It should expand upon, explain in a different manner, the material covered in the lecture
- 113 it easy to give every student to understand, but hard to ask question if the problem has occurred
- 115 could be made available along with lectures as extra resource for students
- 116 If you aren't familiar with computers in general you start at a disadvantage.
- 120 I think tutorials should be in computer form, along with TAs present. I don't think it should replace instruction, however.
- 121 computer aided instruction should be an optional addition for the student to the lectures already being attended
- 122 No
- 123 it is useful for some students more than others ..
- 124 computers can't answer questions or explain concepts, or give personal experiences relating to the concept
- 125 benefit: repeat problem areas and go at your own pace
- 126 Personally I learn from the textbook so the computer (or lectures) is not very helpfull
- 127 use it as well as the regular lectures
- 130 Some is good, but I don't know to what extent since I never tried.
- 131 It would be difficult to get answers to questions you may have This is important in learning
- 132 Since much of this section was review from 94.260 (360 now) I am not sure how much I learnt from the tutorial. Therefore my test result may not indicate how much I learnt from the tutorial Despite this the computer program was fairly well done.

APPENDIX A.5

Statistical Analysis

A.5.1 First Stage Analysis

A.5.2 Results of t-Tests for Significance

A.5.3 Results of Tests for Significant Correlations

A.5.4 Critical Correlation Coefficients

A.5.5 Normalization of Academic Data

A.5.1 First Stage Analysis

- 1 age distribution
1 unknown

- 2 year distribution

- 3 specialization distribution
1 unknown

- 1 - aerospace
2 - mechanical
3 - unknown

- 4 years using computers for academic work

- 5 methods for learning - average amount per method
assumes blank = 0

- 1 lecture
- 2 lecture notes
- 3 computer tutorials
- 4 textbook
- 5 studying with other students
- 6 studying alone
- 7 problems and exercises
- 8 labs
- 9 other

