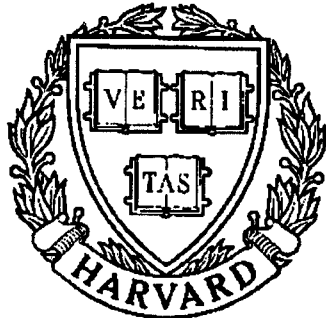


THESIS REPORT
Master's Degree



S Y S T E M S
R E S E A R C H
C E N T E R



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Systems Integration in Education

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Systems Integration In Education

by

Mark Andrew Ottenberg

Thesis submitted to the Faculty of the Graduate School
of the university of Maryland in partial fulfillment
of the requirements for the degree of
Master of Science
1991

Advisory Committee:

Professor Odd A. Asbjornsen
Professor Ted Smith
Professor Patrick Cunniff

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A B S T R A C T

Title of Thesis: **SYSTEM INTEGRATION IN EDUCATION**

Name of degree candidate: **Mark Andrew Ottenberg**

Degree and Year: **Master of Science, 1991**

Thesis directed by: **Dr. Odd A. Asbjornsen**
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Today's universities perform many functions within many highly integrated systems. One of these functions within the system of an institution for higher learning is the transfer of sufficient and practical knowledge to undergraduate students so that, upon graduation, they are ready to begin technical careers. This function has come under fire lately for not effectively preparing graduates for professional careers. The typical response to this type of criticism is to attempt to find and implement more effective knowledge transfer mechanisms. While this may have some effect, it is hypothesized that this treatment ignores many of the true sources of the problem.

The objective of this thesis is to develop a procedure that can be used to integrate the effects and capabilities of each of the university's systems toward the design of a superior education program. This is to be accomplished with the study of this multi-functional and integrated multi-system university and subsequent application of the Systems Engineering approach to the design of a total, integrated, systems-wide design process. This process can then be applied to the design of any of the undergraduate hard science programs. This thesis demonstrates the application of this process to the undergraduate Chemical Engineering program.

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DEDICATION

This thesis is dedicated to my wife Elizabeth.

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I express my special thanks and appreciation to my project advisor, Dr. Odd Asbjornsen for his invaluable guidance, support, and knowledgeable yet objective viewpoint throughout my Masters Project and subsequent thesis. My sincere thanks go to Dr. Ted Smith and Dr. Patrick Cunniff for serving on the oral examining committee and for reviewing this thesis.

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INTRODUCTION

The current undergraduate hard science programs are degenerating and will soon fail to be able to satisfy the future's education demands [Akers 1990, Coates 1990, Asbjornsen 1990b]. Thus, a need exists for the formulation of new programs that will educate future generations of students. In an attempt to offer one solution to this need, a Systems Engineering approach was taken to develop a procedure that could be used to devise undergraduate hard science programs that both better reflect the needs of today's and future customers and which implement recent improvements in education. This procedure was developed and is demonstrated with the design of a new undergraduate Chemical Engineering program at the University of Maryland at College Park.

Systems Engineering is a discipline that was developed to counteract the difficulties encountered in the engineering of increasingly large and complex systems. Today's university education system is, in reality, a very large and complex set of interacting systems. As such, it is a prime candidate for the application of Systems Engineering principles.

The System Engineering process is based upon a system life cycle approach. "The life cycle of a system or product begins with the initial identification of a need and extends through planning, research, design,

production or construction, evaluation, consumer use, field support, and ultimate product phase-out." [Blanchard 1981, p.19] Everything a System Engineer does is based upon the decided life cycle time scale determined early on in the project. In generic form, the life cycle for a project follows that shown in Figure I.1 below.

The System Life Cycle						
Customer	System Producer				Customer	
Need Identification And Development	Concept Definition (System Planning)	Concept Validation (System Research)	Engineering Development (System Design)	Production And / Or Construction	System Evaluation	System Use And Logistic Support (Operations)

Figure I.1 System Life Cycle Activities

Due to the magnitude of the actual design of such an education program and the limitations of the scope of this design project, the project that this thesis describes utilized this life cycle up to the Engineering Development stage. This in no way diminishes its worth as it could easily be continued within a project of larger scope.

This thesis begins with a short description of the steps of the design process in Chapter 1. Chapter 2 identifies the users, customers and expected developers for this program. Chapter 3 gives a short description of the projected life cycle for a developed undergraduate program and some life cycle trends that may help define the environment it will function within. Chapter 4 begins the determination of the needs of the users, customers, etc., on such a future system.

Chapter 5 converts these needs and the previous life cycle trends into requirements and constraints for the program. Chapter 6 begins the design phase for this program with the determination of learning method to be used. This method is then regarded in the determination of course contents and sequencing in Chapter 7. Finally, Chapter 8 determines teaching methods, support mechanisms, and further suggestions to aid in the development of an undergraduate Chemical Engineering program that meets the requirements for the system as closely as possible.

Finally, it should be noted that this entire project is executed from the viewpoint of the students and their process of education. A project performed from the educators' or any other point of view would possibly be different and possibly less far-reaching as educators usually have less contact with the overall university than do students.

CHAPTER 1

THE PROCEDURE FOR DEVELOPING AN EDUCATION PROGRAM

1 TAILORING THE GENERIC PROCEDURE

The first step in the full scope design of such a system is to go through the following listing and write notes, concerns, and questions about how the following steps would need to be tailored to fit this generic process to the design project at hand. This would provide a more exact procedure which could then be followed to develop the desired education program.

As this design project generated this generic procedure, this section will instead generalize the procedure developed in the design of the undergraduate Chemical Engineering program. This generic procedure continues with Phase 2.

2 IDENTIFICATION OF THE SYSTEM USERS, CUSTOMER(S), AND DEVELOPERS

The first step in determining the needs and requirements of any system is to determine:

- 1) who will use the system
 - for what purpose
 - in what manner

- 2) who will be paying for the system to be developed
- 3) who will perform the system development.

This information determines the broad boundaries of the system in terms of the needs and objectives for the system.

3 SYSTEM LIFE CYCLE DESCRIPTION

The life cycle of a system is a concept that permeates the entire structure of a System Engineering approach to systems design. A system or product's life cycle is a projected time line of the system's life into the future. This includes frames for the initial identification of a need, the system conceptual and detailed design, system development and testing, installation, operation and maintenance, system replacement or upgrading, and finally system depletion. This life cycle is a dynamic document and needs to be updated constantly throughout the development of the system.

This life cycle has two basic functions: first, it serves as a basic schedule for all activities, and second, it serves as a mechanism with which to consider, determine, and incorporate trends that will affect the system and its life cycle.

This phase of the project develops a projection of the life cycle for the system. Future trends that may affect this life cycle are then researched and listed.

4 ENVIRONMENTAL AND INTERFACIAL NEEDS OF THE SYSTEM

The next step in the System Engineering process is to sketch out the system qualifications as they correspond to the education program of proposed design. These qualifications come from two sources: external (environmental) and internal (interface). Environmental conditions involve the criteria that are put on the system by external forces such as society and industry. Interface conditions arise from the interactions that occur between the internal interfaces of the subsystems and the users within the university system. In this step the subsystems of the university, the customers, and users are all considered to organize and discuss the general needs placed upon only the undergraduate portion of the Institution For Higher Learning function.

5 DEVELOPMENT OF REQUIREMENTS AND CONSTRAINTS OF THE PROGRAM

Now that the general needs of the system have been specified, this skeleton can then be further fleshed out into specific functional, performance, and logistic requirements and constraints for our undergraduate Chemical Engineering program.

This step would normally be followed by the further refinement of the requirements and constraints. This could be done using performance measures and other specification forms to come up with a second, more precise level of

system requirements. These requirements could then be transformed into specifications with the additional workings of functional allocation, etc., which would refine the imprecise terms of the requirements into precisely termed system specifications.

6 DETERMINATION OF LEARNING METHOD(S)

At this point, the initial design of this system begins. Design of the largest and most analytical portion of the program is performed first and begins with a determination of a high level learning method or methods to be used by the program. The determination of this high level method or methods is a two step sequence. First, a complete list of available, current and practical learning methods must be assembled and understood. Hybrid methods should also be considered. The best method or methods can then be determined with the use of a tradeoff analysis.

7 DEVELOPMENT OF COURSE SEQUENCE

After the high level learning method is determined, courses and sequences are developed. This is usually performed in a two step process. The first step organizes the tangible knowledge lists of the requirements section into courses. The second step then determines a course sequence that meets with the requirements and constraints of the learning methods determined above.

8 TEACHING METHODS & SUPPORT FUNCTIONS

The next phase deals with the low level teaching methods and the support functions which are concerns of the education function. Low level teaching methods are teaching methods of sufficiently small application scope that they can be used within single courses or even to present single topics. Many of these methods are direct design results of individual system requirements or needs. They are first collected then analyzed and linked to particular topics to meet as many individual system requirements and other concerns, such as providing variation and motivation.

The second section of this phase should survey, explore, and develop support functions. Examples of these functions are the effects of human factors on the social environment, course teaching, disposition of the student, sources of extra funding for the program, feedback functions for the system, and any other function or concern which affects the success of other functions of the program or its users at any level. These are very critical topics and must be adequately developed and integrated into the overall program to provide another level of the multi-system integration necessary for the program to be successful.

Though the scope of this project limited it to the above steps, the following is a listing of what steps must also be completed for the Systems Engineering Process to be continued to its full life cycle conclusion. Before they can be performed, though, the first eight steps would need to be completed at a level

deep enough to make the comprehensive development of this program possible.

- 9) In this step, the necessary tradeoffs would be performed to link the potential low level teaching methods to individual topics or courses. This will require a large amount of teaching method studies, technology and learning psychology studies, tradeoffs, etc., but would result in a substantially determined education system.
- 10) Determine and acquire the necessary logistics for the implementation and operation of the new program.
- 11) Implement the system in steps, utilizing any knowledge learned in previous steps.
- 12) Run the system with active monitoring and immediate feedback and control response.
- 13) Begin the cycle of system improvement and optimization with the feedback loops and other appropriate control functions.
- 14) Validate the life cycle plan.
- 15) Begin design of a new system as determined in the life cycle plan. Utilize

all knowledge learned by implementing and running the first system and study the workings and failings of current system.

- 16) Simultaneously phase out old system and phase in new system.

CHAPTER 2

IDENTIFICATION OF THE SYSTEM

USERS, CUSTOMERS, AND DEVELOPERS

The first step in determining the needs and requirements of any system is to determine:

- 1) who will use the system
 - for what purpose
 - in what manner
- 2) who will be paying for the system to be developed
- 3) who will perform the system development.

This information determines the broad boundaries of the system in terms of the needs and objectives for the system.

2.1 CUSTOMER OF THE SYSTEM

When looking at the current system, this question has two different answers. An informal survey of undergraduate Chemical Engineering instructors and administration finds that these groups believe that the customer of the current education system is industry. From the student's point of view, they, the students, are the customers of the education system. This discrepancy has caused much ill will within the student body and deserves further analysis.

A customer, according to The American Heritage Dictionary, is "A person who buys goods or services, especially on a regular basis." This must be contrasted with a user, who is "One that uses." For any given system, it is possible for these two to be the same or different individuals or groups. A rational analysis of the current state university undergraduate structure finds that the customer of this system is actually a combination of four groups, as shown in Figure 2.1. These customers are:

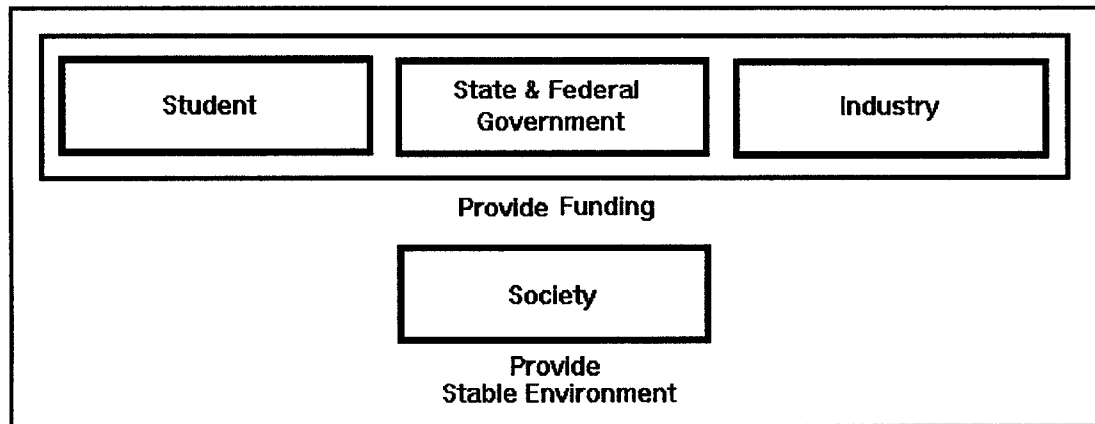


Figure 2.1 Customers Of The University Education System

- 1) The students, who pay a great deal of tuition and other fees to purchase education (self-improvement) from the university "at a price which should guarantee its quality." [Asbjornsen 1991]
- 2) The state and federal governments, who provide additional funds that are usually applied to the campus and buildings, maintenance and administration costs, partial instructor expense and varying amounts of direct and indirect student subsidies.
- 3) Industry, which subsidizes instructors through the funding of research and which often donates equipment for laboratory or student use.
- 4) Society at large, who provides the stable and continuous environment without which the education and even the university environment would be impossible to maintain.

Thus, no one group can claim to be the sole "customer" for the education system. This is indicative of the cooperative and multi-functional nature of today's university institutions.

2.2 USER OF THE SYSTEM

The current undergraduate engineering education programs at the University of Maryland, College Park are designed and implemented based on the customer--solely viewed as industry, in this case--of the system. The student receives no or only minor secondary consideration. This is a dated viewpoint which has been conclusively revised by the relatively new discipline of Systems Engineering. In this discipline, Human Factors has been applied to the system design process to determine that a system is simply a tool for the use of its users. This means, in theory, that a system's best design should be based solely upon the needs of the user of the system. In a real world system, however, these needs are converted into open-ended system requirements that are then bounded by the constraints supplied by the purchaser of the system, the customer. Thus, a properly balanced system must be designed for the user, but with consideration for the constraints of the system customer.

Just as the identification of the customer above showed that a multi-grouped customer exists for this system, this system likewise has multiple users. For almost any given system, there are three separate forms of users. They are

the system as a tool utilizier, the operator, and the maintainer. Figure 2.2 shows a schematic of the users of this undergraduate system. From this figure we can

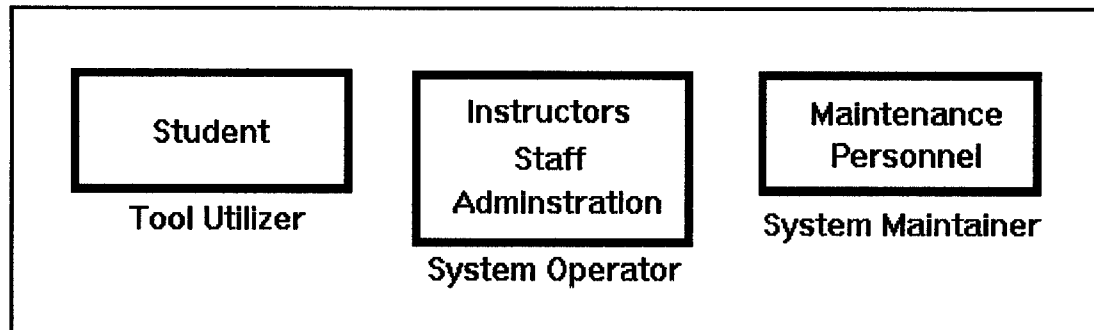


Figure 2.2 Users Of The Undergraduate Education System

see that we have five users for this system:

- students as the tool utiliziers
- instructors, staff and administration as the system operators
- maintenance personnel as the system maintainers

While it was not desirous--at this level of analysis--to determine any priority between the customers, establishing a priority between the system users is very important. Many of the requirements of the different users are likely to conflict. Establishing an overall priority for each of the users will help to eliminate some of these conflicts. An initial, unverified priority listing could be listed as follows:

- 1) students as the system users (if they do not use the system, who cares about anything else?)
- 2) system operators in the order of instructor, instructor support staff, administrators
- 3) maintenance personnel

Obviously, this needs to be verified and its balance maintained periodically.

Regardless of this order, however, each user must receive and exert paramount priority in each of his unique areas of interest. Furthermore, a working system would require that each user remain open-minded to the causes and interests of the others. For example, an administrator may have a strong conflicting opinion about a maintenance need, but the maintenance personnel should not be overruled simply because they have a lower overall priority. Obviously some sort of arbitrator will be needed in some cases.

Because they are more experienced and are professionals, the highest priority may be argued to go to the instructors as they are most likely to have the best view of what the students really need. However, as it is the students who are relying upon the education system provided by the university as their sole tool for the management of their education, and as most students are literally putting their entire future into the decision to attend this program, their rights to self-determination must be upheld. Because of this, the students should be thoroughly exposed to other viewpoints and given the ability to temporarily and selectively defer their decision priorities as they see fit. Their determination of their needs must not be overruled without proven benefit. Thus, the educational system should be designed and run with the needs of the students as the paramount factors which define its form and drive its activities.

2.3 DEVELOPER OF THE SYSTEM

This system could be designed in a number of ways. It could be contracted out in a RFP or Bid format. It could be developed by a national concern such as the American Institute Of Chemical Engineers. It could even be developed in-house by any of a number of different groups or individuals. Each of these methods has intrinsic benefits and drawbacks. Dictating the design method, in fact, limits the scope of the solution space, which could conceivably unintentionally eliminate the best solution. However, as is true in most stages of the design of a system, no progress can be made unless decisions are made. A simple tradeoff is thus necessary.

The contracted method would require a very large capital outlay far in advance of any possible monetary recoveries, which might not even occur. The benefits of such a development would include a professionally designed system that would be relatively unbiased and could be constructed in a minimum of time.

If an outside organization is allowed to develop the program, a number of drawbacks would become evident. First, a suitable organization would have to be located and successfully petitioned to perform the project. This could take a large amount of time and effort. Second, the organization might add a considerable amount of bias to the resulting project as most professional organizations have their own political and philosophical theories about how their

profession should continue to evolve. Third, there is little guarantee that the organization would complete the project in a relatively short period of time. Benefits of such a development would include a vast database of applicable and experienced industrial and other personnel who span the entire realm of applications and who collectively would likely have answers to most problems.

Developing the program in-house would also have some major drawbacks. First, development of a major project within the university environment is becoming increasingly difficult with the decreasing personnel and the increasing workload on each remaining person. Next, the university is very likely to instill a biased or skewed view of the profession due to its limited and often focused interaction with industry. Third, university politics at all levels will surely cause strife and place difficult demands upon the design. Lastly, in-house development leaves no guarantee that the project will ever be completed. Benefits from in-house development, on the other hand, could include the following. If successful, the new program would be unique to this university, thus allowing prestige and other related benefits. Second, development costs could be kept to a minimum and spread over the development and installation as desired.

In evaluating these options the following observations can be made. Unless the unforeseen occurs, insufficient funds will be obtainable to utilize the contracted development method. Finding and interesting a suitable major organization in this project is at this time deemed difficult and holds a large

chance of not being possible. The option of developing the project in-house will be very difficult unless an additional workforce is obtained.

In conclusion, development of this project seems best to be done in-house. First, if the project is not completed, the completed portions will still have value and can be implemented or used as improvements. Second, an additional workforce can be found in the enthusiasm of the student users and in the masters and other projects performed by such graduate students as Systems Engineers. Lastly, the improvements, at whatever scale, will give this single university an increased reputation that will feed the desire for further improvements. In addition, this project will pave the way for a full-scale development.

In this phase we have found a clear understanding of what the relationships between all of these parties should be. The students are the major user of a system of education that is supplied by the university and which is paid for by the customers, namely the students, government, and industry. The university is responsible for the design, operation, and maintenance of the educational system according to the needs of the users but within the bounds placed by the allotted resources of the customers.

CHAPTER 3

SYSTEM LIFE CYCLE DESCRIPTION

The life cycle of a system is a concept that permeates the entire structure of a System Engineering approach to systems design. A system or product's life cycle is a projected time line of the system's life into the future. This includes frames for the initial identification of a need, the system conceptual and detailed design, system development and testing, installation, operation and maintenance, system replacement or upgrading, and finally system depletion. This life cycle is a dynamic document and needs to be updated constantly throughout the development of the system.

This life cycle has two basic functions. First, it serves as a basic schedule for all activities. Second, it serves as a mechanism with which to consider, determine, and incorporate trends that will affect the system and its life cycle.

This phase of the project will show the current projection of the life cycle for this system in Section 3.1. Future trends that may affect this life cycle will then be discussed in Section 3.2.

3.1 LIFE CYCLE FOR THE EDUCATION SYSTEM

The life cycle for this project must be carefully differentiated from the life cycle of the university itself. The life cycle for this project limits itself to the span bounded by the inception and the reevaluation of this project and nothing more. While mechanisms will be suggested for this program which will attempt to keep the system current and applicable into the indefinite future, this project will be given a definite reevaluation point. At this point, the project should be repeated and a new or revised system implemented. This is important because it is not possible to know now what the requirements will be in the future. As such, a situation analogous to that existing today may occur where the system may seem to be moderately close to being functionally satisfactory, but in reality, may not even be applicable in format, content, or other factor. Forcing a review at some specified amount of time will insure that the system is accurately and appropriately updated periodically. As further incentive, it has been shown that a series of successive projects has a better chance in superior performance than a long, continuous, single project. [Source missing]

Figure 3.1 shows the current life cycle projection for this project. We see

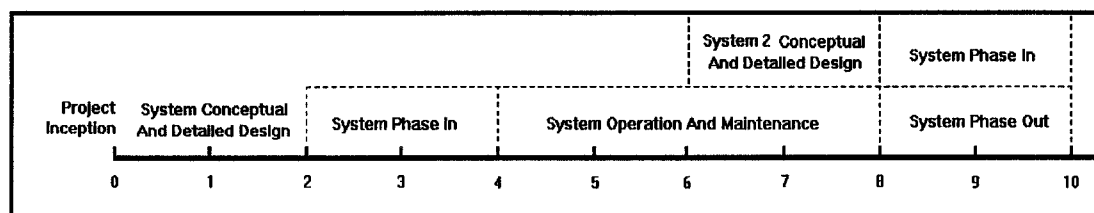


Figure 3.1 System Life Cycle

that the length of the life cycle of the system is taken as ten years from project

inception to completion of phase-out. Other features include a two year phase-in for the system and another two year phase-out. This should be realistic and means that it is not expected for a working system to be instituted and operated immediately, but rather that it should be installed and activated in phases. This will allow for small scale experiments and optimizations to be run on the early phases and easily incorporated into the phases to be installed later. It should be noted that the second iteration of the project is scheduled to begin before the first project ends so that as one is phasing out, the other may be phased in. The duration of the phase-in and operating life of this version of the project is estimated to be of a sufficient length to yield information important to the second version, and yet be short enough to keep it from hindering the introduction of further improvements.

3.2 LIFE CYCLE TRENDS EXPECTED TO AFFECT THE UNIVERSITY

The surveyance of future trends that will affect the implementation, usage or the environment of the system is very important. These trends will help in the prediction of variables in the system design. In addition, they often directly drive many of the requirements and constraints for the system design by introducing some shape to the environment in which the system must operate. Some examples of trends that might affect this system are: [Naisbitt and many others]

3.2.1 TRENDS AFFECTING SOCIAL DEVELOPMENT

communication and information:

- international information highway is forming
- global telecommunication is on the rise
- increased distance of communication, ie. knowledge elements are spreading their influence farther on average than ever before
- cable becomes commonplace, as are VCRs
- advanced and readily available communication forms can now replace most of the business functions that proximity within cities used to perform

competition:

- global economy is booming for those countries which are able to become or remain globally competitive
- trend for successful countries, many with few natural resources, is to rely, emphasize and take advantage of its human resources

economic trends:

- economic considerations are becoming more important than politics
- global privatization of welfare system Eg. state universities are being forced to become less dependent on government
- trends of decreasing state (and other) financial support AND increasing costs, must compensate with decreased costs AND/OR additional financial support sources.

social concerns and trends:

- free trade between nations is mushrooming--this may eventually include education
- increase in environmental concerns
- number of women in all facets of male dominated professions is increasing
- the search for meaning in and of life is increasing, especially through the arts [Naisbitt 1990]
- individual rights, choices, recognition, and power are becoming more important and strong motivators
- social environmental contact decreases for the average person while communication between distant people increases

- need for socially aware engineering to becoming more prevalent, ie. total systems design

3.2.2 TRENDS AFFECTING TECHNICAL DEVELOPMENT

computers and usage:

- computer technologies most important in the next 5 years: optical storage (CD-ROM, worm, emerging re-writables), fiber-optic networks
- Microsoft Windows becoming a very important pc interface, probably will dominate pc future
- computer usage continuing to grow and permeate all work industries
- portable computing is mushrooming as is its capabilities
- multimedia will begin to animate information and information delivery
- computer usage is rising and will continue to do so
- laptop, notebook, and tablet computers becoming increasingly desired and available

movement in industry, business and technology:

- with the filling of common markets, only non-competitive and superior products will sell successfully in the next 10 years
- demand will lessen on materials (bulk) with miniaturization, increased efficiency, and there will be more emphasis on activity and service than on goods. Egs: fiber optic vs copper cable and increased recycling
- very high increase in need and use of such newer sciences as nanotechnology, composite materials, etc.

3.2.3 TRENDS AFFECTING EDUCATION DEVELOPMENT

- number of willing and competent teachers in the future is decreasing

CHAPTER 4

ENVIRONMENTAL AND INTERFACIAL NEEDS OF THE SYSTEM

The next step in the System Engineering process is to sketch out the system qualifications as they correspond to the education program of proposed design. These qualifications come from two sources: external (environmental) and internal (interface). Environmental conditions involve the criteria that are put on the system by external forces such as society and industry. Interface conditions arise from the interactions that occur between the internal interfaces of the subsystems and the users within the university system. To clarify this, Figure 4.1 shows five of the major subsystems to be found in the current university environment. We

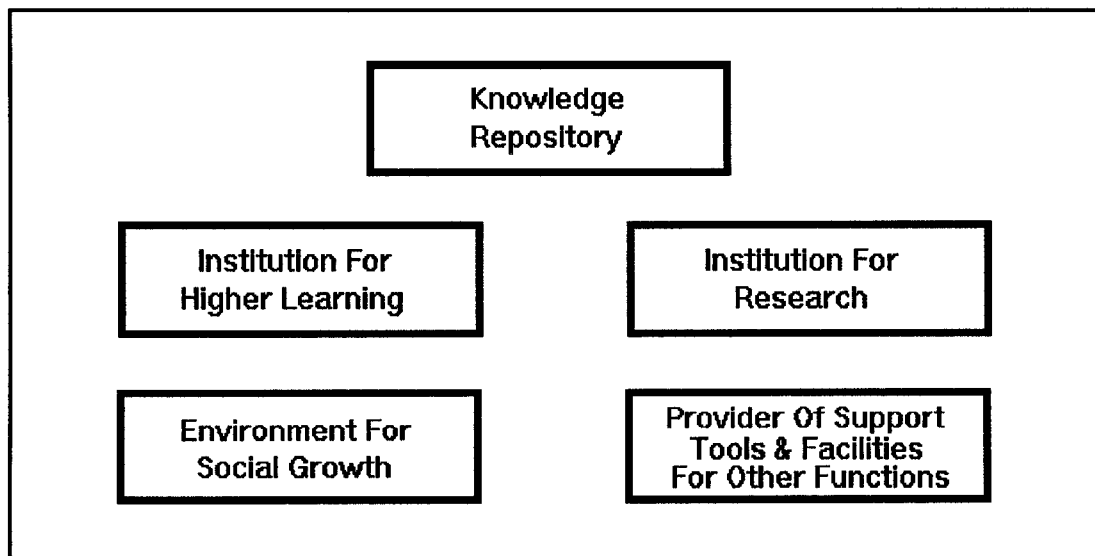


Figure 4.1 Major Functions Of The University

will use these concepts and the customers and users listed in Section 2 to organize

and discuss the general needs placed upon only the undergraduate portion of the Institution For Higher Learning subsystem--as this is our target system. Section 4.1 will discuss the externally generated needs and Section 4.2 will address the needs generated by the interaction of the system sub-functions across their interfaces.

4.1 NEEDS FROM THE ENVIRONMENT OF THE SYSTEM

The environment of this system is a complex and varied community. This community can be broken into four major groups which have concerns about the function, performance, and logistics of the university. These groups are:

- society (customer)
- industry (customer)
- students (customer, user)
- state and federal government (customer)

Each of these groups will be discussed separately in the following sections. Note, however, that many other needs can be found which deal with other functions of the university. As this project is interested only in developing a new undergraduate education program, needs will be restricted to those which may influence this education function either directly or through indirect subsystem interfaces.

4.1.1 NEEDS OF SOCIETY ON THE UNIVERSITY SYSTEM

Function

Society has an ancient understanding of its functional needs for university institutions. First and historically foremost, the university functions as a safe, dynamic, and vast repository for any technical, social, environmental, cultural, and historical knowledge known to the society. Second, the society depends upon the university to provide a cultural center for the social growth of its members. Third, it depends upon the teaching capabilities of the university to enlighten and prepare its best students for productive employment that elevates the society. Fourth, the university provides specialized knowledge, advice and research results in response to society's queries. Lastly, society often depends upon the university to provide many of the tools, techniques and other support functions needed to advance its causes.

Performance

Performance needs refer to the conditions under which the system is to operate. This includes such factors as the system's effectiveness and efficiency, its functional speed, its interface with its users, and its durability. Society benefits from a university system that is very effective, efficient, quick and durable. Its minimum requirements in this area are difficult to define, but can be linked to the highest minimum of the system's users and customers. Society has little concern to focus on the form of interface between the system and its users, but does require that is sufficient for the needs of its users.

Logistics

Logistical needs refer to the materials, workforce, spaces, and other support items necessary to deploy, run, maintain and upgrade a system during its life cycle. As a general tendency, society distances itself from physical support, deferring to government instead. However, as long as there is a surplus, society is usually willing to allow government to acquire the need and pass it on to the university.

Thus, in general, society is the producer of the basic functional needs that a university performs. It benefits from any performance level beyond the minimum performance requirements of its customers and users and grants any needed logistics that can be reasonably afforded by society.

4.1.2 NEEDS OF INDUSTRY ON THE UNIVERSITY SYSTEM

Function

Industry has three basic needs that it desires the university to provide. Industry almost solely depends upon the university to educate students to a knowledge and capability level sufficient to become employed as entry level workers--in this case, chemical engineers. Second, industry needs to find continuing education for these engineers. The university would be an acceptable place for this to occur. Lastly, industry depends upon the university to provide specialized and general research and continued advancement of science and

technology.

Performance

Industry needs students coming out of the program to have the sufficient knowledge, skills, etc., for them to be useful and employable as entry level engineers. Note that while this is a need which is placed on the graduates, students, as future graduates, desire to meet these needs and thus pass them on to the education system. In addition, industry needs the university to provide sufficient quantities of graduates with sufficient interests to constantly fill its current and short-term requirements. As a need that is currently often unfulfilled, industry would also like the university to provide some effective, cheap, quick means for its engineers to efficiently get continuing education periodically throughout their professional career.

Logistics

As a secondary customer of the initial education function of undergraduate students, industry would optimally like to provide no logistical support at all. However, to aid in the procurement of its deficiencies, and in payment for use of a continuing education function, it is willing to provide support up to a limit. Industry seems willing to donate equipment for use in laboratories and for research and to occasionally donate experienced personnel to act as consultants or visiting instructors. In addition, industry is willing to fund some of the financial compensation received by instructors through hiring them to perform

needed research. Related to this, industry's needs are to keep these levels relatively low and stable, and to receive quick benefit for any additional logistical support.

Thus, we see that industry has varied levels of functional, performance, and logistical needs that it would like the university education system to meet. As a large and affluent customer, though, industry is willing to compromise to get its deficiencies filled.

4.1.3 NEEDS OF STUDENTS ON THE UNIVERSITY SYSTEM

The needs of the students are unique in the fact that they come from the viewpoint of both the students as a customer and the students as the primary user of the system. This must still be limited to the environmental origin of these needs, as the interface ones will be discussed in Section 4.2.

Function

The students as system customers need to get the education necessary to either move on to a productive career as an entry level career or to pursue continued education. Students as system users need the system to organize, structure, and teach them both the basic Chemical Engineering education subjects and any material required for their desired field(s) of specialization. In specific,

they want to learn and gain experience in:

- discipline specific knowledge
- discipline related skills
- discipline related tools
- background and support knowledge useful to Chemical Engineers
- understanding of the processes, design concepts, etc., to be found in chemical plants or other industries which employ chemical engineers
- intangibles such as management skills, communication, and understanding of the niche filled by chemical and other engineers
- desired specialty information

The students also need the university to provide an environment that will correct and/or continue their personal, social, professional, and intellectual growth so that they may become healthy, rounded, well-adjusted, and productive adults in society. In addition, they also want to be supported in their efforts to attempt non-standard functions.

Performance

The students as customers want to get the best possible education within the constraint of the money and other resources they can afford. Simply, they want high educational value for their purchase. They recognize the highly competitive nature of the employment market and its importance and need to gain as much of an advantage as education will allow them. Lastly, the student must find the usability of the product of the education system to be 100%. He will not and should not tolerate any lower a figure.

The students as users want the performance of the system to closely match

their ability to incorporate knowledge in both rate and depth and to avoid unnecessary or inefficient learning. In addition, they want to find all of their needs easily met with a minimum of inconvenience, confusion, or confrontation.

Logistics

As the customer, the students have only one basic need: they must find it possible to obtain the necessary financial and other resources. At the current levels of tuition increase, this is already impossible for many potential students and hazardous to most others.

Thus we can see that the students as customers and as users of the educational system have a vast and strongly critical set of needs for their approval of an education system. These needs will become the driving force for many of the design decisions later in the project.

4.1.4 NEEDS OF GOVERNMENT ON THE UNIVERSITY SYSTEM

Function

Government, as an agent of society, has no major functional needs itself that it can place on the undergraduate educational portion of the university system.

Performance

Government does have performance needs for this system. It requires that the educational program fits and functions within those conditions required by ABET for accreditation. For a listing of the ABET requirements see Appendix A. Government also wants any citizen with the desire and sufficient background and capabilities to be able to use the education system. Finally, as an institution concerned with the reputation of its citizens and societies, it wants both the and highest reputation for its educational process and as much published scientific and other noteworthy innovation as possible--even though these are often conflicting possibilities.

Logistics

As a customer of the university in general, the state and federal governments recognize the need of public universities for financial support. However, in these times of increasing budget shortfalls, government must reduce these customary levels of financial support.

Overall, while government does not have many needs to place on the university education system, it does support its users and, in general, requires that the system supply all of the students' needs as it is reasonably able to.

4.2 NEEDS FROM THE INTERACTION BETWEEN SUBSYSTEMS

The interactions that should occur at the interfaces between each of the subsystem functions and also between the users of the system and the subsystems create another set of needs that must be addressed for a successful system. This complex network will be discussed below one set of users or subsystem at a time. Note, however, that as this project is interested only in developing a new undergraduate education program, needs will be restricted to those which directly or indirectly influence this function.

4.2.1 STUDENT INTERFACE TO THE SYSTEM

Function

This is one of the areas most in need of improvement that is cited by students. While students expect to experience their education in the traditional lecture, homework, and test format, reviews of experimental alternate learning environments have shown that other types of teaching can also easily be accepted and are often more efficient. This means that other student-interface forms need to be studied.

Another student-system interface function which students need is full system life cycle support. There should be support from the moment of initial application and orientation, to the moment of accepting a job or continued

education offer.

In addition, many believe that the education function is too focused on the transference of knowledge and procedures. This needs to be heavily supplemented and better balanced with the learning of a mentality that is conducive to problem analysis, formulation and solution.

Performance

As a performance factor, the students, as individuals with individual agendas, need to have as much flexibility as possible in terms of specializations and course substitutions. One of the more important interface performance variables is enthusiasm, especially as a motivator. From experience, there is a great need for increased enthusiasm in almost all students. Similarly, Human Factors, a newer study in engineering, needs to be integrated into the performance of the education system. Finally, the persistence of the learning needs improvement--too much of the information that is learned can be too easily forgotten when not used regularly.

4.2.2 INSTRUCTORS, STAFF, AND ADMINISTRATION INTERFACES TO THE SYSTEM

Function

The operators of the education system need a consistent set of functions that they are expected to operate. Appropriate support functions must be

established and supported for the operators. For example, computer manipulation of symbolic equations is difficult to teach effectively without the availability of some form of real time computer display that is viewable by all in a classroom.

Logistics

Sufficient manpower, materials, and mechanisms need to be continuously supplied in order for the continuing operation of the system. For the initial system and any changes, appropriate training is needed by the operators.

4.2.3 MAINTENANCE PERSONNEL INTERFACE TO THE SYSTEM

Function

The maintainers of this system need a consistent and bounded set of functions. Maintenance of this system needs to include feedback loops from each user, customer, and interactive subfunction in the system in order for the integrated system to remain accurate and authentic.

Logistics

Sufficient manpower, materials, and mechanisms will need to be continuously supplied in order for the continuing maintenance of the system.

4.2.4 KNOWLEDGE REPOSITORY INTERFACE TO THE SYSTEM

Function

Functions that this subsystem is to perform need to be relatively consistent, and any changes or additions need to be detailed sufficiently before they are used.

Performance

The libraries, etc., need to be allowed relatively constant hours of operation. They also need to perform their services for the users with an accuracy and efficiency that does not significantly hamper the users.

Logistics

Sufficient manpower, materials, mechanisms, and funding will need to be continuously supplied in order for the continuing operation and maintenance of this subsystem.

4.2.5 INSTITUTION FOR HIGHER LEARNING INTERFACE TO THE SYSTEM

Function

The functions that this subsystem will perform need to be relatively consistent, and any changes or additions need to be detailed sufficiently before they are used.

Performance

The performance of the learning subsystem needs to be continuously up to at least a level expected by the students and other users.

Logistics

Sufficient manpower, materials, mechanisms, and funding will need to be continuously supplied in order for the continuing operation and maintenance of this subsystem.

4.2.6 INSTITUTION FOR RESEARCH INTERFACE TO THE SYSTEM

Function

This subsystem needs to supply increasingly advanced or new technology, techniques, etc., to the education subsystem. This will thus enable the education subsystem to teach the students sufficient knowledge etc., and render them capable of solving the problems that they will encounter in professional practice.

Performance

The performance of this subsystem needs to be such that it generates this new or advanced material before it is needed by the education subsystem.

Logistics

Sufficient manpower, materials, mechanisms, and funding will need to be

continuously supplied in order for the continuing operation and maintenance of this subsystem.

4.2.7 ENVIRONMENT FOR SOCIAL GROWTH INTERFACE TO THE SYSTEM

Function

This subsystem has a myriad of needed functions. In broad terms it must:

- allow and encourage the continued personal development of the students, all other users, and all those who come in contact with the university
- not cause any psychological or long-term emotional harm to this same group
- instill enthusiasm in this same group
- sufficiently isolate the university so as to be able to provide a positive environment toward the successful functioning of the other subsystems regardless of the external environmental conditions.

These will be expanded in the requirements section.

Performance

The performance of this subsystem needs to be such that its accuracy is very high. This subsystem needs to be kept stable and constant.

Logistics

Sufficient manpower, mechanisms, and funding will be needed to continuously supplied in order for the continuing operation and maintenance of this subsystem.

4.2.8 PROVIDER OF SUPPORT TOOLS, TECHNIQUES, AND FACILITIES INTERFACE TO THE SYSTEM

Function

This subsystem needs to supply all the additional requirements of the other subsystems. Examples include laboratories, computer facilities, and a book store.

Performance

Each of the supplied facilities or tools should work sufficiently well and fast enough so that every user wishing to take advantage of the services should be able to in a reasonable amount of time.

Logistics

Sufficient manpower, materials, mechanisms, and funding need to be continuously supplied for continuous operation and maintenance of this subsystem.

This concludes the listing of the broad needs for the education and other related systems from both environmental viewpoints and from internal and operational interfaces. Phase 5 will convert these needs into more elaborate requirements for the education and other systems.

CHAPTER 5

DEVELOPMENT OF REQUIREMENTS AND CONSTRAINTS OF THE PROGRAM

Now that the general needs of the system have been specified, we need to further flesh them out into specific requirements and constraints for our undergraduate Chemical Engineering program. Note, this step of the process is the first which is precise enough to restrict our process to the development of a Chemical Engineering program. All the previous sections have been worked in broad terms and could apply to other types of programs as well.

This step would normally be followed by the requirements and constraints being further refined with performance measures and other specification forms to come up with a second, more precise level of system requirements. These requirements could then be transformed into specifications with the additional workings of functional allocation, etc., which would refine the imprecise terms of the requirements into precisely termed system specifications. Due to the limited depth of this project, however, this section will only demonstrate the conversion of the system needs into broad system requirements and constraints. This level of criteria will be sufficiently descriptive for us to continue on to the system design at our level of involvement.

To remain consistent with traditional System Engineering organization and to aid in the organization of these needs, the following sections will address the functional, performance, and logistical requirements, and the system constraints in this order in Sections 5.2 to 5.5. Section 5.1 will be used to gain a better understanding of the program we are trying to design.

5.1 CLARIFICATION OF THE EDUCATION PROGRAM

Before we continue and convert the needs to requirements and constraints, it would be beneficial to take a moment to gain a better understanding of the functions of the program that we are trying to build and the environment in which it will exist. To aid the clarification of our Chemical Engineering program, Figure 5.1 shows a three level execution of the standard Systems Engineering tool of functional analysis for our undergraduate Chemical Engineering program and the environment that affects it. From this, we can see that the program we are attempting to build locates itself within a complex area of the integrated university system. Much of this program resides in the subsystem of the Institution For Higher Learning. However, it seems that our program also overlaps and resides in parts of other subsystems of the university. Thus, we can see that the program that we wish to design is a very complex one that exists as integral and inter-related parts of many of the subsystems of the total university system.