- 6 level of knowledge about computers

- 0 - complete novice
- 9 - expert

7 enjoyment of working with computers

8. times using computers for tutorials
11 responses not included

9 ease of material

0 - extremely easy
9 - extremely difficult

10 total time spent - lectures/lab. studying
2 records not included

11 computer group - liking of program

0 - not at all
9 - very much

12 computer group - amount learned about frequency response

0 - nothing
9 - everything

- 13 preference - computers or lectures
2 records not included

0 - much prefer computer
9 - much prefer lectures

- 14 average test mark

1 - computer group - 64.2%
2 - lecture group - 68.3%

- 15 test mark compared to midterm mark
2 records excluded

- 16 computer group - test mark compared to liking computers

- 17 computer group - test mark compared to knowing computers

- 18 computer group - test mark compared to finding the material easy

0 - extremely easy
9 - extremely difficult

19. liking computers compared to knowing computers

20. computer group - test mark compared to liking software

- 21 computer group - liking software compared to liking computers

- 22 computer group - liking software compared to knowing computers

- 23 test mark compared to specialization

24 test mark compared to lecture/software preference

0 - much prefer computer
9 - much prefer lectures

25. computer group - test mark compared to lecture/software preference

0 - much prefer computer
9 - much prefer lectures

26 test mark compared to total time spent

27 years using computers compared to knowing computers

28 years using computers compared to liking computers

29 computer group - test mark compared to amount of frequency response learned

A.5.2 Results of t-Tests for Significance

significance	X 1st column	Y 2nd column	t t-test result	v deg. of freedom	p probability of null hypothesis
	degree program	knowledge of comp	-0.985	29	0.3325
	degree program	enjoyment of comp	-0.074	29	0.9416
yes	degree program	ease of course	2.895	29	0.0071
	degree program	c-liking of software	0.503	14	0.6225
	degree program	test %	-0.129	28	0.8981
yes	degree program	exam %	-2.221	28	0.0346
yes	degree program	grade #	-2.401	28	0.0232
	group (comp. or lecture)	knowledge of comp	-1.156	30	0.2568
	group (comp. or lecture)	enjoyment of comp.	-1.395	30	0.1732
yes	group (comp. or lecture)	ease of course	-2.559	30	0.0158
	group (comp. or lecture)	hours spent	-1.220	25	0.2339
	group (comp. or lecture)	l/c preference	1.494	29	0.1461
	group (comp. or lecture)	test Q1	0.759	30	0.4536
	group (comp. or lecture)	test Q2	-1.519	30	0.1393
	group (comp. or lecture)	test %	-0.664	30	0.5127
	group (comp. or lecture)	exam Q2	-0.031	26	0.9753
	group (comp. or lecture)	exam Q3	-0.884	22	0.3861
	group (comp. or lecture)	exam %	-0.456	29	0.6517
	group (comp. or lecture)	grade #	-0.401	29	0.6916
	group (comp. or lecture)	additional hours	-1.220	25	0.2339
	group (comp. or lecture)	total hours	-1.064	30	0.2959

A.5.3 Results of Tests for Significant Correlations

Note: Significance was determined using the table of Critical Correlation Coefficients. A 5 4

significance	X 1st column	Y 2nd column	r correlation coefficient	c record count	v degrees of freedom
	age	test %	-0.283	31	29
	age	grade #	-0.117	30	28
	age	l/c preference	0.064	30	28
yes	years using comp.	knowledge of comp	0.538	32	30
yes	years using comp	enjoyment of comp	0.402	32	30
	years using comp	times used for tut	0.135	25	23
	years using comp	ease of course	0.089	32	30
	years using comp.	c-liking of software	0.100	16	14
	years using comp	c-amount of FR	-0.106	16	14
	% from lectures	l/c preference	0.053	28	26
yes	knowledge of comp.	enjoyment of comp	0.721	32	30
	knowledge of comp	times used for tut	0.178	25	23
	knowledge of comp	ease of course	0.090	32	30
	knowledge of comp.	c-liking of software	-0.114	16	14
	knowledge of comp	c-amount of FR	0.176	16	14
	knowledge of comp	l/c preference	0.140	31	29
	knowledge of comp	test %	-0.008	32	30
	knowledge of comp.	exam %	0.071	31	29
	knowledge of comp	grade #	0.010	31	29
	enjoyment of comp	times used for tut	0.288	25	23
	enjoyment of comp	ease of course	0.271	32	30
	enjoyment of comp.	c-liking of software	-0.119	16	14
	enjoyment of comp	c-amount of FR	0.038	16	14
	enjoyment of comp.	l/c preference	0.172	31	29
	enjoyment of comp	test %	0.136	32	30
	enjoyment of comp	exam %	0.051	31	29
	enjoyment of comp	grade #	0.053	31	29
	times used for tut	c-liking of software	-0.333	13	11
	times used for tut	amount of FR	0.437	13	11
	times used for tut.	test %	0.281	25	23
yes	ease of course	additional hours	0.463	27	25
	ease of course	c-liking of software	-0.467	16	14
	ease of course	c-amount of FR	0.431	16	14
	ease of course	l/c preference	-0.008	31	29