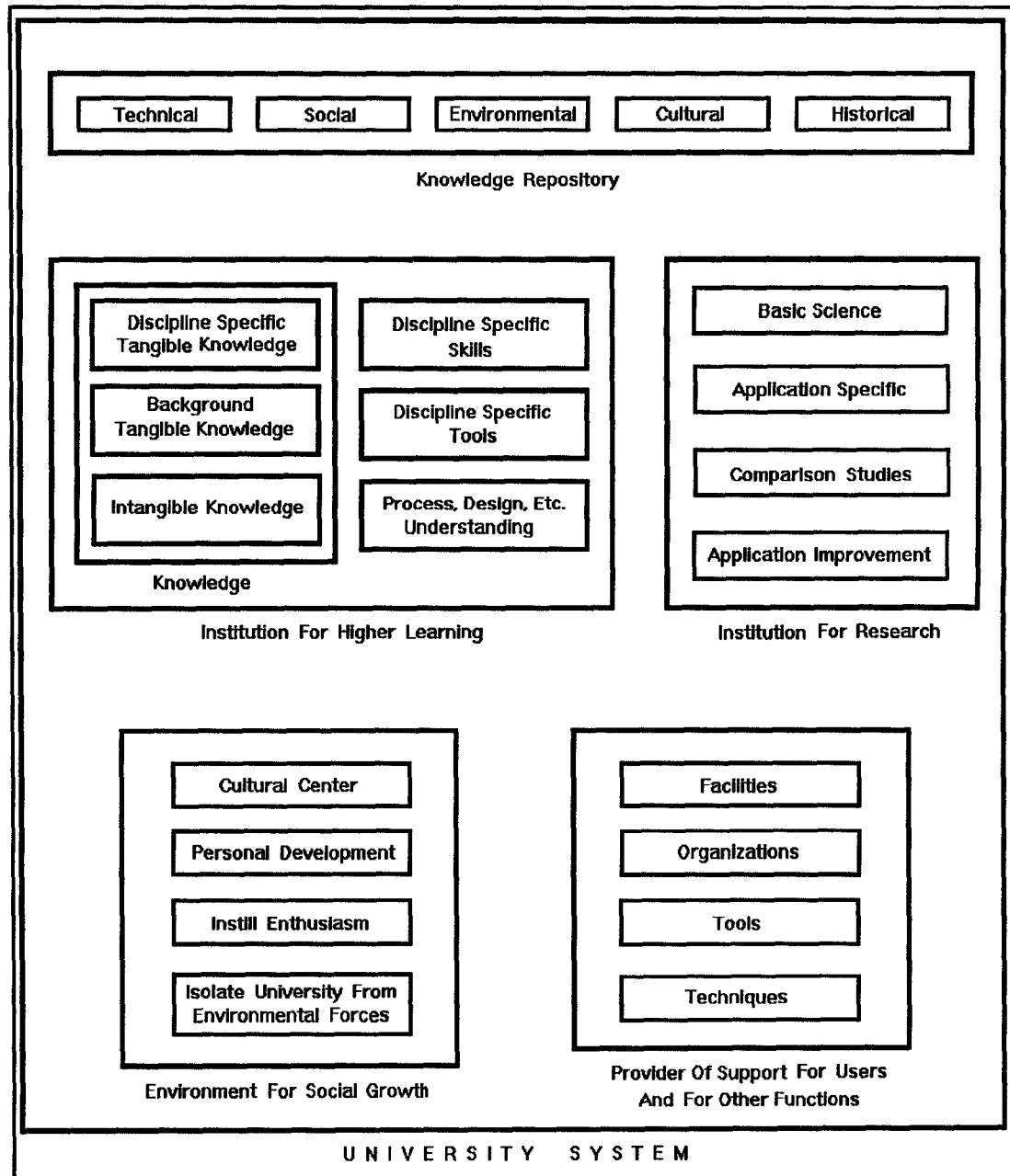


Figure 5.1 Functional Analysis Of ChE Program & Environment

Within the education (higher learning) function itself, we find that there are six functions that need to be performed, three of which can all be blocked into a single knowledge function. While listing these functions is useful, the actual generation of a program that can perform these functions will depend on a thorough comprehension of three things. These three things are:

- the actual knowledge, skills, tools, understandings, etc., that the student needs to acquire
- the necessary level of depth of this understanding
- how all this interrelates

Attempting to understand all this at one time has turned out to be very difficult. To facilitate the simultaneous grasping of the knowledge with the extent and interrelationships of all this, it is necessary to find some way of diagramming it. Figure 5.2 shows a spatial structure that was devised to show this knowledge. (See Appendix B for the derivation of this structure.)

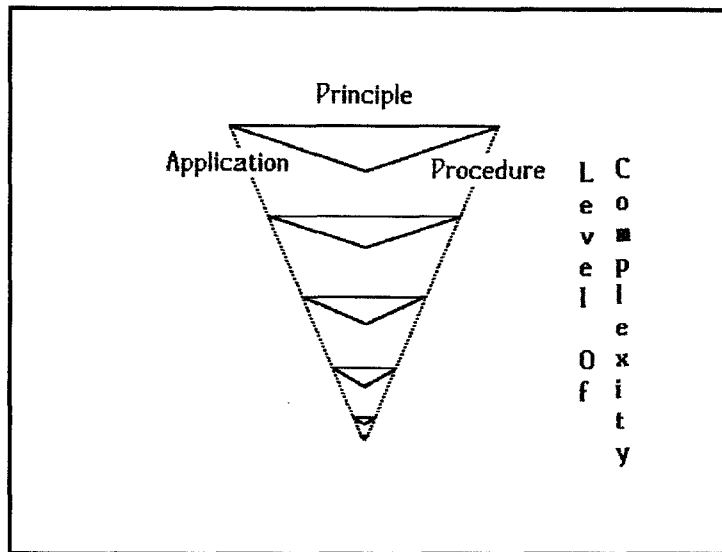


Figure 5.2 Knowledge Space Representation

It was found that it takes a minimum of four dimensions to totally represent the space within which the essence and interrelationships of the knowledge and other functions could be represented. These dimensions, the question they answer, and their conceptual orientations are listed in Table 5.1.

Dimension	Questions Answered	Knowledge/Object/Concept Orientation
(Phenomenological) Principle:	Why	Symbol Oriented
Application:	What and Where	Requirements Oriented
Procedure:	How	Algorithm Oriented
Level Of Complexity:	How much (level of) or To what depth	Inter-relational complexity (involvement, sophistication, depth of knowledge)

Table 5.1 Knowledge Space Dimension Framework

In fact, during the development of this characterization, it was found that the function of any process can likewise be broken up onto a complex, bounded state space with the dimensions of:

Theory/Principles	(Dimension 1)
Form:	symbolic
Content:	the mechanisms involved in the process
Application	(Dimension 2)
Form:	requirements of the system
Content:	bounds and definition (constraints of the application of principle)
Procedure	(Dimension 3)
Form:	algorithm
Content:	prescription to accomplish the application
Complexity	(Dimension 4)
Form:	measurement
Content:	level of Inter-relational complexity (involvement, sophistication, depth of knowledge)

From this viewpoint, the learning to be accomplished by the students is a process (or transfer function) involving the application of the principle of dissemination of theoretical knowledge, within an application framework of Chemical Engineering, with given tools and work procedures and which is offered at specific range of levels of complexity necessary for them to begin work as entry level engineers.

✱

When we view the education function of our process in this light, we finally have a framework that can be successfully used to both organize and quantify the requirements for our system. As such, we will now move on to the requirements and constraints section's listing of some of the more important functional requirements, using the subheadings of "student", "government," and "industry".

5.2 FUNCTIONAL REQUIREMENTS

To make the processes of this phase and Phase 4 easier, we have divided the needs in Phase 4 into three groups: functional, performance, and logistics. The first group, functional, deals with the tasks that the system will perform for the user. In Phase 2 we determined that the undergraduate Chemical Engineering program has three groups of users (Figure 2.2). Again, these are:

- tool (system) user: students
- system operator: instructors, staff, administration
- system maintainer: maintenance personnel

At this point, we will restrict ourselves to the requirements and constraints that these users will place on the undergraduate ChE education system. Likewise, we will restrict our functions to those which are either part of or directly support this portion of the education system. These restrictions will help us restrict our attention on the design of a single program. That is, we will maintain an integrated, system-wide view of a single program.

We then begin a small, partial listing the requirements. A full listing would require far greater resources than are available for this project. The requirements that are listed below should be sufficient to demonstrate their format and scope and allow us to continue with a basic system design in the next section. Within the greater university system, the undergraduate Chemical Engineering program shall provide:

5.2.1 SOCIETY

- F.1.1 cultural and technical enhancement of society
- F.1.2 depositing of new knowledge etc., into knowledge repository

5.2.2 INDUSTRY

- F.2.1 education sufficient to bring entry level students to a level where they are capable of becoming employed as entry level Chemical Engineers
- F.2.2 access to education to update current professionals currently working in the Chemical Engineering field of practice

5.2.3 STUDENTS

- F.3.1 collect, organize, structure, and transfer to the students:
 - 1 discipline specific tangible knowledge
 - 2 background tangible knowledge
 - 3 intangible knowledge
 - 4 discipline specific skills
 - 5 discipline specific tools
 - 6 process, design, etc., understandingincluding all the topics under each of these headings listed in Appendix C
- F.3.2 alternative specialization courses & sequences useful in ChE practice today and in the future
- F.3.3 knowledge about and experience with the teaching of technical subject to peers, supervisors, and less experienced technical and non-technical persons
- F.3.4 social environment such as listed in requirement F.1.2 above

5.2.4 GOVERNMENT

5.2.5 STUDENT INTERFACE

- F.5.1 methods of knowledge, etc., transfer that are as efficient as reasonably cost and implementation feasible (Ie. look for other methods that the traditional lecture, lab, problem set, etc.)
- F.5.2 full system life cycle support from application to graduation and job or graduate offer acceptance
- F.5.3 learning and a mentality growth which is practically balanced between problem analysis, formulation, solution and implementation

5.2.6 OPERATOR INTERFACE

- F.6.1 relatively constant set of functions to be performed
- F.6.2 complete set of integrated support functions for the operation and development of the program

5.2.7 MAINTENANCE PERSONNEL INTERFACE

- F.7.1 relatively constant set of functions to be performed
- F.7.2 feedback loops from each user, customer and interface

5.2.8 KNOWLEDGE REPOSITORY INTERFACE

- F.8.1 depositing of new knowledge etc., into knowledge repository
- F.8.2 accessible facilities for the storage and retrieval of technical, social, environmental, cultural, and historical knowledge sufficient to fulfill the research and study needs of the students and the instructors

5.2.9 INSTITUTION FOR HIGHER LEARNING INTERFACE

- F.9.1 administrative functions to integrate this program into the school of engineering

5.2.10 INSTITUTION FOR RESEARCH INTERFACE

- F.10.1 advances in science, technology, and applications so as to enable the graduating students to solve the current problems of industry
- F.10.2 research which will further the science and practice of Chemical Engineering

5.2.11 ENVIRONMENT FOR SOCIAL GROWTH INTERFACE

F.11.1 proper and sufficient environment for:

- 1 positive personal social and emotional development
- 2 instilling of enthusiasm
- 3 maintaining high morale
- 4 instillation of high moral consideration of social, environmental, safety, and economic concerns
- 5 provision of appropriate role models for engineering students
- 6 isolation of the university from the occurrence of temporary detrimental social fluctuations (political, religious, etc.)

5.2.12 PROVIDER OF SUPPORT TO THE SYSTEM INTERFACE

F.12.1 sufficient support facilities, organizations, tools, techniques, etc., necessary to fulfill all reasonable needs

5.3 PERFORMANCE REQUIREMENTS

5.3.1 SOCIETY

P.1.1 quick, effective, efficient, and durable services

P.1.2 no portion of the university should be biased or influenced by politics, religion, etc.

5.3.2 INDUSTRY

P.2.1 sufficient levels and complexity of knowledge, etc., to be useful as entry level engineers

P.2.2 sufficient numbers of graduates to satiate industry's needs

P.2.3 sufficient graduates with sufficient knowledge, interest, etc., in specialty subjects needed by industry

P.2.4 opportunity for current practicing Chemical Engineers to gain periodic refresher and new knowledge, that is, continuing education

5.3.3 STUDENTS

P.3.1 comprehensive coverage of basic scientific knowledge

P.3.2 ability to choose and receive social studies, languages, etc., to round out education

P.3.3 Chemical Engineering education better than that offered at almost all other schools

P.3.4 complete and successful coverage of all topics listed in Appendix C

P.3.5 large retention times for technical material learned

P.3.6 encourages and stimulates (not to restrain) creative, imaginative, and innovative thinking

P.3.7 most effective teaching methods available

P.3.8 integrated outlook toward project development and industry technology application

- P.3.9 optimized breadth and depth of all subjects
- P.3.10 balanced emphasis between the learning of how to solve problems, how to analyze problems, and how to formulate problems
- P.3.11 option between the choosing of a basic program, or several currently active specialization programs, or a program that is customized for and by the individual student (supervised)
- P.3.12 all material and specializations must remain relevant to current and future potential employment areas.
- P.3.13 the feedback loops of the system must quickly adapt and optimize the system to any rapid changes in technology, corporate needs, size and complexity of normal commercial projects, and society emphasis
- P.3.14 minimum of material repetition
- P.3.15 minimum of irrelevant material
- P.3.16 current study materials (books, etc.)
- P.3.17 8 semester program unless additional funding available
- P.3.18 one large break per year to allow for acquisition of funds
- P.3.19 create and maintain enthusiasm within the students
- P.3.20 create and maintain a feeling of worth in the student
- P.3.21 understand and build the dynamics and procedures of the courses around the students' capabilities to learn, forget, etc.
- P.3.22 understand and emphasize the mechanisms which cause "instant learning" (permanent), and the transference of short-term memory to long-term
- P.3.23 an understanding and natural tendency to think of markets, economies, competition and all other such factors on a global scale, instead of the domestic scale currently emphasized

5.4 LOGISTICS REQUIREMENTS

5.4.1 SOCIETY

5.4.2 INDUSTRY

- L.2.1 low support of experienced personnel for consultants or visiting instructors
- L.2.2 donation of used and/or out of date equipment only
- L.2.3 willing to offer limited number of co-op positions
- L.2.4 willing to offer limited number of scholarships
- L.2.5 willing to subsidize instructors for valuable research results

5.4.3 STUDENTS

- L.3.1 required levels of student funding (tuition) which do not increase more than the students' capabilities to earn (salary inflation)
- L.3.2 adjusted tuition levels that are no higher than \$1,200 per semester for in state students and \$3,600 per semester for out of state students (these Fall 1991 rates [UMD 1991] are already beyond a good fraction of those desiring to attend undergraduate education)
- L.3.3 access to 24-hour convenient, comfortable, and functional study, computing, and meeting places for socialization, team work, problem set conferencing, etc.

This concludes the partial listing of the first iteration of the functional, performance, and logistical requirements for this educational system. We will now continue with a partial listing of constraints for this project.

5.5 CONSTRAINTS TO THE SYSTEM

There are constraints to every system. These constraints are needed for the tradeoffs necessary to allocate a finite number of resources, tolerances, etc., to a set of infinite desires or "needs". Only a few of the system constraints will be listed here as we will only need a few for our level of system design and many of these constraints are usually not known until the quantitative specifications for the system are being developed.

5.5.1 DEVELOPMENT CONSTRAINTS

- C.1 In Section 2.3 we determined that the faculty of the Chemical Engineering Department would be the best choice as the developers for the implementable system. This puts obvious constraints on its development due to the simply limited amount of time of these workers. While this may seem to put a seriously large constraint on the development, Section 8.1.4 will show us how to increase the base value of this constraint.
- C.2 Again, with the faculty being the developers for the system, this limits the areas that can be constructed to those within the expertise of the faculty. Again, Section 8.1.4 will help us keep this constraint from becoming criteria.
- C.3 A simple constraint to the generation of many of the requirements for this program is that these faculty are not qualified to determine many of the requirements of the students. This means that the students will need to be surveyed.

5.5.2 SYSTEM CONSTRAINTS

- C.4 A simple and obvious constraint on the system is that there is only a limited amount of funding which can go toward the development, installation, operation, and maintenance of this program.
- C.5 Likewise, there is a limited amount of facility and building space within which the program may operate.
- C.6 There is a limited amount of support in the form of co-op opportunities, etc., that industry can provide.
- C.7 There is a limited amount of personnel and hours that industry persons can be obtained to help teach or maintain the contents of the program.
- C.8 There are a limited number of computers, processing power, and programming capability for the introduction of computers to the program and for the development of computer based tools for the students and instructors.

It is recognized that some of these requirements and/or constraints may be conflicting or unresolvable. This is acceptable. The program to be developed is developed with today's requirements and is limited to today's capabilities. These currently unobtainable objectives are another reason this process should be recycled on this system again in the future. We now continue on to the design phase of the this project.

CHAPTER 6

DETERMINATION OF LEARNING METHOD(S)

DESIGN SECTIONS ORGANIZATION

This phase begins the addressing of the requirements with the initial design of the system. Figure 6.1 shows a one level functional breakdown of the current and still desired overall University system. This figure reminds us that the

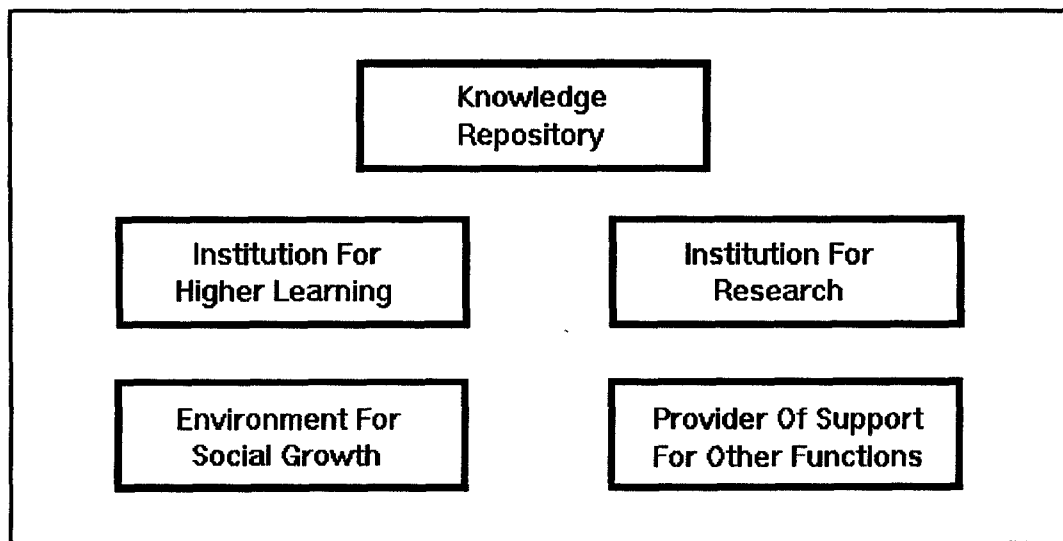


Figure 6.1 Functional Analysis Of University System

university performs five basic functions that will be overlapped by our integrated system.

Design of this system will proceed as follows. As most of the design work will take place within the subsystem of the Institution for Higher Learning, we will separate out this section as a 'learning function' and lump the remaining

areas into a 'support function'. As this learning function is the most analytical and straightforward, it will be addressed first. This design will begin in Section 6 with a determination of the high level learning method or methods to be used by the program. Section 6 will then show how the tangible knowledge topics found in Appendix C can be organized and sequenced in a manner suitable for the learning method(s) determined in Section 7. Proceeding from this, Section 8 will deal with both the lower level teaching methods and the support functions, as these two often interact. This project will stop at this level of design, although concerns that should be considered in the continued design will be discussed. We thus move off to the determination of a learning method.

6 DETERMINATION OF LEARNING METHOD(S)

The determination of the high level method or methods of learning to be utilized in the undergraduate Chemical Engineering program is a two step sequence. Section 6.1 will list and discuss the possible learning methods and Section 6.2 will perform a tradeoff analysis to determine which learning method(s) would be best to use.

6.1 THE HIGH LEVEL METHODS

The first step in this procedure is to accumulate a complete and up-to-date list of applicable teaching methods. Table 6.1 lists five categories of possible high

level learning methods that were collected from widespread research.

- | |
|---|
| <ol style="list-style-type: none">1. Traditional Approach (Current Method)2. Coordinated Totally Integrated Program3. Learning By Experience4. Generic Engineering Base With A ChE Specialty5. Hybrid Systems |
|---|

Table 6.1 Categories Of Possible Teaching Methods

In order to familiarize us with each of the methods, they are subsequently further conceptually described and their merits and faults discussed.

6.1.1 TRADITIONAL APPROACH

The traditional and current approach is a system that is based upon unit operations. This system breaks the ChE knowledge space into a collection of equipment type "units" that can then be utilized in a module format to construct chemical processing systems. Some additional basic theory is given as background and helps to smooth the transition from one unit to another, but each course is proffered as a separate area of physical science with little attention paid to unifying any of the theory. This system is currently not able to produce Chemical Engineers with enough breadth of applicability to succeed in many of today's expanded Chemical Engineering employment alternatives. Further, this method often overwhelms and confuses the student with a vast volume of seemingly different technologies that are in reality, only separate applications of a small set of basic principles.

6.1.2 COORDINATED TOTALLY INTEGRATED PROCESS

Examples of this type of program would include:

- a single, program-long, closely monitored and administered project
- a similar project for each semester or year of the program
- a program which integrated all the classes for each semester together into one day long class, possibly with an integrated lab
- a comprehensive, mentored class, group or individual program of problems to be serially solved (perpetual problem sets)
- combination(s) of any of the above

Although many people will argue that this type of process would result in the best, most intense, most lasting and strongest education, both the amount of work required to setup such an immersion program and the overhead requirements to run, maintain and update such a program (including the high quantity and quality personal attention it requires) are too great to be implemented with the logistical capabilities of today's university environment. As the opportunities of Computer Based Training (CBT) become more common and comprehensive, this option should be reevaluated. This type of program does, however, offer many excellent opportunities for individually and/or self-paced learning.

6.1.3 LEARN BY EXPERIENCE

This older method of teaching involves learning on the job or via the more

modern method of co-oping. While a program based solely on this method would result in a very relevant education, this process does not allow the student the expert teaching advantages of full-time devoted and professional educators. Learning in such a practical form would also most likely be uneven and application specific, thus making reapplication to other areas very difficult. This application specificity could, however, be highly reduced with a carefully managed program of variation of the co-op, etc. Finally, this system does not condone itself to the university environment. Other benefits of such a program would include resume experience and company contacts and job leads.

6.1.4 GENERIC ENGINEERING WITH A ChE SPECIALTY

Generic engineering with a Chemical Engineering specialty tacked on would result in a broadly applicable knowledge base. However, in order to provide sufficient specialty knowledge either a second degree or a program of 5 to 6 years in duration would be required. The alternate proposal of giving students a more generic Systems Engineering undergraduate education followed by a Chemical Engineering Masters education has not been fully explored. Nevertheless, it is expected that this program would not work well as undergraduate students usually have insufficient maturity and scientific and engineering experience to comprehend the concepts of System's Engineering. This process would also take a minimum of 6 years to complete.