significance	X 1st column	Y 2nd column	r correlation coefficient	c record count	v degrees of freedom
	ease of course	test Q1	0.065	32	30
	ease of course	test Q2	0.295	32	30
	ease of course	test %	0.265	32	30
yes	ease of course	midterm %	-0.401	30	28
	ease of course	exam %	-0.168	10	8
	ease of course	grade #	-0.248	10	8
	hours spent	c-liking of software	0.226	13	11
	hours spent	c-amount of FR	-0.008	13	11
	hours spent	l/c preference	-0.220	26	24
	hours spent	test %	0.267	27	25
	hours spent	exam %	-0.226	26	24
	hours spent	grade #	-0.252	26	24
	c-liking of software	c-amount of FR	-0.133	16	14
	c-liking of software	l/c preference	-0.408	16	14
	c-liking of software	test Q1	-0.022	16	14
	c-liking of software	test Q2	-0.331	16	14
	c-liking of software	test %	-0.283	16	14
	c-liking of software	exam Q2	-0.093	13	11
	c-liking of software	exam Q3	-0.042	11	9
	c-liking of software	exam %	-0.395	15	13
	c-liking of software	grade #	-0.381	15	13
yes	c-amount of FR	l/c preference	0.584	16	14
	c-amount of FR	test Q1	0.308	16	14
	c-amount of FR	test Q2	-0.104	16	14
	c-amount of FR	test %	0.059	16	14
yes	c-amount of FR	exam Q2	0.614	13	11
	c-amount of FR	exam Q3	0.078	11	9
	c-amount of FR	exam %	0.213	15	13
	c-amount of FR	grade #	0.221	15	13
	l/c preference	test Q1	0.073	31	29
	l/c preference	test Q2	-0.248	31	29
	l/c preference	test %	-0.145	31	29
	l/c preference	exam Q2	0.325	27	25
	l/c preference	exam Q3	-0.192	23	21
	l/c preference	exam %	0.247	30	28
	l/c preference	grade #	0.289	30	28
	test %	midterm %	-0.172	30	28
	test %	exam Q2	0.179	28	26
yes	test %	exam Q3	0.432	24	22
	test %	exam %	0.171	31	29
	test %	grade #	0.228	31	29
	midterm %	exam %	0.301	29	27

significance	X 1st column	Y 2nd column	r correlation coefficient	c record count	v degrees of freedom
yes	midterm %	grade #	0.494	29	27
yes	exam %	grade #	0.952	31	29
yes	total hours	ease of course	0.365	32	30
	total hours	c-liking of software	0.026	16	14
	total hours	c-amount of FR	0.339	16	14
	total hours	l/c preference	0.095	31	29
yes	total hours	test Q1	0.420	32	30
	total hours	test Q2	0.185	32	30
	total hours	test %	0.339	32	30
	total hours	exam Q2	0.114	28	26
	total hours	exam Q3	0.056	24	22
	total hours	exam %	-0.068	31	29
	total hours	grade #	-0.054	31	29
	c only -tms used for tut.	liking of software	-0.333	13	11
	c only -tms used for tut.	l/c preference	0.470	13	11
	c only -tms used for tut.	test %	-0.092	13	11
	c only -tms used for tut.	exam %	0.010	12	10
	c only -tms used for tut.	grade #	-0.059	12	10
	c only -l/c preference	test %	-0.056	16	14
	c only -l/c preference	exam %	0.266	15	13
	c only -l/c preference	grade #	0.334	15	13
yes	c only -total hours	test %	0.508	16	14
	c only -total hours	exam %	-0.017	15	13
	c only -total hours	grade #	0.035	15	13
	c only -test %	midterm %	-0.217	15	13
	c only -test %	exam Q2	0.187	13	11
	c only -test %	exam Q3	0.517	11	9
	c only -test %	exam %	0.323	15	13
	c only -test %	grade #	0.357	15	13
	c only -yrs using comp.	software hours	-0.172	16	14
	c only -yrs using comp.	additional hours	-0.166	13	11
	c only -yrs using comp.	liking of software	0.100	16	14
	c only -yrs using comp.	amount of FR	-0.106	16	14
	c only -yrs using comp.	l/c preference	0.011	16	14
	c only -yrs using comp.	test Q1	-0.181	16	14
	c only -yrs using comp.	test Q2	-0.055	16	14
	c only -yrs using comp.	test %	-0.131	16	14
	c only -yrs using comp.	exam Q2	-0.216	13	11
	c only -yrs using comp.	exam Q3	-0.107	11	9
	c only -yrs using comp.	exam %	-0.199	15	13
	c only -yrs using comp.	grade #	-0.192	15	13
	c only -yrs using comp.	total hours	-0.323	16	14
	c only -% lectures	liking of software	-0.358	14	12

significance	X 1st column	Y 2nd column	r correlation coefficient	c record count	v degrees of freedom
	c only -% lectures	l/c preference	0.198	14	12
	c only -% lectures	test %	-0.133	14	12
	c only -% lectures	exam %	0.229	13	11
	c only -% lectures	grade #	0.251	13	11
	c only -know. of comp.	liking of software	-0.114	16	14
	c only -know. of comp.	l/c preference	0.388	16	14
	c only -know. of comp.	test %	0.036	16	14
	c only -know. of comp.	exam %	0.166	15	13
	c only -know. of comp.	grade #	0.124	15	13
	c only -enjoy. of comp.	liking of software	-0.119	16	14
	c only -enjoy. of comp.	l/c preference	0.329	16	14
	c only -enjoy. of comp.	test %	0.259	16	14
	c only -enjoy. of comp.	exam %	0.076	15	13
	c only -enjoy. of comp.	grade #	0.072	15	13
	l only -l/c preference	test %	-0.462	15	13
	l only -l/c preference	exam %	0.440	15	13
	l only -l/c preference	grade #	0.427	15	13
	l only -total hours	test %	0.225	16	14
	l only -total hours	exam %	-0.157	16	14
	l only -total hours	grade #	-0.175	16	14
	l only -test %	midterm %	-0.141	15	13
	l only -test %	exam Q2	0.216	15	13
	l only -test %	exam Q3	0.255	13	11
	l only -test %	exam %	-0.077	16	14
	l only -test %	grade #	0.018	16	14

A.5.4 Critical Correlation Coefficients

This table contains critical values k (+/-) of the correlation coefficient r , at which the probability of the null hypothesis is 0.05

The number of degrees of freedom, v , is the number of individuals less 2. The values in normal script come from Rohlf and Sokal (1981).

"TABLE 25 Critical values for correlation coefficients"

Numbers in italics are interpolated

v	k		v	k
10	0.576		24	0.388
11	0.553		25	0.381
12	0.532		26	0.374
13	0.514		27	0.367
14	0.497		28	0.361
15	0.482		29	0.355
16	0.468		30	0.349
17	0.456		31	<i>0.344</i>
18	0.444		32	<i>0.339</i>
19	0.433		33	<i>0.334</i>
20	0.423		34	<i>0.329</i>
21	0.413		35	0.325
22	0.404		36	<i>0.320</i>
23	0.396			

A.5.5 Normalization of Academic Data

All participants - course grade compared to cumulative GPA

record	group	grade	cum gpa	g-gpa/gpa	% incr
101 c		3	5.6	-0.46	-46.43
102 l		1	6.1	-0.84	-83.61
103 l		4	7.6	-0.47	-47.37
104 l		7	6.3	0.11	11.11
105 c		10	5.4	0.85	85.19
106 l		10	5.2	0.92	92.31
107 c		0	3.8	-1.00	-100.00
108 l		4	4.9	-0.18	-18.37
109 c		4	5.5	-0.27	-27.27
110 c		9	7.9	0.14	13.92
111 l		0	4.7	-1.00	-100.00
112 l		6	8.1	-0.26	-25.93
113 c		1	4.8	-0.79	-79.17
114 l		7	4.8	0.46	45.83
115 c		12	10	0.20	20.00
116 l		4	4.8	-0.17	-16.67
117 l		10	7.7	0.30	29.87
118 l		1	4.9	-0.80	-79.59
119 c		0	4.5	-1.00	-100.00
120 c			4.7	-1.00	-100.00
121 l		3	5.1	-0.41	-41.18
122 c		3	3.7	-0.19	-18.92
123 c		5	6.9	-0.28	-27.54
124 c		9	5.6	0.61	60.71
125 c		1	3.8	-0.74	-73.68
126 c		4	6.9	-0.42	-42.03
127 c		3	5.1	-0.41	-41.18
128 l		7	5.7	0.23	22.81
129 l		3	8.8	-0.66	-65.91
130 l		1	5.2	-0.81	-80.77
131 l		12	9.7	0.24	23.71
132 c		3	9.9	-0.70	-69.70