6.1.5 HYBRID SYSTEMS

Though seldom the simplest method, hybrid systems often result in the most applicable, efficient, and synergistic solution to a given complex set of problem requirements and constraints. There are many types and combinations of hybrid systems that could be used for our purposes. Some of the better ones include (See Table 6.1 for standard types 1 to 4):

- H1. Combination of #2 and #4:**
(Coordinated Totally Integrated Program and Generic Engineering Base With A ChE Specialty) One possible organizational format for the coordinated program is that of integrating a phenomenologically based basic principle theory perspective with discipline specific applications and procedures similar to that shown in Figure 5.2. The basic principles education could then be used to teach a generic engineering background and the applications and procedures could be used to teach the Chemical Engineering discipline as a specialty. This program would result in a broad engineering understanding with a greater depth of emphasis in ChE.
- H2. Combination of #1 and #3:**
(Traditional Approach and Learning By Experience) Utilizing the traditional approach as the organizational base for the program and adding Full Team Teaching by the inclusion of temporary instructors from industry creates another beneficial hybrid system. This program benefits from the well developed current structure but adds the benefits to be gained from the co-teaching of currently practicing Chemical Engineers. This education would be highly practical in its areas of emphasis and yet very similar to the current program.
- H3. Combination of #1 and #2:**
(Traditional Approach and Coordinated Totally Integrated Program) The combination of the traditional approach with a single, real life, program-long example problem is a valid hybrid combination. While this can be taken to the extreme of the development of a coordinated total system, a balance tilted more toward the current approach would be much easier to design and run. In this hybrid system, a coordinated and integrated set of successive problems could be used as both examples and homework to result in a practical education. This would lend itself to a clearer view of how the separate topics are to be used as well as a developing view of the total Chemical engineering discipline application.

The benefits and drawbacks of these hybrid systems will not be elaborated here due to time and space constraints. They will, however, be somewhat

detailed in the process of tradeoff, our next section.

6.2 TRADEOFF OF THE METHODS

A tradeoff study can be performed at any of a large number of levels of detail. The choice of the high level learning method(s) to use is a very important one. As such, a moderately complex form, a weighted criterion tradeoff, will be performed.

6.2.1 CRITERIA

The criteria to be used in this evaluation will attempt to reflect the major requirements and constraints that apply to these learning methods. These criteria will be limited to a single level of complexity and all of them refer to the evaluation of a program that is based on the methods above. In no particular order, these criteria are:

- duration of program
- difficulty of development
- ability to create student enthusiasm
- difficulty to run program, including logistics
- competency of resulting broad base education
- competency of resulting deep specialty education
- interdisciplinary application of program
- level at which program emphasizes the linking of separate concepts into a single field of scientific application
- capability to allow specialization and/or customization
- opportunity for program to incorporate refresher course students
- balanced emphasis between problem analysis, formulation, and solving

As these criteria are relatively self-explanatory, they will not be further clarified.

6.2.2 RANKING AND WEIGHING OF THE CRITERIA

The next step is to order and rank these criteria. Table 6.2 shows the decreasing order of the criteria's perceived importance, their ranking versus the most important criteria, and their determined weighing so that the total weight is equal to 100. The ranking was performed by a sort which determined which criteria was more harmful in a worst case scenario.

Criteria No.	Criteria Name	Relative Weight	Weighing Factor
1	Deep Specialty	1.00	0.253
2	Broad Base	0.80	0.203
3	Interdisciplinary	0.70	0.177
4	Duration	0.40	0.101
5	Create Enthusiasm	0.30	0.076
6	Specialization	0.20	0.051
7	Balanced	0.15	0.038
8	Concept Linkage	0.13	0.033
9	Difficulty To Run	0.10	0.025
10	Difficulty To Develop	0.09	0.023
11	Refresher Course	0.08	0.020

Table 6.2 Sorted and Weighted Criteria

As most of the evaluations for the criterion's value for each method were subjective, the scoring function listed in Table 6.3 was used. The scoring function for this tradeoff was taken as linear: that is, it assumed equal value distance between subjective evaluation values. (A more complex tradeoff would fit a curve to the perceived and most likely uneven distances between the criterion's values and find numeric values from this curve.)

Rating Value	Abrev.	Score
Perfect	Perf	1.0
Excellent	E	0.8
Good	G	0.6
Fair	F	0.4
Poor	P	0.2
Not Acceptable	N/A	0.0

Table 6.3 Criteria Values

6.2.3 TRADEOFF MATRIX

At this point, we are able to fill the criterion's values into our tradeoff matrix. The resulting matrix is shown in Table 6.4 and the results are summarized in Table 6.5.

Criteria No.	Name	Relative Weight	Weighing Factor	1. Traditional Value Score WScore	2. Coordinated Value Score WScore	3. Experience Value Score WScore	4. Base & Specialty Value Score WScore
1	Deep Specialty	1.00	0.253	E 0.8 0.202	Perf 1.0 0.253	Perf 1.0 0.253	E 0.8 0.202
2	Broad Base	0.80	0.203	F 0.4 0.081	E 0.8 0.162	F 0.2 0.040	Perf 1.0 0.202
3	Interdisciplinary	0.70	0.177	F 0.4 0.070	E 0.8 0.141	F 0.2 0.035	Perf 1.0 0.177
4	Duration	0.40	0.101	Perf 1.0 0.101	Perf 1.0 0.101	G 0.6 0.060	N/A 0.0 0.000
5	Create Enthusiasm	0.30	0.076	P 0.2 0.015	E 0.8 0.060	G 0.6 0.045	G 0.6 0.045
6	Specialization	0.20	0.051	E 0.8 0.040	F 0.4 0.020	F 0.2 0.010	E 0.8 0.040
7	Balanced	0.15	0.038	P 0.2 0.007	G 0.6 0.022	P 0.2 0.007	E 0.8 0.030
8	Concept Linkage	0.13	0.033	F 0.4 0.013	Perf 1.0 0.032	G 0.6 0.019	E 0.8 0.026
9	Difficulty To Run	0.10	0.025	Perf 1.0 0.025	P 0.2 0.005	F 0.4 0.010	E 0.8 0.020
10	Difculty To Develop	0.09	0.023	Perf 1.0 0.022	P 0.2 0.004	F 0.4 0.009	F 0.4 0.009
11	Refresher Course	0.08	0.020	P 0.2 0.004	F 0.4 0.008	N/A 0.0 0.000	P 0.2 0.004
Totals		3.95	1.000	0.584	0.813	0.492	0.758
Ranking				6	2	7	4

Criteria No.	Name	Relative Weight	Weighing Factor	5. H1: #2 & #4 Value Score WScore	6. H2: #1 & #3 Value Score WScore	7. H3: #1 & #2 Value Score WScore
1	Deep Specialty	1.00	0.253	Perf 1.0 0.253	Perf 1.0 0.253	E 0.6 0.151
2	Broad Base	0.80	0.203	Perf 1.0 0.202	G 0.6 0.121	F 0.4 0.081
3	Interdisciplinary	0.70	0.177	Perf 1.0 0.177	F 0.4 0.070	F 0.4 0.070
4	Duration	0.40	0.101	Perf 1.0 0.101	Perf 1.0 0.101	Perf 1.0 0.101
5	Create Enthusiasm	0.30	0.076	E 0.8 0.060	E 0.8 0.060	E 0.8 0.060
6	Specialization	0.20	0.051	E 0.8 0.040	E 0.8 0.040	G 0.6 0.030
7	Balanced	0.15	0.038	E 0.8 0.030	Perf 1.0 0.037	E 0.8 0.030
8	Concept Linkage	0.13	0.033	Perf 1.0 0.032	Perf 1.0 0.032	E 0.8 0.026
9	Difficulty To Run	0.10	0.025	G 0.6 0.015	F 0.4 0.010	E 0.8 0.020
10	Difculty To Develop	0.09	0.023	N/A 0.0 0.000	G 0.6 0.013	E 0.8 0.018
11	Refresher Course	0.08	0.020	F 0.4 0.008	Perf 1.0 0.020	N/A 0.0 0.000
Totals		3.95	1.000	0.922	0.763	0.591
Ranking				1	3	5

Table 6.4 High Level Learning Method Tradeoff Matrix

#	Method	Rank	Score
5.	H1: #2 & #4 (phenomenological)	1	0.922
2.	Coordinated	2	0.817
6.	H2: #1 & #3 (team teaching)	3	0.763
4.	Base & Specialty	4	0.758
7.	H3: #1 & #2 (1 large project)	5	0.591
1.	Traditional	6	0.584
3.	Experience	7	0.492

Table 6.5 Results of Method Tradeoff

6.2.4 CONCLUSION

From these results we can see that both the first hybrid method and the coordinated approach yield very good tradeoff results. However, both of these methods are very difficult to develop and do not offer good opportunities for integrated refresher courses. As the second best method does not give any major improvement to the flaws of the best scoring method, a single method will be chosen. Development of this method will be expected to take a long time and most likely will continue well into the transition period. Some alternate function and method will need to be found to allow for the fulfillment of the requirement of continuing education. We now move on to the next section and develop courses and a course sequence for a program that will begin with the current traditional approach and then transform into a hybrid, phenomenologically based one.

CHAPTER 7

DEVELOPMENT OF COURSE SEQUENCE

Section 6 determined that a hybrid system utilizing a combination of a program-long coordinated base of learning phenomenological principles and their application to a specialization of Chemical Engineering discipline knowledge, applications, and methods would yield the best higher order learning method for the undergraduate program. This method needs the program-wide integration of a progression of theoretical basic principles and the linked specialization material. Because these principles have never before been separated from the general knowledge space, it is very difficult to design a program for this method. Because of this, the proposed method of this system's design is for the new method to be transformed out of a traditional type program over a period of time. This transformation would begin with the identification of the basic phenomena (theoretical principles), applications and procedures in each course. This set of data would then be combined in a suitable manner into a structure functioning as that shown in Figure 5.2. From this point, the classes could be reorganized to form a more integrated and coordinated set of courses. These courses would utilize a progression of these phenomenological principles to give the students:

- a broad scientific understanding of why things occur as they do
- a deep Chemical Engineering discipline specialization knowledge of which of these principles can be applied where
- the related how procedures of these applications.

See Appendix B for further information on the why, what and where, and how dimensions on the knowledge space.

It should be noted that the more obvious approach for developing such a program--that of determining a listing of the principles, applications, procedures and desired level of depth from which a program could be constructed--was attempted during the dimensional analysis of the overall knowledge space. However, the determination of the hierarchy of the principles, etc., turned out to appear to be an almost impossible task. This was due to the size of the knowledge space and the very dense and complex nature in which the lower level principles, etc., combined to form higher level ones. It was thus determined that this process would only be possible with smaller knowledge spaces or a highly coordinated, repetitious and iterative group project. This method is thus not suggested here.

Now that a higher level learning method and its design method have been determined, we can begin to design the learning function. This phase begins that design by first organizing the tangible knowledge lists of Appendix C into courses and then determining an hierarchial course sequence that will become our undergraduate Chemical Engineering program.

7.1 DETERMINATION OF COURSES

In this section, the state space knowledge representation, the requirements and constraints of Sections 4 and 5, and the tangible knowledge lists of Appendix C are considered, and a collection of courses that will eventually make up the education program is determined. The current Chemical Engineering courses at the University of Maryland cannot be used for this because the listing in Appendix C is an expanded list which contains many topics which are not taught in the current program.

7.1.1 SEPARATION OF TANGIBLE DISCIPLINE AND TANGIBLE SUPPORT TOPICS INTO COURSE UNITS

After carefully reviewing a total list of both the tangible discipline specific topics and the tangible support topics, minimal (required) topics and exposure levels for each were determined. To preserve the current length of the ChE program, those required and other topics were then combined so that they formed a number of courses that had a credit total very near to 41, which equals the current total of 53 minus 12 credits of engineering electives. The remaining extra topics were preserved and would be converted into more topic extensive engineering elective courses that would be substituted for the required credits. Table 7.1 shows a listing of what topics would be combined into courses and what required and elective credit levels these courses could be taken at. This table uses alphabetical order as no sequencing can yet be determined.

CREDITS		TOPICS
REQD	ELECTIVE	
3		Analysis and understanding of ChE Systems
3	6	Computers: usage and programming
6		Design and Economics
3		Kinetics and reactor design
6	9	Laboratory
1	3	Maintenance
1	3/6	Materials
3	6*	Mathematics
1	3	Optimization
1	3	Process control
1	3	Safety
1	3	Surface and colloid science
3	7	Thermodynamics
6	9	Transport processes
1		Other topics
3	12**	Computer and software engineering
		Civil engineering
		Electrical engineering
		Mechanical engineering

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Table 7.1 First Iteration Of ChE Required And Elective Courses

* Three of these credits will go toward replacing the advanced engineering math course (currently Applied Mathematics In ChE, ENCH 453) usually taken after the differential equations class at most institutions.

**This knowledge would be extremely useful to any student determining to go on to Systems Engineering or many other programs at a graduate level. Thus, this student would be wise to instead substitute a well chosen introductory course from each of the respective programs in place of this course.

7.1.2 ITERATION 2: OPTIMIZE COURSE TOPICS

While this listing meets the required needs for a Chemical Engineering education, it is far from desired levels. In specific, it is felt that it would be better to have:

- 6 credits of computer usage and programming instead of 3 required and 3 optional
- 7 credits of design instead of 6 (extra space for the design project)
- 4 required credits for thermodynamics instead of 3
- 8 required credits for transport instead of 6

Thus, we would like to see if we can enlarge the allowed credits expended on Chemical Engineering courses by 7 credits. This can be attempted by performing a second iteration of this section but enlarging its scope to include the background tangible knowledge.

Addition Of Background Tangible Knowledge

Appendix C and Table 7.2 list the background tangible knowledge required for the students of the current program in the form of the current courses.

Chem 103, 113:	General Chemistry I&L, II&L	(4,4)
Chem 233, 243:	Organic Chemistry I&L, II&L	(4,4)
Chem 481, 482, 483:	Physical Chemistry I, II, L	(3,3,2)
Phys 161, 262, 263:	General Physics I, II&L, III&L	(3,4,4)
Math 140, 141, 241:	Calculus I, II, III	(4,4,4)
MATH 246:	Differntl Eqns. for Sci & Eng	(3)
ENCH 453:	Applied Mathematics In ChE	(3)
ENES 101:	Intro Eng Science	(3)
ENES 110:	Statistics	(3)
ENGL 101:	Introduction to writing	(3)
Total		62

Table 7.2 Background Tangible Knowledge

While this credit total is higher than that of the required and elective Chemical Engineering classes, we must remember that a solid basic science foundation is absolutely necessary if a student is to be properly prepared for the ChE classes and later productive work in the ever expanding use of ChE's in industry. Thus, we are faced with a dilemma: we do not wish to decrease any of this learning, but need to free up 7 more credits.

Before resorting to a tradeoff to eliminate the least useful topics, we can

first try to see if any of these topics can be compressed. Our first step is to try to reduce any overlap of material or inefficiency. At first glance, this is not possible. Upon further inspection, however, new technology may aid our cause. If 3 of these freed up credits will be spent to teach the students how to use computers to do such things as symbolic manipulation (egs. Mathcad and Mathematica) and help them make their problem sets easier and faster to correct (eg. Mathcad: see Appendix G, TK Solver), students can use these tools to decrease their problem solving time and thus increase the intensity and thus efficiency of their learning. Thus, giving the students this capability before they have certain classes can speed up their learning and even, with proper predeveloped computer forms, increase both the depth and number of topics addressed. This assumption, of course, should be tested.

Thus, if students immediately take 6 credits of computer usage and programming classes their Freshman year, they can most probably then complete a special sequence of (4,4) credit physics in their Sophomore year. This special sequence would become even more possible if this sequence would eliminate topic overlap, such as introduction to thermodynamics, which would be covered again soon or concurrently in other courses. Likewise, the third semester of Calculus could probably be eliminated in favor of:

- beginning to utilize computer technology in the first or second semester of calculus, thus making more room for calculus III topics in these classes
- shifting complex calculus topics to a computerized and thus compressed Advanced Mathematics In ChE course (should be taken

- directly after differential equations)
- eliminating calculus topics currently useless to engineers (eg. using calculus to numerically determine square, cubed, etc., roots of integers, which most scientific calculators excel at)
- creating special calculus I and II sections for engineers who, overall, will be more able to handle calculus at a faster pace than the average calculus student

The deletion of useless topics and the shifting of the remaining calculus III topics to calculus I, II, and Advanced Math classes would free up the remaining needed 4 credits. As calculus courses continue to become more popular in high schools, more students will already have a semester equivalence of calculus and thus make this less of a high-paced learning area for students.

In addition, other course modifications can be made in this section to improve its applicability to undergraduate Chemical Engineers. First, the "Introduction to Writing" course can better benefit students if it instead emphasizes and is titled "Introduction To Technical Writing". Second, the statistics course would be more useful if it also included probability. Third and lastly, the Physical Chemistry course sequence should be reevaluated to determine if it is overlapping any material that is or could be better included in other courses containing contextually related topics. This would again free up more available credits that could then be used to make room for the topics in other courses or for other new topics.

Thus, at the end of this iteration, we find that we have course topics as shown in Tables 7.3 and 7.4. Further optimization iterations would no doubt be

possible after further study or with feedback from this structure.

CREDITS	BACKGROUND COURSE TOPICS
4,4	General Chemistry I&L, II&L
4,4	Organic Chemistry I&L, II&L
3,3,2	Physical Chemistry I, II, Lab
4,4	Physics For Engineers I&L, II&L
4,4	Calculus For Engineers I, II
3	Differential Equations For Engineers
3	Applied Mathematics In ChE
3	Introduction To Engineering Science
3	Practical Statistics and Probability
3	Introduction To Technical Writing

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Table 7.3 Second Iteration Of Background Knowledge Courses

CREDITS REQD ELECTIVE	ChE REQUIRED AND ELECTIVE COURSE TOPICS
3	Analysis And Understanding Of ChE Systems
3,3	Computer Usage And Programming I & II
3	Design & Econ Of ChE Equipment & Processes
4	Design & Econ Of ChE Processes & Plants
3	Kinetics And Reactor Design
3,3	ChE Laboratory I & II
1	3 Maintenance Of Chemical Systems And Plants
1	3/6 Engendering Materials
3	Mathematics
1	3 Optimization
1	3 Process control
1	3 Safety
1	3 Surface And Colloid Science
4	7 Thermodynamics
4,4	11 Transport Processes I & II
1	Other Topics
3	12 Basics Of Civil, Computer, Electrical, Mechanical And Software Engineering

50	

Table 7.4 Second Iteration Of ChE Required And Elective Courses

7.1.3 SPECIALIZATION: OTHER ENGINEERING ELECTIVE COURSES

In addition to the substitution engineering elective courses listed in Table 7.4, we can preserve the current engineering electives shown in Table 7.5.

CREDITS	ELECTIVE TOPIC
3	Biochemical Engineering (ENCH 482)
1	Research (ENCH 468)(Take with ENCH 482)
2	Biochemical Engineering Lab (ENCH 485)
3	Introduction To Polymer Science (ENCH 490)
3	Applied Physical Chem Of Polymers (ENCH 492)
3	Polymer Technology Laboratory (ENCH 494)
3	Chemical Process Development (ENCH 450)
3	Advanced ChE Analysis (ENCH 452)
3	Applied Mathematics In ChE (ENCH 453)
3	Chemical Process Analysis & Optimization (ENCH 454)

Table 7.5 Specialization Elective Courses

7.2 DETERMINATION OF COURSE SEQUENCE

The next step in this phase is to organize these courses into a sequenced program. Again, this is not a simple step. To build a sequence for these courses, they must first have their prerequisites determined. After this, there is the task of fitting all of these courses into a workable order in only 8 semesters. Human Factors Engineers, who specialize in the development of training programs [Baker 1990], have found that the easiest way to accomplish this is to begin with the specification of the goal state and then chain backwards using the requirements (prerequisites) for a particular level to determine the precursory level of topics. This method also eliminates the need to determine prerequisites for each course before some type of logical structure is available. It turns out that the availability of this structure greatly aids the understanding of the minimum of prerequisites, thus eliminating superfluous prerequisites, which would make a solution sequence logically impossible.

The design of such a sequence would be a simple matter if we had a single set of courses. Our task is much more difficult, however, because our course sequence must allow for both the opportunity of permutations to include specialization sequences and the user selection of random, high level electives.

It has been found that if these permutations are ignored, backward chaining results in a program that is shorter than it needs to be and is too dense to allow the easy insertion of additional classes. Going back to a purely forward chaining development of the program results in a frustratingly highly cyclic synthesis that eventually leads to a program which starts off logically, but then becomes lost in a difficult to solve logic puzzle.

For this reason, a hybrid approach was attempted and quickly resulted in the course structure listed in Figure 7.1. This hybrid uses the obvious logical sequence of background course topics for the early semesters, and then it filled in the rest of the sequence working backward from the goal state. The biggest benefit of using this method was that after the first 3 semesters were determined the remaining number of semesters was small enough to make it relatively easy to balance both the course density and the necessary prerequisites while backward chaining. This backward chaining was performed with only the minimum courses, to which space for elective courses was added as a third and last step.