avg inc % -27.494599

t-Test Results

deg. free.	t value	probability of null hypothesis
30	-0.677	0.5033

A.5.5 Normalization of Academic Data

Computer group - course grade compared to cumulative GPA

record	group	grade	cum gpa	g-gpa/gpa	% incr
101 c		3	5.6	-0.46	-46.43
105 c		10	5.4	0.85	85.19
107 c		0	3.8	-1.00	-100.00
109 c		4	5.5	-0.27	-27.27
110 c		9	7.9	0.14	13.92
113 c		1	4.8	-0.79	-79.17
115 c		12	10	0.20	20.00
119 c		0	4.5	-1.00	-100.00
120 c			4.7	-1.00	-100.00
122 c		3	3.7	-0.19	-18.92
123 c		5	6.9	-0.28	-27.54
124 c		9	5.6	0.61	60.71
125 c		1	3.8	-0.74	-73.68
126 c		4	6.9	-0.42	-42.03
127 c		3	5.1	-0.41	-41.18
132 c		3	9.9	-0.70	-69.70
avg inc %					-34.130389

Lecture group - course grade compared to cumulative GPA

record	group	grade	cum gpa	g-gpa/gpa	% incr
102 l		1	6.1	-0.84	-83.61
103 l		4	7.6	-0.47	-47.37
104 l		7	6.3	0.11	11.11
106 l		10	5.2	0.92	92.31
108 l		4	4.9	-0.18	-18.37
111 l		0	4.7	-1.00	-100.00
112 l		6	8.1	-0.26	-25.93
114 l		7	4.8	0.46	45.83
116 l		4	4.8	-0.17	-16.67
117 l		10	7.7	0.30	29.87
118 l		1	4.9	-0.80	-79.59
121 l		3	5.1	-0.41	-41.18
128 l		7	5.7	0.23	22.81
129 l		3	8.8	-0.66	-65.91
130 l		1	5.2	-0.81	-80.77
131 l		12	9.7	0.24	23.71
avg inc %					-20.858808

A.5.5 Normalization of Academic Data

All participants - test mark compared to cumulative GPA

group	test	eqv. grade	cum gpa	(g-gpa)/gpa	% inc
c	66.67	6	5.6	0.07	7.14
i	53.33	2	6.1	-0.67	-67.21
i	86.67	11	7.6	0.45	44.74
i	86.67	11	6.3	0.75	74.60
c	80.00	10	5.4	0.85	85.19
i	80.00	10	5.2	0.92	92.31
c	26.67	0	3.8	-1.00	-100.00
i	80.00	10	4.9	1.04	104.08
c	46.67	0	5.5	-1.00	-100.00
c	86.67	11	7.9	0.39	39.24
i	73.33	8	4.7	0.70	70.21
i	60.00	4	8.1	-0.51	-50.62
c	60.00	4	4.8	-0.17	-16.67
i	66.67	6	4.8	0.25	25.00
c	93.33	12	10	0.20	20.00
i	46.67	0	4.8	-1.00	-100.00
i	73.33	8	7.7	0.04	3.90
i	73.33	8	4.9	0.63	63.27
c	86.67	11	4.5	1.44	144.44
c	60.00	4	4.7	-0.15	-14.89
i	53.33	2	5.1	-0.61	-60.78
c	86.67	11	3.7	1.97	197.30
c	60.00	4	6.9	-0.42	-42.03
c	53.33	2	5.6	-0.64	-64.29
c	86.67	11	3.8	1.89	189.47
c	60.00	4	6.9	-0.42	-42.03
c	26.67	0	5.1	-1.00	-100.00
i	73.33	8	5.7	0.40	40.35
i	80.00	10	8.8	0.14	13.64
i	60.00	4	5.2	-0.23	-23.08
i	46.67	0	9.7	-1.00	-100.00
c	46.67	0	9.9	-1.00	-100.00
				avg inc %	7.28997277