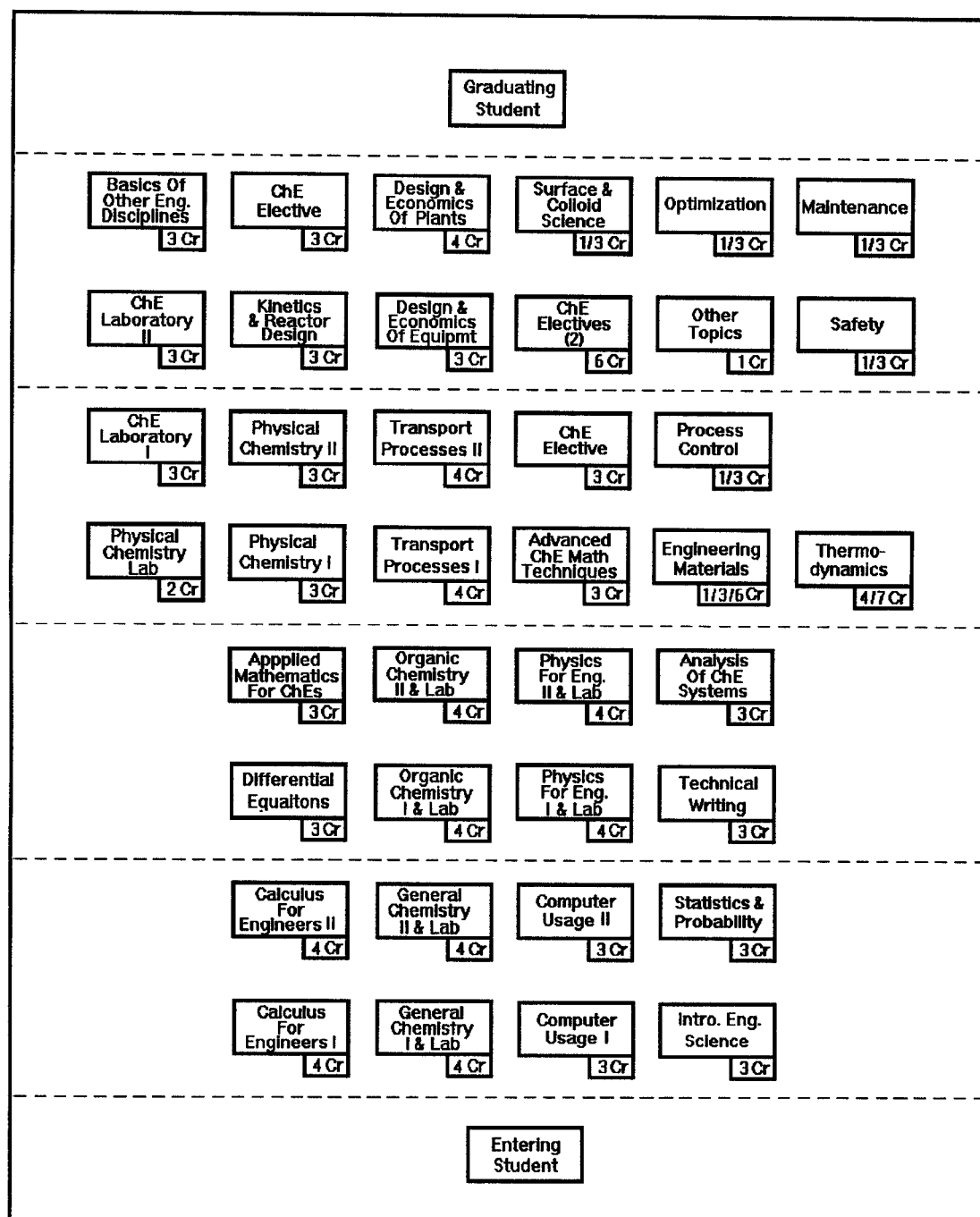


Figure 7.1 Course Sequence

The resulting system also allows a maximum of course selection flexibility for the student. Many of the later non-core courses allow the student to take only a one credit survey of the topic or a full three credit version. Furthermore, the ambitious student can take the extended version of these classes in a different

semester by using an elective. Taking the courses in another order should also be allowed as long as the sequence is closely scrutinized and approved by the student's adviser.

We have thus successfully converted the tangible knowledge topics into courses and a four year course sequence that maintains the requirements and constraints of Section 5. A listing equivalent of the courses and their sequence as shown in Figure 7.1 can be found in Appendix D.

CHAPTER 8

TEACHING METHODS & SUPPORT FUNCTIONS

This section collects all the remaining design topics and considerations that will be developed in this document. As the chapter title suggests, the two major categories of these topics are the determination and development of low level teaching methods and any functions that can be used to support either the program or the users. This chapter will conclude with a final section which comments on further work, methods, and concerns pertaining to any design completion, implementation, and operation of this education program.

It should be noted that this section is not intended to be complete in terms of the remainder of topics that should be addressed before attempting to implement such a program.

8.1 DEVELOPMENT AND CONCERNS OF LOW LEVEL TEACHING METHODS

In this design project, 'low level teaching methods' pertain to teaching methods which are of sufficiently small application scope that they are to be used within single courses or even to present single or linked topics within a single

course. Many of these methods are direct design results of individual system requirements or needs.

While we already have an overall large scale learning method that will define the orientation and structuring of the information to be learned, there is still a great deal of room for the selection and development of suitable teaching methods which can be drawn upon to best teach individual tangible and intangible topics within each of the courses. For example, team projects as homework for a class may be selected to help the student learn the intangible issues of leadership, team spirit, task decomposition and delegation, weak link theory, peer politics, synergism within interdisciplinary groups, etc. All of this can be experienced and learned within the framework of the learning of basic principles and discipline specific applications and procedures. This type of integration of the student's learning is the entire point behind this undergraduate program's answers to an integrated multi-system education environment and an integrated and multi-system education knowledge space. It is believed that any equal length system that does not function in this manner will not be able to fulfill the basic requirements put on the graduates.

As this is a limited project, equal emphasis will not be given to each topic; topics with more potential or useful novelty will receive more attention than others. In addition, as would be expected from an integrated system, many of these teaching methods and support functions overlap in function and purpose.

8.1.1 ALTERNATIVE TEACHING METHODS

There are a myriad of different teaching methods that can advantageously be used for different topics, different effects, and to fulfill different system requirements. Each has its benefits and drawbacks for the teaching of different subjects. The knowledge of which method would be best for which subject and for what effect would be an extensive 2-dimensional matrix. We will not perform that job here but instead leave it for further study. A variety of methods and effects will instead be listed.

Teaching Methods:

- | | |
|------------------------------------|-----------------------------------|
| 1) Team teaching | 2) Team projects |
| 3) Projects | 4) Computer Based Training (CBT) |
| 5) Interdisciplinary group project | 6) Lecture |
| 7) Problem sets | 8) Lecture critique |
| 9) Seminar | 10) Field trips |
| 11) Co-op with professionals | 12) Mentor interaction |
| 13) Apprenticeship | 14) Internship |
| 15) Self-paced learning | 16) The "hard way" (sink or swim) |
| 17) Rediscovery method | 18) Laboratory |
| 19) Peer teaching | 20) Examination |

Controllable Effects:

- 1) Variation (alleviate boredom)
- 2) Constancy (student knows what to expect)
- 3) Gain initial interest
- 4) Regain interest amid a long haul
- 5) Novelty (new method can spark personal creativity, new ways of looking at something, etc.)
- 6) Widen sphere of interests
- 7) Build confidence
- 8) Build social experience, knowledge, contacts
- 9) Long-term knowledge retention
- 10) Incorporation of knowledge into personal abstractions and higher level principles.

In addition, several more modern teaching methods should be introduced. These methods are still being explored in various levels of sophistication, but seem to be beneficial even at more simple levels.

Instantaneous, non-volatile learning

This is often also called 'permanent learning'. This unusual learning form is characterized by very long retention times for very short learning times. A classic but simple example is learning that a stove is hot from a burn from a stove burner. It is felt by some that almost anything is learnable in this fashion if the right context exists for the particular individual to assimilate at necessary level. This context is often difficult to determine and usually varies somewhat from person to person and with topics.

Phenomenological Learning

This is very similar to the high level learning method decided in Section 6, but it is applied here on a single principle level. It has been found that most people cannot learn pure theory without first liking the theory to some memorable practical example. This method utilizes a four step approach that is designed to overcome this general problem:

- 1) Begin by giving a non-contrived example of a phenomenon to introduce a principle and hopefully spark curiosity or interest.
- 2) Move on to an analysis of the phenomenon and then into an analytical exploration of the underlying principle behind the phenomenon. This is intended to allow the fulfilling of the curiosity and generalize it to a principle.

- 3) Demonstrate the use of the principle in a variety of widely different applications to expand its range of application and to increase possibility of assimilation of the concept by linking it to a schema of the student's own interest.
- 4) This should soon be followed by allowing the student to utilize the principle in another application problem, possibly even of his own choosing.

Thus, in general, this process piques interest about how a specific event occurs, explores why the event occurs, generalizes it to a basic scientific principle, expands upon how, and then finally demonstrates when or where with other examples that hopefully allow the assimilation of the basic theory into long-term memory.

Multi-Channel Learning

The effectiveness of learning can be increased by increasing both the naturalness of the learning and the sum of the order of the channels (aural, visual, tactile, etc.) of its presentation. Although the specifics of this are still in research, "seeing" something has a higher order than "hearing", "doing" has a higher order than "seeing" and thus higher than "hearing", etc. This method proposes that the more forms the learning input is simultaneously coming from, and the higher total order of this input, the better the chance the student has for learning the material. A constraint of this is that the student must not be receiving too large a number of inputs so that he does not become overwhelmed or confused. Likewise, conflicting information on different channels can quickly lead to deep confusion and possibly anger and in extreme cases, probable mental blocks. This

can also be seen to be arising in a grass-roots format in the increasing popular usage of multi-media presentations.

8.1.2 INTANGIBLE KNOWLEDGE TEACHING

Intangible knowledge, such as that listed in Appendix C.3 cannot be taught in the same ways as tangible knowledge, yet it is often just as important as tangible knowledge. As was described in the section above, there are a variety of methods that can be used to teach this knowledge and for each topic, they have their own advantages and disadvantages. Again, we will not fully describe this information here but will instead list a few of the basic methods that can be used to teach these topics.

- 1) Team projects with:
 - students divided into departments of specialty and duty
 - rotating responsibilities or constant responsibilities depending upon specialties
 - periodic presentation of project status and results to the instructor and rest of the class
 - can be small teams, parallel teams, whole class as a team, etc.
- 2) Students are given the instructor's lecture notes and asked to critique them and their presentation
- 3) Students study the text materials and lecture handouts in cooperative learning groups assisted by the instructor. They then present the results of the learning process to the other groups of the class as a series of class talks.
- 4) Simulations in which students role-play particular real life scenarios. The other students can be given passive learning roles or can be allowed to critique afterwards.
- 5) Students can volunteer to teach "help sessions" to lower level students.

Help sessions are loosely structured optional classes that offer additional help, advice, hints, etc., for the solving of problems in their problem sets or to help students prepare for tests.

When well managed, these methods do aid in the learning of intangible knowledge. However, these methods also increase the difficulty of student evaluation because of the increased ability to hide lack of understanding. Many of these methods also increase time requirements for the instructor because of the need to gain a relatively deep acquaintance with each student. These factors must be weighed in the decision to use any of these methods. Likewise, these methods must be considered for compatibility and synergy when they are mixed with those methods used above.

8.1.3 COMPUTERS AND TEACHING

Computers have permeated nearly every facet of our workplaces and will continue to an even greater extent in the future. If nothing else, their use in education should prepare us for their use in our careers. They can, however, be used in the education process as well. The use of computers for teaching and training, often termed CBT for Computer Based Training, is becoming commonplace.

CBT Uses

A few possible uses for well developed CBT programs in our new

undergraduate Chemical Engineering program are:

- Can give the students application examples which they can manipulate themselves as much as they need to understand the relationships and trends involved
- Can give any student who needs it extra help or practice at his convenience
- Can allow resources for a student motivated in a particular subject to learn beyond that minimum given in class
- Can allow for student directed hypothesis testing with models and simulations without the costs, required effort and liabilities of actual systems (Eg. Blowing up a plant on computer is acceptable when compared to leveling the main ChE laboratory.)
- Instill high levels of interest and enthusiasm that can spark the incentive for extra learning. For example, blowing up a particular computer simulation of a complex chemical plant may become a game. This in turn may cause exploration of the various causes and much more complete and thorough understanding of what unsafe factors and limits are involved in a variety of dangerous industrial situations. A corollary or continuation of the game could even be added where the computer, by way of a software saboteur, causes unsafe conditions and it is then up to the student to investigate, alter, and save the given plant. (Learning through gaming is an entire major learning field by itself!)

In addition, computers could be very valuable as a tool for problem analysis, setup, and solving.

CBT System Formats

There are many possible formats for a CBT system or for the use of computers as tools. A few of these are:

- pc applications that come with each book, class, etc.
- computerized simulations for preparation or extension of laboratory applications
- computerized simulations for application demonstrations
- encompassing workstations which perform both roles as CBT and provide general and specialized tools for student use

- multimedia presentations, possibly even interactive, which teach a particular subject

There are, of course many other possible formats.

Benefits Of CBT

There are many benefits that can be gained from properly implemented

CBT. Some of these benefits include:

- can remove some of the confusion behind some of the currently difficult subjects by moving the complex mathematical or physical details behind the demonstration, keeping them from distracting the student from the subject which should be considered the main emphasis
- can help to keep teaching consistent.
- can keep the teaching of a subject at its best as CBT never becomes worse than its best version, and properly administrated with feedback, only improves with time
- can make learning easier by the utilization of direct manipulation to decrease the cognitive distance between the method of a subject's presentation and its use
- can teach with what will be the engineer's most useful tool in his/her actual career work: the integrated workstation.
- workstation can allow for better self-paced learning or extra-curricular browsing (especially for hypertext based systems) in areas of a student's personal interest
- can be introduced and optimized slowly and 'grown' to any desired level of breadth or complexity
- can even be developed and improved by the advanced projects of groups or individual students
- can allow the motivated student to get involved in a facet of the education process where he can define the scope of the work he wants to offer and can benefit from feeling useful and productive

This list could be extended for pages.

Dynamic Workstation Concepts

Lastly, an integrated CBT and tool for students could be developed into a workstation that could benefit the students, instructors, the university, and industry. Three basic concepts for this workstation are:

- the increasing benefit of the computer to the student in terms of problem analysis, setup, and solution
- the almost universal interest students gain for working with computers once they get their feet wet
- the desire for students to be able to learn their profession utilizing the same tools they can use in their careers.

The basic platform for such a workstation would contain a complete set of generic tools such as word processors, spread sheets, programming languages, graphics programs, mathematics and symbolic manipulation programs (egs. Mathcad, MATHEMATICA, MACSYMA), statistics, communications, etc. On top of this, a hierarchial level of CBT modules and their related databases could be established. Integrated throughout these levels, could be student derived tools for problem solving, etc.

The premise is to give each incoming student an up-to-date copy of this software. (Until every student has his own computer, access to such an equipped computer will have to suffice.) This student would also receive any improved, updated, or new software produced by any of the other students, instructors, or other sources as it comes out and would take all of this with him when he graduates and begins working. Eventually, students and others, in their desire for tools to fit their specific needs, will create a relatively complete and constantly

improving workstation which will be both very useful to them as students and as professionals. The inclusion of integrated CBT modules will allow professionals to review material learned in the past as they need refreshing.

Another benefit of this type of dynamic system is that preceding students and possibly others will want to continue to receive updates to the software. This will create an external need for a product that can easily be supplied by the university. Thus, a natural supplement for income to the program is born.

There are a large number of other concerns that must be addressed in such a system. As such, this type of system lends itself to further study in other masters and doctoral projects. A small development of these concerns can be found in Appendix F.

Thus, CBT and computers as tools for the students and others are potentially useful for our education program. It offers a variety of benefits and can be implemented with a minimum of costs by utilizing the programming and ideas of students and instructors to design, implement and improve and update a system over a period of time.

8.1.4 TEACHING WITH A DEVELOPMENT PROCESS

While many experts have stated that the disposition of the students can be improved with actions that allow students to become more involved in the teaching process, none have mentioned making them part of the course development process. This is unfortunate as this could be beneficial both to the program and to the students. This teaching method proposes to use the learning capabilities, interest, creativity, and understanding of students to simultaneously educate the students and develop a new or update an old course. While this process will most likely work best with upper level students, it may work with others as well. In addition, courses that do not have a large and constant number of topics which must all be covered will be better candidates for the utilization of this process. Lastly, to be fair to the students, the initial semesters of this method should only be utilized in elective courses and students should be notified of the method before they sign up for the course.

The main format of this type of class is student research and reporting. For example, we will take the development of a new class entitled Chemical Process Safety. From Appendix C.1 we find that we have some possible topics for this course. Depending on the depth and number of the topics to be studied, groups of between 1 and 5 students should be formed at the beginning of the semester and each should pick a topic. It is then the job of each of these teams to accumulate information and problems relevant to their topic and then to present this to the rest of the class and the instructor. This way, knowledge is collected

for the next semester of the course, the students do most of the work, and all the students benefit from the involvement and work of each of the other students. It might be a good idea if the instructor was to take a topic or two as well, to guide by setting an example and to keep the students from feeling abused.

The following semester would begin with presentation--either by the instructor or even the students of the last semester--of the information found and developed by the previous semester's work. The remainder of the semester would continue with the exploration of new topics and/or deepening of old ones. With repeated semesters, the material would become more complete and would eventually become equivalent to a full regular course. At this point, it could be turned into a course taught in the normal way but reserving a few weeks to do short projects. These short projects would have the effect of updating, improving, and possibly optimizing the course regularly.

Thus, in addition to the increased interest, morale, and involvement that this method would breed in the students, this method would quickly develop new courses and maintain old ones. In addition to all this, allowing the students to develop the courses will help determine at what level of information they are able to absorb a particular topic and to assimilate it into their previous knowledge. As long as too much work is not expected in a semester, this is a teaching and learning method that should be experimented with. Lastly, this method is also very applicable to the development of computer tools and CBT

modules that fit in with the section above.

8.2 SUPPORT FUNCTIONS

There is an almost infinite number of potential support functions that can be applied throughout the various levels of this new education program. Again, we will address only a few of the more important or potential ones. We will first start off with functions and concerns which are put forth by the application of human factors to our system and will then move on to topics pertaining to support functions.

8.2.1 SOCIAL ENVIRONMENT REFLECTED BY HUMAN FACTORS

The social environment for the student and the university community at large is a very important function. As such, human factors concerns directly affect the function, methods, and attitudes of this environment.

Human Factors In The Program

Full system life cycle support is the most needed function suggested by human factors at the program level. This program needs to support the student completely and continuously throughout the program. This should include help from the moment of initial consideration of the program to the point of accepting

an offer for employment or continued education.

One simple but very useful function that would help provide life cycle support would be the establishment and operation of a consulting group of upper level students. These students should be knowledgeable about the courses and their topics, the university in general, and the procedures and sequences involved in the undergraduate and graduate programs. Such a group of more knowledgeable, helpful peers would give applicants and students an invaluable source for needed information. It might even be useful for this group to give annual seminars pertaining to topics such as deciding between looking for a job and attending graduate school, how to find and apply for jobs or to graduate schools, etc. The functions such a group could perform are bounded only by the imagination of the members and the needs of the other students.

Another consideration that should eventually be addressed is the determination of which life cycle of the student user should be supported by the university. The current life cycle supports only the initial education of the student. It may, however, be more advantageous to change this life cycle to that of the total life cycle of the engineer. This would include both his initial education and any continuing education he will need. Such a professional or his employer will certainly be better able to pay for his continuing education than he was as an undergraduate student. Further, the social structure of the country would benefit in terms of increased competitiveness and other factors if engineers

were able to and did efficiently update their education as needed.

Lastly, a thorough, human factors emphasized tradeoff analysis should be made into the determination of whether instructing professors should be separated from research ones, and if so, in what fashion. The best solution may involve no separation, an alternating procession, or any of a variety of other possible scenarios. This function needs to be clarified, as it is becoming increasingly under question.

Human Factors In Course Teaching

The vast realm of this area is extensive enough for a thesis of its own. Most of the topics in this area are geared toward matching the teaching of material to an increasingly knowledgeable definition of what factors are involved in how students learn. One of the biggest of these areas stems from improvements based upon increased cognitive understanding.

One sub-area within this area involves the differentiation of semantic and syntactic knowledge and the learning forms for each. (See Appendix E for more information.) Semantic knowledge pertains to knowledge about concepts, whereas syntactic knowledge pertains to knowledge about the details of a particular application. An example of semantic knowledge within our ChE knowledge realm would be the principle of conservation. An example of syntactic knowledge is the numerical range of the average efficiencies obtained

per stage for a given type of distillation plate in a simple binary distillation. There have been many studies and models made regarding the differences in these two types of knowledge, the ways each are learned, stored and used, and the types of teaching methods that lend themselves to the learning of each. This should be further researched and incorporated into the choice of teaching methods and the formatting of the learning of complex topics.

Another area of importance is that of Learning and Forgetting Curves. Again, this is an area of cognitive science that is receiving more attention as time progresses. Because these curves are highly subject and student dependent, they should be further researched, tested and made part of the sequencing and load determinations within the program.

The area of Learning and Forgetting Curves has another cognitive science area as one of its major variables. This is the area of Cognitive Load and Confusion. Again, this area is highly student and subject dependent. This means that ranges for the parameters of increasing quality of information as a function of amount of material and error frequency [Asbjornsen 1991, p.12 Figure 3, and Figure H.2 in Appendix H] must be determined for each class. This information must then be applied to the optimizing of the class loading function for the mean student and alternate methods must be designed to deal with those students above or below this mean. See Appendix H for further information on both learning and forgetting curves and cognitive load.

Human Factors In The Disposition Of The Student

Lastly, human factors concerns must be applied to alter the disposition of the students. Students in the current programs are plagued with low interest and motivation, low feelings of worth, inferiority, burnout, anger towards administration and instructors, carelessness, and low morale. It is hoped that the application of human factors concerns such as those listed below can counteract or cure some of these problems.

The single most cited and possibly most potent human factors related direction that should be woven into the new program is to get the students involved. This means getting them involved in the learning, teaching, quality control, tool generation, evaluation, feedback, and any other feasible role. One qualifier to this is that the student must be treated and respected as an equal in all of these roles. Accomplishment of all this will result in an increase in student enthusiasm, self-motivation, sense of being needed, participation, interest, and pride in the program. This will also decrease the workload on the instructors and possibly the administration while giving the students a more rounded education and the new program both necessary and improved feedback.

A second important human factors related problem is that of the lack of student perception of their accomplishments. This is often one of the major causes of burnout and could probably be linked to many other problems. In general, students need to have a clear visual description of how much of the

program they have completed in relation to the total program and some way to grasp the sum of their accomplishments to date. Solutions can be as simple as a continuously updated thermometer graph showing what percentage of the program has been completed and a total listing of the topics covered so far. Obviously, more complex solutions could be devised, but at least one such method should be integrated into the program so that each student sees his progress at least once or twice a semester as well as whenever he wants. This could even be combined with some form of mapping of the program that could also show the possible paths through the program and display suggestions about what to do next.

On another front, students need to feel supported and need the opportunity to mix socialization and work. In specific, it is both to the students' and the program's advantage for the students to have a convenient, 24-hour facility where they can meet, do homework, work on computers, study in groups, study privately, etc. Such a facility that is comfortable, complete, aesthetically appealing, and well cared for provides both a needed and useful functionality and student confidence that they are supported and cared about and not just part of an endless, nondescript stream flowing through the university. Management in business is beginning to perceive the worth of such facilities; the university should take advantage of this as well.

8.2.2 FUNCTIONS TO SUPPORT THE PROGRAM

The undergraduate Chemical Engineering program that is the focus of this design project has a vast number of needed support functions. This section will discuss some of them and some possible useful solutions that again are in the spirit of the integration of the student's learning processes and/or an integrated multi-functional undergraduate program.

Continuing Education

While continuing education is not a support function of the program in design, it is a need of industry as a customer and thus of past student customers. This results in an enormous potential need for education. It is this need that offers the potential for support of the education program and introduces our next topic.

Education As A Source Of Extra Funding And Student Enthusiasm

A relatively recent method for marketing the potential of a given product that has gained both widespread acceptance and success is syndication. This concept, combined with the vast need for continuing education, can lead to a viable source of income for the undergraduate Chemical Engineering program and a significant source of student excitement, enthusiasm and possibly even student funding. The syndication of education has already been attempted in a variety of forms. Mr. Tom Rollins [Grahm] has founded Teaching Co., a company whose only product is packaged audio and video cassettes of "brilliant teaching".

Lastly, most people have at least seen advertisements for study at home VCR based programs to learn electronics, computer repair, etc. One of these companies, NEI, even offers upwards of a hundred or more such programs.

For such ventures to exist in such broad markets must mean that they can be profitable. There must likewise be a small but reasonable market for continuing education on video formats. The equipment necessary to produce such a video is easily obtainable and, from experience, the simple mention of a video project never fails to result in a number of highly motivated, creative and often adroit volunteers. This will assure that the videos can be produced at a low price and useful quality that will assure them salable and profitable.

The direction of these video projects is critical. The videos should not be intended as a main education, but rather emphasize their use as updated or extended education to be used by companies or individuals on a regular or as needed basis. Also critical is the variety of topics to be developed and offered. The obvious starting point is with a set of topics that are in confirmed need by a relatively large number of potential customers. An obvious and easily reached starting clientele would be with the firms of past graduates.

The generation of these videos can be reasonably performed as extra curricular projects, graduate projects, possibly as extended class projects, and, as a full blown feature, these projects could even be generated as a summer job.

This would require a substantial return to the students, but would also result in a Summer that is filled with productive learning as well. This type of Summer work would easily lend itself to co-op programs. For example, a small team of students could spend the Summer or a semester researching and making a customized tutorial for a particular company which desires the tutorial as a continued education aid, training product (e.g. for sales people), or even as a video to be packaged with a product. As added benefits, this form of co-op would also advertise the university as the video source and increase interest in continuing education through this medium.

The future should hold even more useful mediums for this form of continuing education. With increased capacities on CD-ROMs or other computer mediums, useful, personally instructed programs and computer tools could be distributed either in conjunction or separate from these videos. These CD's can then be played through the individual user's computer whenever he needs assistance with the included program tools. As another medium comes of age, multi-media could be taken advantage of to enhance the efficiency and aesthetics of the presentation of this information. This multi-media could even eventually be taken to the limits of total animation or even virtual experiences: an encounter sure to motivate enthusiasm and support.

In a simple summary we can state some of the major benefits. First, producing the videos would be a great way to boost enthusiasm and morale in

all of those involved. Second, it can lead to an additional source of revenue for the program. Third, this would help fulfill the vast need for some form of easily usable continuing education for practicing engineers. Fourth, and last, it is a very efficient and lasting way to teach.

Feedback Functions

Feedback loops are critical to the proper active design, maintenance, and updating of this type of system. The current feedback loop is very crude and exists with a minimum four year dead time--an absurdly long time for most industrial control systems. This is diagrammed in Figure 8.1. This is not a problem if the system needs only a small and non-critical correction. However,

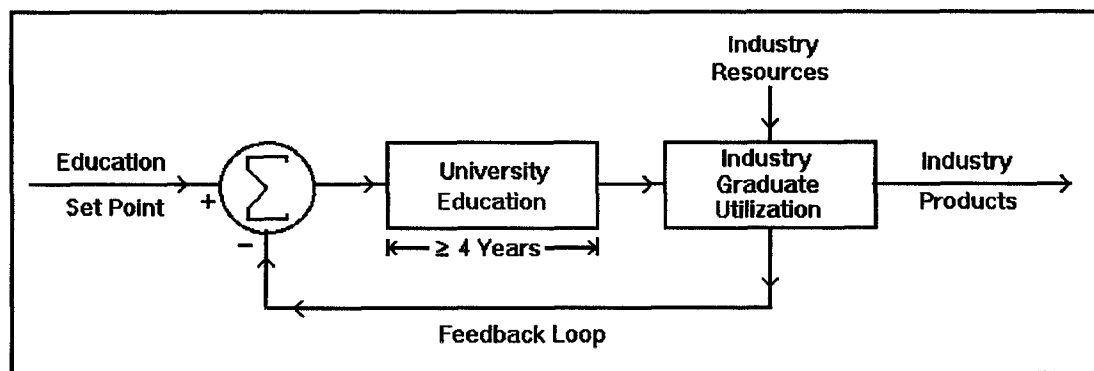


Figure 8.1 Program Feedback System

as limited magnitude (in the form of limited accuracy if implemented change) in the controller gain will require that any change will usually take a number of feedback iterations to reach completion, a large or critical change can result in an extremely inefficient education system. Even though the quick observer will point out that some feedback changes can be made in the final years of the program, which would decrease the 4 year lag time, the time it takes to develop and

implement the changes must be considered and added to the dead time, most probably bringing the dead time back to around 4 years. Likewise, industry will not immediately identify imperfections in the graduates, thereby again increasing the dead time involved in the feedback loop and thus in the duration of the needed change.

This means that this system most likely has an unacceptably long correction time for today's fast changing industrial environment. The typical dead time compensation methods are not applicable due to the vast nature of the variables (the knowledge space). This would be a critical problem except for four possible additional control mechanisms. [Stephanopoulos 1984]

First, an inner control loop can be introduced and implemented by using the knowledge of both co-op students and industry professionals. Co-op students could bring back information and direct it to the necessary programs by participating in scheduled feedback meeting with the all the instructors after each internship. A second similar method would also reduce the dead time of both the education system and that in industry by encouraging team teaching with knowledgeable industry professionals. Both of these methods would have the overall effect of decreasing the dead time inherent in the system and, by their direct and personal recycling of the needed corrections, effectively increase the possible overall controller gain.

The third possible control addition would be the addition of a cascaded control on the education set point. This would reduce the total time required to effect a change by reducing the deviation of the feedback variable from the set point, thus allowing each correction to be more accurate.

The fourth and last possible control change for this system would be the addition of a feed forward controller to the set point function. While it is ridiculous to try to predict actual variables within the vast knowledge space, trend analysis can yield accurate and very useful information on how this dynamic knowledge space will shift. This information can be passed as trending of clumped variables to the individual functions within the university training transfer function, which could cause a magnitude reduction of some of the feedback deviations. Of course, the most intelligent of these feed forward loops would also be serially, parallelly, or feedback-linked with industry and the system users to increase the accuracy of the trend identification and their potential impacts.

To this complex and integrated set of feedback (or more accurately, control) systems should be added and incorporated strong and frequent feedback loops within each of the course sequences, individual courses, and the teaching methods within the program. This control setup is really no different from the integrated control mechanisms found in today's current industrial plants. Further, this industry control is not likely to become any simpler in the future, but then,

neither are their products likely to become any less perfect. Neither should ours.

8.3 COMPLETION OF THIS PROJECT

The following topics are some scattered topics pertaining to the advice for the future system and listing of work that should be done after this project if this venture is to be continued.

8.3.1 SYSTEM INSTALLATION SEQUENCE

It is suggested that the new undergraduate Chemical Engineering program be installed as a batch of students progress. That is, in year 1, new Freshman classes are installed; in year 2, Sophomore classes are installed; etc. Overall, this should reduce the potential for confusion originating from students with old backgrounds suddenly running into new classes dependent upon a different background. This will also give the opportunity to run limited comparisons between successive years of old and new program students. Lastly, this will allow learning from installation to be immediately utilized and will spread out the installation workload over a longer period of time, possibly making installation easier.

8.3.2 QUALIFICATIONS FOR INSTRUCTORS

The instructors are also users of the system. However, as operators, their competence is more critical than that of the students as users. It is suggested that most of the permanent instructors be full time professionals with broad industry experience and learned in education theory and methods. This will mean that many of the current instructors will need to be further educated and will need to gain further practical experience. As professionals, this should not be thought of as a negative liability, but instead should be considered continued education and personal enrichment. Lastly, the same human factors that were applied to the students should be applied to all the other users of the system. This is because they need to feel useful, wanted, competent, worthwhile and supported just as much as any others of their equals.

8.3.3 WHAT WORK SHOULD BE PERFORMED AFTER THIS PROJECT IF THIS VENTURE WERE TO BE CONTINUED

In blocks similar to those used in this project, the following is a listing of what steps would continue this project to implementation and operation. Before they can be performed, though, steps one to eight above would need to be completed at a level deep enough to make the comprehensive development of this program possible. We could then proceed with step 9:

- 9) In this step the necessary tradeoffs would be performed to link the potential low level teaching methods to individual topics or courses. This will include a large amount of teaching method studies, technology and learning psychology studies, tradeoffs, etc., but would result in a substantially determined education system.
- 10) Determine and acquire the necessary logistics for the implementation and operation of the new program.
- 11) Implement the system in steps, utilizing any knowledge learned in previous steps.
- 12) Run the system with active monitoring and immediate feedback and control response.
- 13) Begin the cycle of system improvement and optimization with the feedback loops and other appropriate control functions.
- 14) Validate the life cycle plan.
- 15) Begin design of a new system as determined in the life cycle plan. Utilize all knowledge learned by implementing and running first system and study workings of current system.
- 16) Simultaneously phase out old system and phase in new system.

CHAPTER 9

CONCLUSIONS

This Masters Project and Thesis have been very valuable and have lead me to the following conclusions. First, the application of Systems Engineering to the university environment has produced an invaluable generic process for education program design. Second, upon inspection, it seems as though this generic process, with proper tailoring, may be applied to the development of almost any education program at any level. Third, within the scope of the project, requirements, and available logistics of this thesis, this generic process can be used to design a ChE program which addresses more requirements than the current program. Fourth, programs designed with this process are likely to be highly integrated. This mirrors the current trend in business and industry--they have recently transmogrified from segregated to highly integrated institutions. Fifth and last, at the very least, the use of this process has pointed out various specific areas of science, education, and society which are in need of further research and development and whose results could be used to further improve today's education programs.

APPENDICES

Appendix A: ABET Criteria

Appendix B: Knowledge State Space Structure

Appendix C: Topics

Appendix D: Undergraduate Course Sequence

Appendix E: Semantic And Syntactic Knowledge

Appendix F: CBT Workstation Concepts

Appendix G: Mathcad Demo Program

Appendix H: Learning & Forgetting Curves And Cognitive Load

APPENDIX A

ABET CRITERIA

**General Criteria For
Engineering Programs**

And

**Criteria For
Chemical Engineering Programs**

Criteria for Accrediting Programs in Engineering in the United States¹

I. INTRODUCTION

A. Purposes

Among the purposes of the Accreditation Board for Engineering and Technology (hereafter referred to as ABET) as delineated in the Constitution, the following relate to accreditation:

In the next edition of these criteria it is proposed that the following paragraph be added and the subsequent sections renumbered:

1. Enhance the practice and profession of engineering through the establishment of standards and goals for engineering education.

1. Organize and carry out a comprehensive program of accreditation of pertinent curricula leading to degrees, and assist academic institutions in planning their educational programs.

2. Promote the intellectual development of those interested in engineering and engineering-related professions, and provide technical assistance to agencies having engineering-related regulatory authority applicable to accreditation.

B. Responsibilities

1. ABET accomplishes its purposes through standing committees or commissions, one of which is the Engineering Accreditation Commission (hereafter referred to as EAC or EAC of ABET.) The accreditation commissions are charged with the following responsibilities.

a. The accreditation commissions shall propose policies, procedures, and criteria to the ABET Board of Directors for approval. The Board of Directors shall review policies, procedures, and accreditation criteria and may specify changes to be made in them to the appropriate accreditation commissions.

b. The accreditation commissions shall administer the accreditation process based on policies, procedures, and criteria approved in advance by the Board of Directors. The accreditation commissions shall make final decisions, except for appeals, on accreditation actions.

2. Procedures and decisions on all appeals to accreditation actions shall be the responsibility of the Board of Directors.

3. Accreditation decisions are based solely on the *Criteria for Accrediting Programs in Engineering* as published by ABET. Other documents published by ABET or Participating Bodies are advisory in nature.

C. Objectives of Accreditation

The purpose of accrediting is to identify those institutions which offer professional programs in engineering worthy of recognition as such. In keeping with the broad purposes of

ABET as given above, accreditation is intended to accomplish the following specific objectives:

1. To identify to the public, prospective students, educational institutions, professional societies, potential employers, governmental agencies, and state boards of examiners, the institutions and specific programs that meet minimum criteria for accreditation.

2. To provide guidance for the improvement of the existing educational programs in engineering and for the development of future programs.

3. To stimulate the improvement of engineering education in the United States.

D. National Recognition

ABET is recognized by the U.S. Department of Education and the Council on Postsecondary Accreditation (COPA) as the sole agency responsible for accreditation of educational programs leading to degrees in engineering. The wide acceptance of the ABET list by organizations such as the National Council of Examiners for Engineering and Surveying, by nearly all of the individual state boards, by the professional engineering societies, by employers of engineers and by the institutions themselves, is gratifying evidence of the cooperation and respect of the institutions and organizations concerned.

E. Development

The first statement of the Engineers' Council for Professional Development (ECPD, now ABET) relating to accreditation of engineering educational programs was proposed by the Committee on Engineering Schools and approved by the Council in 1933. It was subsequently approved by the constituent member organizations of ECPD. Amendments and additions to the statement have from time to time been adopted. The original statement and its amendments and additions are combined here into a unified statement of the policies, methods of evaluation, criteria, and procedures which pertain to the accreditation of engineering programs.

II. POLICIES

A. Accreditation Policies

Through continuing and careful study of the problems of accreditation, ABET has evolved the following basic policies:

1. To accredit educational programs rather than institutions, departments, or degrees, for it is well recognized that programs of quite different quality may sometimes be found at the same institution. In order for a program to be accredited, all routes to completion of the program must be accreditable.

a. Definition of Program

An engineering program is an organized educational experience that consists of a cohesive set of courses, or other educational modules, sequenced so that reasonable depth is obtained in the upper-level courses.

A definite engineering stem should be obvious in the

¹Incorporates all changes as of October, 1990.

II.A.1.a. to II.A.9.

program and, again, depth should be reached in pursuing courses in the engineering stem. Furthermore, the program should develop the ability to apply pertinent knowledge to the practice of engineering. An engineering program must also involve the broadening educational objectives expected in modern postsecondary education. For engineering disciplines, ABET has developed program criteria (see section IV.B.2.) that define specific program requirements within the general realm of engineering.

b. Program Differentiation

ABET criteria for accrediting programs address faculty, curriculum, students, administration, facilities, and commitment (see sections IV.C.1. to 6.). Programs may be differentiated and separately accredited if there are differences in any of the above categories such that the configuration of one program offering is subject to judgments different from other patterns. Not only do different curricula and disciplines require separate accreditation, but the use of two or more substantially different faculties, facilities, student characteristics, or administrations within the same discipline implies that there are two or more programs, each of which may require separate accreditation.

c. Options

Alternative curricula within a major engineering program (commonly called options) leading to a degree in a subfield of the major discipline may be accredited and listed as separate programs at the request of the institution. In such cases the option must have been formally designated by the institution prior to the request for evaluation. It must conform to the general criteria and to any program criteria applicable to independent programs in the same curricular area as the option. The accreditation status of the option must be clearly identified and distinguished from any non-accredited options within the same major program, and from any other programs.

d. Cooperative Work-Study Programs

In addition to accrediting programs against basic or advanced general criteria and appropriate program criteria, an institution may request accreditation for the co-op feature of some or all of its programs in accordance with criteria for co-op programs (section IV.D.).

2. To invite institutions to submit programs without persuasion or pressure.

3. To require as a prerequisite to EAC of ABET evaluation and accreditation of its engineering educational programs that the institution be in one of the following categories:

a. Institutions currently accredited by a regional or national institutional accrediting agency or formally approved by a State authority recognized by COPA and/or the U.S. Department of Education.

b. Institutions holding appropriate approval by a State authority to offer only engineering, engineering technology or engineering-related programs, or a combination thereof, and not offering programs in any other field or discipline; or other institutions offering programs in engineering whose accreditation would further the objectives of ABET.

c. Institutions that comply with II.A.3 and operate a branch campus outside the United States under the direct supervision and control of the home campus, and conduct a program that is substantially equivalent to one located on the home campus, will be considered.

4. To accredit programs at either the basic or advanced level. Our complex society demands increasing numbers of engineers with a level of competency achieved by completion of advanced programs as well as significant numbers of engineers who are graduates of basic programs of shorter duration. Hence, either level of program may be accredited and criteria suitable for both levels are described below. However, a program may be accredited at only one level in a particular curriculum at a particular institution.

5. To favor broad basic programs in engineering that will prepare a student to take advantage of as many different opportunities as possible. ABET prefers to minimize the number of specially designated programs to be considered for accreditation.

6. To deny accreditation to programs which omit instruction in a significant portion of a subject in which engineers in a particular field may reasonably be expected to have competence. This policy is intended to be a safeguard to the public. It should be noted that programs which are perhaps contiguous to engineering but do not develop the basic abilities of the engineer are not eligible for accreditation as engineering programs, however excellent and useful they may be.

7. To avoid rigid standards as a basis for accreditation in order to prevent standardization or ossification of engineering education, and to encourage well-planned experimentation

a. Recognizing the value of innovation and experimentation in engineering education and the possibility that innovative programs may have difficulty in meeting fixed quantitative criteria, the Engineering Accreditation Commission will evaluate such programs, on request, on the basis of their demonstrated ability to meet the overall objectives of these criteria and to produce graduates fully qualified to enter the practice of engineering.

b. It is incumbent on the institution wishing to offer a program for evaluation under these provisions to provide complete documentation, in Volume II of the self-study questionnaire (see section III.A.), of the means by which the objectives of these criteria are met in each instance where the program is not in strict compliance with the stated requirements.

8. To assess qualitative as well as quantitative factors in making an accreditation decision. These are assessed by a visit to the institution by a competent team of engineers.

9. To grant initial accreditation only if students have graduated from a program prior to the on-site visit. If the EAC determines that the program followed by these graduates is

essentially the same as that reviewed then such accreditation action may extend to the graduates of the program in the academic year prior to the visit.

10. To require institutions to represent the accreditation status of engineering programs accurately and without ambiguity.

- a. The title of an EAC of ABET accredited program must be properly descriptive of the content of the program and be shown on the graduating student's transcript. An institution may not use the same program title to identify both an accredited program and a non-accredited program. Although the selection of program titles is the prerogative of educational institutions, ABET discourages the proliferation of engineering program titles, because different titles for essentially the same programs are confusing or misleading to the public, including students, prospective students, and employers.
- b. If an institution offers a non-accredited program at the same level in the same field as an engineering program that is accredited by EAC of ABET, the institution must indicate, in the descriptions of its programs that are made available to the public, that the non-accredited program is not accredited by EAC of ABET.
- c. All engineering programs must include the word "engineering" in the program title.²

11. To submit the findings and recommendations of the visiting team for review by the institution, by officers of EAC of ABET, and finally by the full membership of EAC of ABET.

12. To publish a list of accredited programs only. Information as to whether a program or institution not on the accredited list had been under consideration by EAC of ABET will not be made available except to the appropriate officials of the institution in question.

B. Revocation of Accreditation

Questions regarding the continued compliance of programs during the period of accreditation may be directed to ABET. If it appears that an accredited program is not in compliance with ABET criteria, the institution is so notified. If the response from the institution is not adequate, ABET may institute revocation for cause procedures. The institution is notified as to the cause why revocation is to be instituted. An on-site visitation is scheduled to determine the facts. A comprehensive document showing the reasons for revocation is provided to the institution for its analysis and its response. If the institution's response is not adequate, revocation for cause is implemented. The institution is promptly notified by the President of ABET of such action together with a supporting statement showing cause. A revocation constitutes a "not to accredit" action and is appealable. Accreditation is continued until the appeal procedure has terminated.

²An exception has been granted for programs accredited prior to 1984 under the title of Naval Architecture

C. Appeal

Provision is made for appeal of "not to accredit" actions to the ABET Board of Directors. (see V.E. below.)

D. Public Release Policy

1. Accreditation by EAC of ABET is based on satisfying minimum educational criteria. As a measure of quality, it assures only that an accredited program satisfies the minimum standards. The various periods or terms of accreditation do not represent a relative ranking of programs in terms of quality. At no point is an institution allowed to publish or imply the term or period of accreditation. Public announcement of the accreditation action should only relate to the attainment of accredited status. Because accreditation is specific to a program, all statements on accreditation status must refer only to those programs that are accredited. No implication should be made by an announcement or release that accreditation by EAC of ABET applies to any programs other than the accredited ones.

2. Direct quotation in whole or in part from any statement by EAC or ABET to the institution is unauthorized. Correspondence and reports between the accrediting agency and the institution are confidential documents and should only be released to authorized personnel at the institution. Any document so released must clearly state that it is confidential. Wherever institution policy or state or federal laws require the release of any confidential documents, the entire document must be released.

3. The institution must avoid any implication that programs offered are accredited under program criteria against which they have not been evaluated. Where subdesignators such as "option," "area of concentration," or similar nomenclature are used for programs, the institution must clearly identify the program criteria under which accreditation has been obtained.