t-Test Results

deg. free.	t value	probability of null hypothesis
30	-0.057	0.9551

A.5.5 Normalization of Academic Data

Computer group - test mark compared to cumulative GPA

group	test	eqv. grade	cum gpa	(g-gpa)/gpa	% inc
c	66.67	6	5.6	0.07	7.14
c	80.00	10	5.4	0.85	85.19
c	26.67	0	3.8	-1.00	-100.00
c	46.67	0	5.5	-1.00	-100.00
c	86.67	11	7.9	0.39	39.24
c	60.00	4	4.8	-0.17	-16.67
c	93.33	12	10	0.20	20.00
c	86.67	11	4.5	1.44	144.44
c	60.00	4	4.7	-0.15	-14.89
c	86.67	11	3.7	1.97	197.30
c	60.00	4	6.9	-0.42	-42.03
c	53.33	2	5.6	-0.64	-64.29
c	86.67	11	3.8	1.89	189.47
c	60.00	4	6.9	-0.42	-42.03
c	26.67	0	5.1	-1.00	-100.00
c	46.67	0	9.9	-1.00	-100.00

avg inc % 6.43000035

Lecture group - test mark compared to cumulative GPA

group	test	eqv. grade	cum gpa	(g-gpa)/gpa	% inc
l	53.33	2	6.1	-0.67	-67.21
l	86.67	11	7.6	0.45	44.74
l	86.67	11	6.3	0.75	74.60
l	80.00	10	5.2	0.92	92.31
l	80.00	10	4.9	1.04	104.08
l	73.33	8	4.7	0.70	70.21
l	60.00	4	8.1	-0.51	-50.62
l	66.67	6	4.8	0.25	25.00
l	46.67	0	4.8	-1.00	-100.00
l	73.33	8	7.7	0.04	3.90
l	73.33	8	4.9	0.63	63.27
l	53.33	2	5.1	-0.61	-60.78
l	73.33	8	5.7	0.40	40.35
l	80.00	10	8.8	0.14	13.64
l	60.00	4	5.2	-0.23	-23.08
l	46.67	0	9.7	-1.00	-100.00

avg inc % 8.14994519

APPENDIX A.6

Cost Analysis

A.6.1 Cost Analysis for Basic Model

A.6.2 Cost Analysis for Varying Parameters

A.6.1 Cost Analysis for Basic Model		
Item	L100	C100
One-Year Model		
professor cost	11500	3833
TA cost		3300
development cost		12500
room capital (room and furniture)	3947	3948
room maintenance	1052	1316
classroom AV	439	
computer lab capital (software and hardware)		6580
computer personnel		768
Total	16938	32245
Differential	-15307	15307
Percent	-90.37	47.47
Five-Year Model		
lecturer cost	57500	19165
TA cost		16500
development cost		16346
room capital (room and furniture)	19735	19740
room maintenance	5260	6580
classroom AV	2195	
computer lab capital (software and hardware)		32900
computer personnel		3840
Total	84690	115071
Differential	-30381	30381
Percent	-35.87	26.40

A.6.2 Cost Analysis for Varying Parameters

Cost vs. Number of Students

students	lecture 1yr	comp 1yr	lecture 5yr	comp 5yr
25	13188	23553	65940	71613
50	14438	26037	72190	84030
75	15688	29092	78440	99307
100	16938	32246	84690	115074
125	30127	42531	150635	166501
150	31377	45683	156885	182263
175	32626	48836	163130	198025
200	33876	51989	169380	213792

additional assumptions:

max lecture size 100

Cost vs. Number of Students

A.6.2 Cost Analysis for Varying Parameters

Cost vs. Development Cost

1yr dev	lecture 1yr	comp 1yr	lecture 5yr	comp 5yr
0	16938	19746	84690	98728
10000	16938	29746	84690	110266
20000	16938	39746	84690	121805
30000	16938	49746	84690	133343
40000	16938	59746	84690	144882
50000	16938	69746	84690	156420

additional assumptions:

mininum - student purchase

maximum - full yr programmer at \$50,000

5yr dev cost = 1 yr cost + 4* (2/52)salary

Cost vs. Development Cost

A.6.2 Cost Analysis for Varying Parameters

Cost vs. Computer Use Rate

cp use rate	lecture 1yr	comp 1yr	lecture 5yr	comp 5yr
0 085	16938	27779	84690	92741
0 100	16938	29216	84690	99926
0 115	16938	30654	84690	107116
0 130	16938	32091	84690	114301
0 145	16938	33529	84690	121491
0 160	16938	34966	84690	128676
0 175	16938	36404	84690	135866
0 190	16938	37841	84690	143051
0 205	16938	39279	84690	150241
0 220	16938	40716	84690	157426

additional assumptions:

cp use rate = course hrs / (total hrs * util)

course hrs = 6 hours per week

total hrs = hours lab available per week (default=57)

util = utilization rate (default=0.8)

base number is $6 / (57 * 0.8) = 0.1316$

lower = lab avail more hrs (generally)

higher = util lower (generally)

Cost vs. Computer Use Rate

A.6.2 Cost Analysis for Varying Parameters

Combination Model:

125 students

computer utilization rate 0.1

development cost \$5000

Item	L125	C125
One-Year Model		
lecturer cost	23000	7666
TA cost		6600
development cost		5000
room capital (room and furniture)	4933	3750
room maintenance	1316	1250
classroom AV	878	
computer lab capital (software and hardware)		6250
computer personnel		729
Total	30127	31245
Differential	-1118	1118
Percent	-3.71	3.58
Five-Year Model		
lecturer cost	115000	38330
TA cost		33000
development cost		5769
room capital (room and furniture)	24665	18750
room maintenance	6580	6250
classroom AV	4390	
computer lab capital (software and hardware)		31250
computer personnel		3645
Total	150635	136994
Differential	13640.8	-13641
Percent	9.06	-9.96

APPENDIX A.7

Software

A.7.1 Asymetrix Multimedia ToolBook

A.7.2 MATLAB

A.7.3 LView

A.7.4 StatView

A.7.1 Asymetrix Multimedia ToolBook

ToolBook is a development environment which facilitated the creation of Microsoft Windows applications. It provides both object creation tools and an object-oriented programming language, OpenScript. A full set of multimedia tools are included

According to Asymetrix, ToolBook facilitates the following:

- custom Windows applications:
- simple and sophisticated multimedia.
- powerful text handling:
- author-friendly visual environment
- comprehensive learning aids
- professional distribution

More information about Asymetrix ToolBook is available from:

Asymetrix Sales
110-110th Ave. N.E., Suite 700
Bellevue, WA 98004
Phone: 800-448-6543
Fax: 206-637-1504

A.7.2 MATLAB

The MathWorks' MATLAB is software for numeric computation, data analysis and graphics. When originally designed in the 1970s, MATLAB capabilities included matrix theory, linear algebra and numerical analysis tools.

The MATLAB functions include

- linear equation solving, differential equations, polynomial arithmetic, and nonlinear optimization
- eigenvalues, matrix math, convolution, and spectrum estimation
- one-dimensional and two-dimensional FFTs, Bessel, and elliptic functions
- curve-fitting and cubic splines
- two-dimensional and three-dimensional graphics

More information about MATLAB is available from:

The MathWorks
University Sales Department
Cochituate Place
24 Prime Park Way
Natick, MA 01760-1520
Phone: 508-653-1415
Fax: 508-653-2997

A.7.3 LView

LView and LView Pro are image process software packages for Microsoft Windows. They are useful for manipulating digitized images and for moving between file formats. Both were developed by Leonardo Haddad Loureiro and are distributed by MMedia Research Corporation, but LView is distributed as freeware and LView Pro is distributed as shareware.

More information about LView and LView Pro can be obtained from

MMedia Research

Attn: Leonardo Haddad Loureiro

1501 East Hallandale Beach Boulevard, #254

Hallandale, Florida 33009

USA

Fax: 305-458-9698

A.7.4 StatView

StatView 512+ is an interactive statistics and graphics program produced by Abacus Concepts and published by Brain Power Incorporated. The last available version was published in 1988.

More information about StatView is available from:

29009 Ventura Boulevard
Suite 250
Calabasas, California 91302

END

0 | 5 - 0 6 - 9 | 6

FIN