4. In addition to an accredited advanced-level program, an institution may offer one for which it may not seek accreditation and which would allow the admission of non-engineering students and/or baccalaureate engineering degree holders from other curricula who may not wish to remedy all deficiencies in their basic-level preparation. There are many advanced-level programs of high quality which admit such students but which do not meet the objectives of the current criteria. Where these differences exist, two different advanced-level programs may be offered which must be clearly distinguished as to their title, content, objectives, and accreditation status.

5. Information published for students, prospective students, and the general public on an engineering program should provide sufficient definition of the program to show that it meets the ABET accreditation criteria. For example, if some fraction of the total elective courses must be taken in one curricular area in order for the criteria to be met, this requirement should be published, even though adequate counseling of students by faculty members may be shown to achieve the same objective.

6. College catalogs and similar publications must clearly indicate the programs accredited by EAC of ABET as separate and distinct from any other programs or kinds of accreditation.

II.D.6. to IV.A.

No implication should be made in any listing that all programs are accredited because of an institution's regional or institutional accreditation. Accredited engineering programs should be specifically identified as "accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology."

III. METHOD OF EVALUATION

A. Questionnaire

An institution's engineering educational programs will be initially evaluated on the basis of data submitted by the institution to ABET in the form of a self-study questionnaire.

B. On-site Visit

The questionnaire will be supplemented by a report of an on-site visit by a carefully selected team representing ABET and its Participating Bodies. The purpose of the on-site visit is three-fold:

1. It should assess factors that cannot be adequately described in the questionnaire. The intellectual atmosphere, the morale of the faculty and the students, the caliber of the staff and student body, and the outcome of the education offered as evidenced by the character of the work performed are examples of intangible qualitative factors that are difficult to document in a written statement.
2. The visiting team should help the institution assess its weak as well as its strong points.
3. The team should examine in further detail the material compiled by the institution and relating to:
 - a. Auspices, control, and organization of the institution and of the engineering division.
 - b. Educational programs offered and degrees conferred.
 - c. Age of the institution and of the individual educational programs.
 - d. Basis of and requirements for admission of students.
 - e. Number of students enrolled:
 - (1) in the engineering college or division as a whole, and
 - (2) in the individual educational programs.
 - f. Teaching staff and teaching loads.
 - g. Physical facilities—the educational plant devoted to engineering education.
 - h. Finances—investments, expenditures, sources of income.
 - i. Curricular content of the program.
 - j. Representative samples of student work that reveal the spectrum of educational outcome.

C. Interpretation of Criteria

Considerable latitude in the choice and arrangement of subject matter in the curriculum is allowed. While the qualitative factors are more important than the quantitative assignment of credit hours to any particular area, the general principles outlined in the criteria will be checked closely by analyzing each

particular curriculum. The coverage of basic information rather than the offering of specific courses is the important criterion.

It is emphasized that any program accredited by EAC of ABET must offer primarily an engineering curriculum with or without some modifier in its title. Therefore, the prime considerations in evaluating any engineering curriculum are: (1) that it is considered satisfactory as an engineering curriculum regardless of any modifying word or phraseology used in the title, and (2) that the curriculum or curriculum option merits the designation of the modifier. If a program title is identified with one or more of the fields for which program criteria have been approved (see section IV.B.2.), that program must also meet the requirements of any relevant program criteria. Curricula not covered by other program criteria must meet the program criteria for nontraditional programs.

Methods for delivery of instruction and their use are developing, and ways for evaluating the learning accomplishment are evolving as well. When a course offered as part of an engineering program employs a method for delivery of instruction that differs from the more frequently encountered methods (e.g., lecture, discussion, laboratory) there must be a provision for evaluating the learning accomplishment to ensure that educational objectives are met.

IV. CRITERIA

The proposed General and Program Criteria, which are found in the shaded areas of the criteria, have been developed by appropriate Participating Bodies of ABET, reviewed by the Engineering Accreditation Commission (EAC), and approved in principle by the Board of Directors of ABET. Before being adopted for implementation in the accreditation process, criteria are to be circulated among the institutions with accredited programs, as well as other interested parties, for review and comment.

Comments will be considered until June 14, 1991. Based upon comments received, the ABET Board of Directors will determine, with the advice of the EAC, the content of the adopted criteria. The adopted criteria will become effective following the ABET Annual Meeting in the fall of 1991 and will first be applied by the EAC for accreditation actions during the 1992-93 academic year and the following years.

Comments relative to the proposed General and Program Criteria should be addressed to the Accreditation Director for Engineering, Accreditation Board for Engineering and Technology, 345 East 47th Street, New York, NY 10017-2397.

A. Program Design and Level

In order to be considered for accreditation, engineering programs must be designed to prepare graduates for the practice of engineering at a professional level. Depending on the requirements of different technologies, this entry may occur at the levels characterized here as "basic" or "advanced." Programs designed to prepare graduates for supporting roles in engineering (e.g., engineering technology) are not eligible, nor

are programs which do not provide an adequate base for the application of fundamental concepts to the practice of engineering. To assist in the identification and recognition of characteristics of engineering programs for accreditation purposes, the criteria that follow have been adopted by ABET. Some of these criteria are differentiated according to the bachelor's or master's level of accreditation sought, and all will be applied with this level in mind.

B. Intent of Criteria

1. General Criteria

These criteria are intended to assure an adequate foundation in science, the humanities and the social sciences, engineering sciences and engineering design methods, as well as preparation in a higher engineering specialization appropriate to the challenge presented by today's complex and difficult problems. They are intended to afford sufficient flexibility in science requirements so that programs requiring special backgrounds, such as in the life or earth sciences, can be accommodated. They are designed to be flexible enough to permit the expression of an institution's individual qualities and ideals. They are to be regarded as a statement of principles to be applied with judgment in each case rather than as rigid and arbitrary standards. Finally, they are intended to encourage and stimulate and not to restrain creative and imaginative programs. In any case in which EAC of ABET is convinced that well-considered experimentation in engineering educational programs is under way, it shall give sympathetic consideration to departures from the criteria.

2. Program Criteria

Program criteria relative to the accreditation of engineering programs in particular disciplines are developed by the cognizant Participating Bodies of ABET or, at the request of EAC of ABET, by other societies or groups having appropriate expertise. The program criteria provide the specificity needed for interpretation of the general criteria as applicable to a given discipline. Program criteria must be accepted by the EAC and ABET before they can have effect in the accreditation process. When approved, program criteria are published as an integral part of this document, following the general criteria. A program in a curricular area covered by approved program criteria must be in compliance with both the general criteria and the program criteria in order to be accredited. Provisions of the program criteria may be more restrictive than related provisions of the general criteria.

If a program, by virtue of its title, becomes subject to two or more sets of program criteria, then that program must satisfy each set of program criteria, understanding that overlapping requirements need to be satisfied only once. However, the General Criteria are emphatic that there must be sufficient faculty (IV.C.1.b.) and resources (IV.C.5. and 6.) to assure that program objectives are met. These programs must have faculty and resources sufficient to meet the additional curricular objectives implied by the expanded title.

C. General Criteria

1. Faculty

This section of the criteria relates to the size and competence of the faculty, the standards and quality of instruction in the engineering departments and in the scientific and other operating departments in which engineering students receive instruction, and evidence of concern about improving the effectiveness of pedagogical techniques.

- a. The heart of any educational program is the faculty. All other matters are secondary to a competent, qualified, and forward-looking faculty that can give an overall scholarly atmosphere to the operation and provide an appropriate role model for engineering students.
- b. The overall competence of the faculty may be judged by such factors as the level of academic training of its members; the diversity of their backgrounds; their non-academic engineering experience; their experience in teaching; their ability to communicate fluently in English; their interest in and enthusiasm for developing more effective teaching methods; their level of scholarship as shown by scientific and professional publications; their registration as Professional Engineers; their degree of participation in professional, scientific and other learned societies; their participation in professional development programs; recognition by students of their professional acumen; and their personal interest in the students' curricular and extracurricular activities.
- c. The faculty, in size and composition, must be structured to support the stated objectives of the educational program. Normally, a program at the basic level must have no fewer than three full-time faculty members whose primary commitments are to that program. This statement shall not be interpreted to preclude the accreditation of programs offered primarily by part-time faculty members; however, for such programs the institution must demonstrate that, in addition to the commitment of at least three full-time equivalent faculty members to the program, effective mechanisms are in place to assure adequate levels of student-faculty interaction, student advising, and faculty concern for and control over the curriculum, as would be expected in programs offered primarily by full-time faculty members. If the faculty has additional obligations, such as graduate teaching and/or research, additional faculty members must be present to ensure that at least three full-time-equivalent faculty members are devoted to each basic-level program. Under no circumstances should a program be critically dependent on one individual.
- d. *Teaching loads* must be consistent with the stated program objectives and expectations for research and professional development. Engineering faculty members, regardless of their individual capabilities, cannot function effectively either as teachers or seekers of new understanding if they are too heavily burdened with classroom assignments. Stimulation of student minds presuppose continuing professional growth of the

IV.C.1.d. to IV.C.3.c.

faculty through study of new developments in areas of technology and science and in areas of instructional innovation.

- e. The engineering faculty must assume the responsibility of assuring that the students receive proper *curricular and career advising*. Those individuals responsible for and involved in advising must know and understand ABET criteria for accrediting engineering programs.

2. Curricular Objective

Engineering is that profession in which knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind. A significant measure of an engineering education is the degree to which it has prepared the graduate to pursue a productive engineering career that is characterized by continued professional growth.

This section of the criteria relates to the extent to which a program develops the ability to apply pertinent knowledge to the practice of engineering in an effective and professional manner.

Included are the development of: (1) a capability to delineate and solve in a practical way the problems of society that are susceptible to engineering treatment, (2) a sensitivity to the socially-related technical problems which confront the profession, (3) an understanding of the ethical characteristics of the engineering profession and practice, (4) an understanding of the engineer's responsibility to protect both occupational and public health and safety, and (5) an ability to maintain professional competency through life-long learning. These objectives are normally met by a curriculum in which there is a progression in the coursework and in which fundamental scientific and other training of the earlier years is applied in later engineering courses.

Institutions are expected to develop and articulate clearly program goals that are in keeping with the overall institutional goals, the student body served, and any other constraints that affect the program. In addition, they are expected to demonstrate success in meeting these goals.

3. Curricular Content

Coursework which meets the ABET engineering criteria may be accomplished in fewer academic years than are normally required for the completion of basic-level or advanced-level degree programs. Although additional time is thus available in an accreditable engineering program for the implementation of individual educational objectives of students or their institutions, additional coursework in engineering or related areas beyond that specifically required by ABET will be needed to fulfill the objective of preparing the graduate adequately to enter the engineering profession. The program must not only meet the specified minimum content, but must also show evidence of being an integrated experience aimed at preparing the graduate to function as an engineer. The institution must address these needs and objectives in developing the program and its content. The institution should consider

also the quality of its educational programs and assure sufficient individual attention to each student by faculty. Section enrollments appropriate to class objectives and accessibility of faculty to students are considerations appropriate to the assessment of educational quality. Admission requirements should be established to both strengthen the quantitative approach to engineering and support the development of the social and humanistic aspects of the engineering student's education.

In the statements that follow, one-half year of study can, at the option of the institution, be considered to be equivalent to 16 semester credit hours (24 quarter hours) (See footnote below.)

- a. For those institutions which elect to prepare graduates for entry into the profession at the basic level, ABET expects the curricular content of the program to include the equivalent of at least three years of study in the areas of mathematics, basic sciences, engineering sciences, engineering design, and the humanities and social sciences.

The coursework must include at least:

- (1) one year of an appropriate combination of mathematics and basic sciences,
- (2) one year of engineering sciences,
- (3) one-half year of engineering design, and
- (4) one-half year of humanities and social sciences.

- b. The overall curriculum must provide an *integrated educational experience* directed toward the development of the ability to apply pertinent knowledge to the identification and solution of practical problems in the designated area of engineering specialization. The curriculum must be designed to provide, and student transcripts must reflect, a sequential development leading to advanced work, and must include both analytical and experimental studies. The objective of integration may be met by courses specifically designed for that purpose, but it is recognized that a variety of other methods may be effective.

Some of the requirements in a particular curricular area may be met through elective courses. However, it is incumbent upon the institution to publish in its catalog or printed advisement guide directions for choosing electives that will assure that ABET engineering criteria are met by all students.

- c. The classification of a course into one or more of the curricular areas depends on the course content rather

Note. For a program of 128 semester hours (192 quarter hours), one-half year of study equals exactly 16 semester hours (24 quarter hours). For a program requiring more than 128 semester hours or 192 quarter hours, 16 semester hours or 24 quarter hours may be considered to constitute one-half year of study in any of the curricular components specified by the ABET criteria. For a program requiring fewer total credit hours, one-half year of study is considered to be one-eighth of the total program. Programs using measurements other than semester or quarter credit hours will be evaluated on a reasonably comparable basis to the above.

- than the course title or the name of the offering department. A course may be classified as being partially in one curricular area while the remainder of it is in another.
- d. While ABET favors a flexible approach to the design of curricular content, it also recognizes the need for specific coverage in each curricular area. These are:
- (1) *Mathematics and Basic Sciences.*
 - (a) Studies in *mathematics* must be beyond trigonometry and must emphasize mathematical concepts and principles rather than computation. These studies must include differential and integral calculus and differential equations. Additional work is encouraged in one or more of the subjects of probability and statistics, linear algebra, numerical analysis, and advanced calculus.
 - (b) The objective of the studies in *basic sciences* is to acquire fundamental knowledge about nature and its phenomena, including quantitative expression. These studies must include both general chemistry and calculus-based general physics at appropriate levels, with at least a two-semester (or equivalent) sequence of study in either area. Also, additional work in life sciences, earth sciences, and/or advanced chemistry or physics may be utilized to satisfy the basic sciences requirement, as appropriate for various engineering disciplines.
 - (c) Coursework devoted to developing skills in the use of computers or computer programming may not be used to satisfy the mathematics/basic sciences requirement.
 - (2) *Engineering Sciences.* The engineering sciences have their roots in mathematics and basic sciences, but carry knowledge further toward creative application. These studies provide a bridge between mathematics/basic sciences and engineering practice. Such subjects include mechanics, thermodynamics, electrical and electronic circuits, materials science, transport phenomena, and computer science (other than computer programming skills), along with other subjects depending upon the discipline. While it is recognized that some subject areas may be taught from the standpoint of either basic science or engineering science, the ultimate determination of engineering science content is based on the extent to which there is extension of knowledge toward creative application. In order to promote breadth, the curriculum must include at least one engineering science course outside the major discipline area.
 - (3) *Engineering Design.*
 - (a) Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. The engineering design component of a curriculum must include at least some of the following features: development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, and detailed system descriptions. Further, it is essential to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact.
 - (b) Courses that contain engineering design normally are taught at the upper-division level of the engineering program. Some portion of this requirement must be satisfied by at least one course which is primarily design, preferably at the senior level, and draws upon previous coursework in the relevant discipline.
 - (c) Coursework devoted to developing drafting skills may not be used to satisfy the engineering design requirement.
 - (4) *Humanities and Social Sciences.*
 - (a) Studies in the humanities and social sciences serve not only to meet the objectives of a broad education, but also to meet the objectives of the engineering profession. Therefore, studies in the humanities and social sciences must be planned to reflect a rationale or fulfill an objective appropriate to the engineering profession and the institution's educational objectives. In the interests of making engineers fully aware of their social responsibilities and better able to consider related factors in the decision-making process, institutions must require coursework in the humanities and social sciences as an integral part of the engineering program. This philosophy cannot be overemphasized. To satisfy this requirement, the courses selected must provide both breadth and depth and not be limited to a selection of unrelated introductory courses.
 - (b) Such coursework must meet the generally accepted definitions that humanities are the branches of knowledge concerned with man and his culture, while social sciences are the studies of individual relationships in and to society. Examples of traditional subjects in these areas are philosophy, religion, history, literature, fine arts, sociology, psychology, political science, anthropology, economics, and foreign

IV.C.3.d.(4)(b) to IV.C.3.j.

languages other than a student's native language(s). Nontraditional subjects are exemplified by courses such as technology and human affairs, history of technology, and professional ethics and social responsibility. Courses that instill cultural values are acceptable, while routine exercises of personal craft are not. Consequently, courses that involve performance must be accompanied by theory or history of the subject.

(c) Subjects such as accounting, industrial management, finance, personnel administration, engineering economy, and military training may be appropriately included either as required or elective courses in engineering curricula to satisfy desired program objectives of the institution. However, such courses usually do not fulfill the objectives desired of the humanities and social science content.

e. *Other courses*, which are not predominantly mathematics, basic science, engineering science, engineering design, humanities or social sciences, may be considered by the institution as essential to some engineering programs. Portions of such courses may include subject matter that can be properly classified in one of the essential curricular areas, but this must be demonstrated in each case.

f. Appropriate *laboratory experience* which serves to combine elements of theory and practice must be an integral component of every engineering program. Every student in the program must develop a competence to conduct experimental work such as that expected of engineers in the discipline represented by the program. It is also necessary that each student have "hands-on" laboratory experience, particularly at the upper levels of the program. Instruction in safety procedures must be an integral component of students' laboratory experiences. ABET requires some coursework in the basic sciences to include or be complemented with laboratory work.

g. Appropriate *computer-based experience* must be included in the program of each student. Students must demonstrate knowledge of the application and use of digital computation techniques to specific engineering problems. The program should include, for example, the use of computers for technical calculations, problem solving, data acquisition and processing, process control, computer-assisted design, computer graphics, and other functions and applications appropriate to the engineering discipline. Access to computational facilities must be sufficient to permit students and faculty to integrate computer work into coursework whenever appropriate throughout the academic program.

In the next edition of these criteria it is proposed that the following shaded portion be added and the subsequent items h. through j. be changed to i. through k.:

h. **Probability and statistics.** Students must demonstrate knowledge of the application of probability and statistics to engineering problems.

i. Competency in *written communication* in the English language is essential for the engineering graduate. Although specific coursework requirements serve as a foundation for such competency, the development and enhancement of writing skills must be demonstrated through student work in engineering courses as well as other studies. *Oral communication* skills in the English language must also be demonstrated within the curriculum by each engineering student.

j. An understanding of the *ethical, social, economic, and safety considerations* in engineering practice is essential for a successful engineering career. Coursework may be provided for this purpose, but as a minimum it should be the responsibility of the engineering faculty to infuse professional concepts into all engineering coursework.

k. For those institutions which elect to prepare graduates for entry into the profession at the *advanced level*, ABET requires that students' curricular work: (1) satisfy ABET engineering criteria at the basic level for the program being evaluated (unless for that program area no program criteria exist, in which case general ABET basic-level criteria must be satisfied), and (2) have the equivalent of one additional year of study beyond that required for a basic-level program. This additional year must include at least two-thirds of a year of study in a combination of advanced mathematics, basic sciences, engineering sciences, and engineering design. Of this component, engineering design must constitute no less than one-third year. This additional year of study must consist essentially of subject material at an advanced level not normally associated with a basic-level program, including thesis, research, or special projects. Coursework should be arranged to meet the objectives of a particular program or to complete a meaningful individual course of study.

The following SPECIAL SECTION proposes changes to the entire IV.C.3. Curricular Content section of the criteria. This section has been reviewed by the Engineering Accreditation Commission (EAC), and approved in principle by the Board of Directors of ABET. Before being adopted for implementation in the accreditation process, criteria are to be circulated among the institutions with accredited programs, as well as other interested parties, for review and comment.

Comments on this section will be considered for an extended TWO YEAR period until June 19, 1992. Based upon comments received, the ABET Board of Directors will determine, with the advice of the EAC, the content of the adopted criteria. If approved, the adopted criteria will become effective following the ABET Annual Meeting in the fall of 1992 and will first be ap-

plied by the EAC for accreditation actions during the 1993-94 academic year and the following years.

Comments relative to the proposed criteria should be addressed to the Accreditation Director for Engineering, Accreditation Board for Engineering and Technology, 345 East 47th Street, New York, NY 10017-2397.

IV.C.3. PROPOSED

Course work which meets the ABET engineering criteria may be accomplished in fewer academic years than are normally required for the completion of basic-level or advanced-level degree programs. Although additional time is thus available in an accreditable engineering program for the implementation of individual educational objectives of students or their institutions, additional course work in engineering or related areas beyond that specifically required by ABET will be needed to fulfill the objective of preparing the graduate adequately to enter the engineering profession. The program must not only meet the specified minimum content but must also show evidence of being an integrated experience aimed at preparing the graduate to function as an engineer. The institution must address these needs and objectives in developing the program and its content. The institution should consider also the quality of its educational programs and assure sufficient individual attention to each student by the faculty. Section enrollments appropriate to class objectives and accessibility of faculty to students are considerations appropriate to the assessment of educational quality. Admission requirements should be established both to strengthen the quantitative approach to engineering and to support the development of the social and humanistic aspects of the engineering student's education.

In the statements that follow, one-half year of study can, at the option of the institution, be considered to be equivalent to 16 semester credit hours (24 quarter hours). (See footnote page 6.)

- a. For those institutions which elect to prepare graduates for entry into the profession at the *basic level*, ABET expects the curricular content of the program to include the equivalent of at least three years of study in the areas of mathematics, basic sciences, humanities and social sciences, and engineering topics. The course work must include at least:
 - (1) one year of an appropriate combination of mathematics and basic sciences,
 - (2) one-half year of humanities and social sciences, and
 - (3) one and one-half years of engineering topics.
- b. The overall curriculum must provide an *integrated educational experience* directed toward the development of the ability to apply pertinent knowledge to the identification and solution of practical problems in the designated area of engineering specialization. The

curriculum must be designed to provide, and student transcripts must reflect, a sequential development leading to advanced work and must include both analytical and experimental studies. The objective of integration may be met by courses specifically designed for that purpose, but it is recognized that a variety of other methods may be effective.

Some of the requirements in a particular curricular area may be met through elective courses. However, it is incumbent upon the institution to publish in its catalog or printed advisement guide directions for choosing electives that will assure that ABET engineering criteria are met by all students.

- c. The classification of a course into one or more of the curricular areas depends on the course content rather than the course title or the name of the offering department. A course may be classified as being partially in one curricular area while the remainder of it is in another.
- d. While ABET favors a flexible approach to the design of curricular content, it also recognizes the need for specific coverage in each curricular area.

These are:

(1) *Mathematics and Basic Sciences.*

- (a) Studies in *mathematics* must be beyond trigonometry and must emphasize mathematical concepts and principles rather than computation. These studies must include differential and integral calculus and differential equations. Additional work is encouraged in one or more of the subjects of probability and statistics, linear algebra, numerical analysis, and advanced calculus.

- (b) The objective of the studies in *basic sciences* is to acquire fundamental knowledge about nature and its phenomena, including quantitative expression. These studies must include both general chemistry and calculus-based general physics at appropriate levels, with at least a two-semester (or equivalent) sequence of study in either area. Also, additional work in life sciences, earth sciences, and/or advanced chemistry or physics may be utilized to satisfy the basic sciences requirement, as appropriate for various engineering disciplines.

- (c) Course work devoted to developing skills in the use of computers or computer programming may not be used to satisfy the mathematics/basic sciences requirement.

(2) *Humanities and Social Sciences.*

- (a) Studies in the humanities and social sciences serve not only to meet the objectives of a

broad education but also to meet the objectives of the engineering profession. Therefore, studies in the humanities and social sciences must be planned to reflect a rationale or fulfill an objective appropriate to the engineering profession and the institution's educational objectives. In the interests of making engineers fully aware of their social responsibilities and better able to consider related factors in the decision-making process, institutions must require course work in the humanities and social sciences as an integral part of the engineering program. This philosophy cannot be overemphasized. To satisfy this requirement, the courses selected must provide both breadth and depth and not be limited to a selection of unrelated introductory courses.

- (b) Such course work must meet the generally accepted definitions that humanities are the branches of knowledge concerned with man and his culture, while social sciences are the studies of individual relationships in and to society. Examples of traditional subjects in these areas are philosophy, religion, history, literature, fine arts, sociology, psychology, political science, anthropology, economics, and foreign languages other than the student's native language(s). Non-traditional subjects are exemplified by courses such as technology and human affairs, history of technology, and professional ethics and social responsibility. Courses that instill cultural values are acceptable, while routine exercises of personal craft are not. Consequently, courses that involve performance must be accompanied by theory or history of the subject.
- (c) Subjects such as accounting, industrial management, finance, personnel administration, engineering economy, and military training may be appropriately included either as required or elective courses in engineering curricula to satisfy desired program objectives of the institution. However, such courses usually do not fulfill the objectives desired of the humanities and social sciences content

mathematics and basic sciences on the one hand and engineering practice on the other. Such subjects include mechanics, thermodynamics, electrical and electronic circuits, materials science, transport phenomena, and computer science (other than computer programming skills), along with other subjects depending upon the discipline. While it is recognized that some subject areas may be taught from the standpoint of either the basic sciences or engineering sciences, the ultimate determination of the engineering sciences content is based upon the extent to which there is extension of knowledge toward creative application. In order to promote breadth, the curriculum must include at least one engineering course outside the major disciplinary area.

- (c) Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system descriptions. Further, it is essential to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact.

(3) *Engineering Topics.*

- (a) Engineering topics include subjects in the engineering sciences and engineering design.
- (b) The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between

- (d) Each educational program must include a meaningful, major engineering design experience that builds upon the fundamental concepts of mathematics, basic sciences, the humanities and social sciences, engineering topics, and communication skills. The scope of the design experience within a program should match the requirements of practice within that discipline. The major design ex-

perience should be taught in section sizes that are small enough to allow interaction between teacher and student. This does not imply that all design work must be done in isolation by individual students; team efforts are acceptable where deemed appropriate. Design cannot be taught in one course; it is an experience that must grow with the student's development. A meaningful, major design experience means that, at some point when the student's academic development is nearly complete, there should be a design experience that both focuses the student's attention on professional practice and is drawn from past course work. Inevitably, this means a course, or a project, or a thesis that focuses upon design. "Meaningful" implies that the design experience is significant within the student's major and that it draws upon previous course work, but not necessarily upon every course taken by the student.

- (e) The public, from catalog statements and other advising documents, and ABET, from the Self-Study Questionnaire, should be able to discern the goals of a program and the logic of the selection of the engineering topics in the program. In particular, the institution must describe how the design experience is developed and integrated throughout the curriculum, show that it is consistent with the objectives of the program as required by section IV C 2. above, and identify the major, meaningful design experiences in the curriculum.
- e. Other courses, which are not predominantly mathematics, basic sciences, the humanities and social sciences, or engineering topics, may be considered by the institution as essential to some engineering programs. Portions of such courses may include subject matter that can be properly classified in one of the essential curricular areas, but this must be demonstrated in each case.
- f. Appropriate laboratory experience which serves to combine elements of theory and practice must be an integral component of every engineering program. Every student in the program must develop a competence to conduct experimental work such as that expected of engineers in the discipline represented by the program. It is also necessary that each student have "hands-on" laboratory experience, particularly at the upper levels of the program. Instruction in safety procedures must be an integral component of students' laboratory experiences. ABET requires some course work in the basic sciences to include or be complemented with laboratory work.
- g. Appropriate computer-based experience must be

included in the program of each student. Students must demonstrate knowledge of the application and use of digital computation techniques for specific engineering problems. The program should include, for example, the use of computers for technical calculations, problem solving, data acquisition and processing, process control, computer-assisted design, computer graphics, and other functions and applications appropriate to the engineering discipline. Access to computational facilities must be sufficient to permit students and faculty to integrate computer work into course work whenever appropriate throughout the academic program.

- h. Students must demonstrate knowledge of the application of *probability and statistics* to engineering problems.
- i. Competency in written communication in the English language is essential for the engineering graduate. Although specific course work requirements serve as a foundation for such competency, the development and enhancement of writing skills must be demonstrated through student work in engineering work and other courses. *Oral communication* skills in the English language must also be demonstrated within the curriculum by each engineering student.
- j. An understanding of the *ethical, social, economic, and safety considerations* in engineering practice is essential for a successful engineering career. Course work may be provided for this purpose, but as a minimum it should be the responsibility of the engineering faculty to infuse professional concepts into all engineering course work.
- k. For those institutions which elect to prepare graduates for entry into the profession at the *advanced level*, ABET requires that students' curricular work (1) satisfy ABET engineering criteria at the basic level for the program being evaluated (unless for that program no program criteria exist, in which case general ABET basic-level criteria must be satisfied), and (2) have the equivalent of one additional year of study beyond that required for a basic-level program. This additional year must include at least two-thirds of a year of study in a combination of advanced mathematics, basic sciences, and engineering topics. Of this component, engineering design must constitute no less than one-third year. This additional year of study must consist essentially of subject material at an advanced level not normally associated with a basic-level program, including thesis, research, or special projects.

Course work should be arranged to meet the objectives of a particular program or to complete a meaningful individual course of study.

4. Student Body

This section of the criteria relates to the admission, retention, and scholastic work of students and the records of graduates both in further academic study and in professional practice.

- a. An important consideration in the evaluation of an engineering program is the quality and performance of the students and graduates. When students are carefully selected either at the time of admission or by appropriate retention standards, the level and pace of instruction can be high.
- b. In view of the increasing number of students who take their initial college-level work at institutions other than the degree-granting schools having programs accredited by EAC of ABET, it is appropriate for the degree-granting institutions to establish policies for the acceptance of transfer students and for the validation of credit for courses taken elsewhere. The institution must have in place procedures to assure that the programs of all transfer students satisfy all applicable ABET general and program criteria.
- c. Sources of information on the quality of student work include examples of examinations, homework problems, laboratory exercises, designs, and reports. These items, which include the competence of students in both subject matter areas and communication skills, must be made available to the visiting team.
- d. The record that graduates are making in the profession or in further academic study in other institutions is a factor to be considered in accrediting. An institution applying for accreditation of a program should be prepared, if possible, to produce records of graduates over a period of at least three years.

5. Administration

This section of the criteria relates to the attitude and policy of the administration of the engineering division towards teaching, research, and scholarly production, and the quality of leadership at all levels of administration of the division.

- a. A capable faculty can perform its functions best in an

Note For a program of 128 semester hours (192 quarter hours), one-half year of study equals exactly 16 semester hours (24 quarter hours). For a program requiring more than 128 semester hours or 192 quarter hours, 16 semester hours or 24 quarter hours may be considered to constitute one-half year of study in any of the curricular components specified by the ABET criteria. For a program requiring fewer total credit hours, one-half year of study is considered to be one-eighth of the total program. Programs using measurements other than semester or quarter hours will be evaluated on a reasonably comparable basis to the above.

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atmosphere of good relations with the administration. This requires good communication between faculty members and administrators, and a mutual concern with policies that affect the faculty.

- b. The college administration should have four basic roles: selection, supervision, and support of the faculty; selection and supervision of the students; operation of the facilities for the benefit of the faculty and students; and interpretation of the college to members of the profession and to the public. In performing many of these functions, the administrators should not operate alone, but should seek advice from individual faculty members, faculty committees, and special consultants.
- c. Constructive leadership by the dean of the college and by the heads or chairs of the departments is important. Characteristics of successful administrators often include engineering background and scholarly attainments, participation in the affairs of engineering organizations, positive interest in the educational process, cooperation with other administrators, and willingness to assume the responsibilities of the position.

6. Institutional Facilities

- a. An engineering program must be supported by adequate physical facilities, including office and classroom space, laboratories, and shop facilities suitable for the scope of the program's activities.
- b. The libraries in support of the engineering unit must be both technical and nontechnical, to include books, journals, and other reference material for collateral reading in connection with the instructional and research programs and professional work. The library collection should reflect the existence of an active acquisition policy; this policy should include specific acquisitions on the request and recommendation of the faculty of the engineering unit. While the library collections should be reasonably complete and should go well beyond the minimum collection required for use by students in specialized programs, there should be in existence such arrangements as are necessary for computer-accessible information centers and inter-library loan services for both books and journals. The library collections, whether centralized or decentralized, should be readily available for use with the assistance of a trained library staff, or through an open-stack arrangement, or both. The ultimate test of the library is the use made of it by the students and faculty. Use of the library depends on many factors including opening and closing hours, reading room space, availability and helpfulness of the staff, and accessibility of material.
- c. The computer facilities available to the engineering students and faculty must be adequate to encourage the use of computers as a part of the engineering educational experience. These facilities must be appropriate for engineering applications such as engineering computation, modeling and simulation, computer-assisted

design, and laboratory applications. Students and faculty should have ready access to computational facilities. These facilities should have reasonable turnaround and response time and a competent support staff. The ultimate test of the computer facilities is the use made of them by the students and the faculty.

- d. The laboratory facilities must reflect the requirements of the offered educational program. The laboratories must be equipped with instruments and equipment of kind and quality to ensure the effective functioning of the laboratory.

Each curriculum must have a carefully constructed and functioning plan for the continued replacement, modernization, maintenance, and support of laboratory equipment and related facilities. This plan is an essential part of these criteria and must be carefully presented, monitored, and implemented.

7. Institutional Commitment

This section of the criteria relates to the commitment of the institution, both financially and philosophically, to the program in engineering. This commitment may be evidenced by the relationship of the engineering unit to the institution as a whole, by the fiscal policy toward and the financial resources available to the engineering unit, and by the suitability of facilities including laboratories, libraries, and computer facilities.

- a. The organizational structure of a university should be designed to bring together and to correlate its resources effectively. ABET is specifically interested in the general status of the engineering unit and its programs in the institution, and in the overall administration as it relates to the engineering unit and the achievement of its educational objectives.
- b. A sound fiscal policy must ensure the provision of sufficient funds for the acquisition and retention of a well-qualified faculty; the acquisition, maintenance, and operation of office and laboratory facilities, equipment, and instrumentation; the creation and maintenance of a library, both technical and nontechnical; and the creation, maintenance, and operation of computer facilities appropriate to the needs and requirements of the engineering unit. A sound fiscal policy must ensure the provision of sufficient funds for the acquisition, retention and continued professional development of a well-qualified faculty.
- c. The institution must provide facilities adequate for the support of the engineering programs offered, as defined in section IV.C.5.a.

D. Cooperative Education Criteria

1. Identification

The requirements which must be fulfilled by students who enter and complete the cooperative education program should be identified in an official publication of the institution.

2. Requirements

In addition to meeting the general criteria for engineering programs, a cooperative education program must include the following requirements.

- a. Admission of students to co-op programs must be the responsibility of the educational institution.
- b. Formalized alternation of periods of full-time academic college training with periods of full-time work experience of approximately equal length.
- c. At least one calendar year of institution-supervised work experiences in several industrial periods.
- d. Enrollment by the student in the co-op program during the periods of employment. Evidence of cooperative education participation, progress, and employer evaluation of the student must be maintained as a matter of permanent institutional record.
- e. Productive academic relationship between the faculty of the college and the co-op program administrators.
- f. Efforts must be made to ensure that work assignments are related to academic and career goals, and that progressively more responsible positions are realized in the work experience periods.
- g. Students must be informed of the evaluation of their work experience.

3. Employer Commitment

There should be evidence of marked commitment on the part of the institution and the participating employers of the program. The cooperative work experience period should be more than incidental employment—it should be part of an industry training activity, recognized as an acceptable part of a professional employee development program.

V. PROCEDURE

A. Application and Preparation for Visit

1. Consideration of engineering educational programs with a view toward accrediting is done at the invitation of the institution. EAC of ABET is prepared to examine, for approval, any programs that appear likely to satisfy its criteria for education for professional entry or advanced specialized competence.

2. An institution that wishes to have any or all of its engineering programs considered for accreditation may communicate directly with ABET. Arrangements will then be made for securing information by questionnaire and for an evaluation of the educational facilities of the institution by a visiting team chaired by a member or recent member of EAC of ABET. It is suggested that an institution contemplating an accreditation evaluation for the first time contact ABET prior to making the formal request. This request should be made not later than March 1 preceding the academic year in which the campus visit is desired.

B. Confidentiality of Information

Information supplied by the institution is for the confidential use of ABET and its agents and will not be disclosed without the specific written authorization of the institution concerned

C. Visit and Report

1. Each visiting team is selected, on the basis of the programs to be considered, from lists provided by the professional societies. The visiting team reports its preliminary findings and recommendations in writing to the officers of EAC of ABET for editing and transmission to the institution visited

2. Between the time of the visit and the annual meeting of EAC of ABET the responsible administrative officer of the institution may submit to the Commission any supplemental information which he or she believes may be useful to the Commission in its consideration and appraisal of the visiting team's report. With reference to formal responses from institutions to the preliminary statements, the Commission will retain a flexible attitude but, in general, will base its accreditation actions on the status of the respective programs at the time of the on-site visit. The primary purpose of the response is to correct errors of fact or observation that were made at the time of the visit. Deficiencies existing at the time of the visit are considered to have been corrected only when the correction or revision has been made effective during the year of the visit and is substantiated by official documents signed by the responsible administrative officers. Where action has been initiated to correct a problem but has not yet taken full effect, or where only indications of good intent are given, the effectiveness of the corrective action (such as the employment of a new faculty member, the addition of new coursework, the provision of additional funding or new equipment, for example) must be evaluated by ABET at the time of the next scheduled visit or progress report

3. The reports of the visiting teams on programs in chemical engineering are viewed also by the Committee on Chemical Engineering Education and Accreditation of the American Institute of Chemical Engineers, which transmits its recommendations to EAC of ABET.

D. Accreditation Action

1. Final decision on accreditation rests with EAC of ABET, which acts on the recommendations made to it by the visiting team and on consideration of the institution's response to the preliminary report of findings or, in the case of actions based on progress reports, on the institution's report.

2. Accreditation of a program is granted for a specific period, usually three or six years. The term of accreditation is subject to review for cause at any time during the period of accreditation. Accreditation is granted if current conditions are judged to be meeting or exceeding the minimum requirements. If, for any reason, the future of a program appears precarious, or definite weaknesses exist, the accreditation will be granted for a shorter period, usually three years. Factors which might limit the term of accreditation include uncertainty as to financial status, uncertainty due to the nature of the administrative

organization, a need for additions to or improvements in staff or equipment, a new or changing curriculum, undue dependence upon a single individual, etc.

3. A "not to reaccredit" action under "show cause" is effective as of the beginning of the academic year closest to September 30 of the calendar year following the year of the "not to reaccredit" decision by an accreditation commission or by the Board of Directors in appeal cases. The notification to the institution shall indicate (a) that the termination supersedes the accredited status listing of the program in the current annual report and (b) that ABET expects the institution to formally notify students and faculty affected by the termination of the program's accredited status, not later than September 30 of the calendar year of the "not to reaccredit" action. When accreditation of a program has been denied by EAC and not reversed by the ABET Board of Directors on appeal, ABET will include a note in its next annual listing of accredited programs indicating the date of expiration of accreditation.

4. From time to time, an institution may decide to discontinue a program. ABET will work with the institution to assure validity of accreditation until the desired discontinuation date, providing that the following steps are taken.

- a. For programs being discontinued by the educational institution within the period for which accreditation has been granted, accreditation may be extended from the date of notification to the date of discontinuation on a year-by-year basis subject to acceptance by the EAC of a satisfactory continuation report by the institution
- b. For programs being discontinued on a specific date that is no more than three years beyond the current period of accreditation, EAC may choose to extend accreditation to that specific date with a "Termination" ("T") action. A visit will be required to implement this action
- c. ABET will include a note in its next annual listing of accredited programs indicating the expected date of discontinuation of programs receiving a "termination" action.

5. A comprehensive evaluation of an institution's total program under EAC of ABET purview, including all engineering programs accredited or seeking accreditation and the supporting and related offerings, will be held at intervals not exceeding six years. Interim accreditations of individual programs will not normally extend beyond the next scheduled comprehensive evaluation and accreditation date.

6. A list of programs which have been accredited by EAC of ABET is prepared annually and published in the Annual Report of ABET. The accredited status of a program listed in the Annual Report applies to all graduates who completed the program during the preceding year. In order to keep the list dependable and up-to-date, re-evaluations based on campus visits are made as required at intervals of six years or less.

7. The functions of ABET are restricted by its Participating Bodies to the granting of accreditation and the publication of a list of those programs that are approved. It has no authority

to impose any restrictions or standardizations upon engineering colleges, nor does it desire to do so. On the contrary, it aims to preserve the independence of action of individual institutions and thereby to promote the general advancement of engineering education.

E. Appeal

In the event an institution wishes to appeal an action of "not to accredit" taken by EAC of ABET, written notice of intent to appeal must be given to the Executive Director of ABET within thirty days of the date of notification of the action. Upon receipt of such notice, the President of ABET will appoint a special committee of the Board of Directors having a minimum of three members. This special committee will schedule a meeting at the ABET headquarters or other location as soon as practical and convenient for all parties concerned. Appropriate administrative officers of the institution and representatives of EAC of ABET shall be present at this meeting to consider the impor-

tance and relevance of statements submitted in support of the appeal. The findings of the special committee will be reported at the next scheduled meeting of the Board of Directors and the final action will then be taken.

F. Changes during Periods of Accreditation

It is the obligation of the administration officer responsible for the engineering program at the institution to notify ABET of any significant changes in staffing, administration, content and/or title of curriculum during the period of accreditation and to submit catalog revisions of accredited programs to ABET when the catalog revisions are published.

G. Further Information

Requests for further information relative to ABET and the engineering accreditation program may be addressed to the Executive Director, Accreditation Board for Engineering and Technology, 345 East 47th Street, New York, N.Y. 10017-2397.

**PROGRAM CRITERIA FOR CHEMICAL AND
SIMILARLY NAMED ENGINEERING PROGRAMS**
Submitted by the American Institute of Chemical Engineers

1. Applicability.

These program criteria apply to engineering programs including "chemical" and similar modifiers in their titles.

2. Curriculum.

a. Curricular Objective and Content. (Amplifies criteria section IV.C.2.)

Chemical engineers must receive thorough grounding in chemistry, and the chemistry courses they take should be the same as, or equivalent to, those taken by chemistry majors. An accreditable chemical engineering curriculum must include at least one-half year of advanced chemistry in addition to the usual two-semester (or three-quarter) freshman-level course in general chemistry. Up to one-eighth of an academic year of other advanced natural science may be substituted for advanced chemistry. Other advanced natural science must build on basic science prerequisites and may include physics, life sciences, and materials science. A portion of the advanced chemistry may be used to satisfy the basic science requirement as needed, and up to one-fourth of an academic year of advanced chemistry may be counted toward the engineering sciences requirement, provided that such advanced chemistry demonstrates an application of theory that qualifies it as chemical engineering science. In general, engineering science credits may not be used to satisfy the advanced chemistry requirement.

b. Engineering Sciences. (Amplifies criteria section IV.C.2.d.(2))

A coherent plan of instruction in the chemical engineering sciences must be provided to include material and energy balances in chemical processes; thermodynamics with emphasis on physical and chemical equilibria; heat, mass and momentum transfer; chemical reaction engineering; continuous and stagewise separation operations; and process dynamics and control. (Also see 2.a. above.)

c. Engineering Design. (Amplifies criteria section IV.C.2.d.(3))

The various elements of the curriculum must be brought together in one or more capstone engineering design courses built around comprehensive, open-ended problems having a variety of acceptable solutions and requiring some economic analysis.

d. Computer Use. (Amplifies criteria section IV.C.2.g.)

Appropriate use of computers must be integrated throughout the program. Acceptable computer use will include most of the following: (1) programming in a high-level language; (2) use of software packages for analysis and design; (3) use of appropriate utilities such as editors; (4) simulation of engineering problems.

3. Administration and Institutional Commitment.
(Amplifies criteria sections IV.C.4. and IV.C.6.)

When the chemical engineering program is administered outside a school or college of engineering, it must be demonstrated that the program is guided by qualified chemical engineering faculty and that the budgetary support and freedom of action are equivalent to those ordinarily found in a department of an engineering school.

APPENDIX B

KNOWLEDGE STATE SPACE STRUCTURE

1 HOW AND WHY

The entire formulation of the knowledge space structure for the knowledge to be transferred to the students in the undergraduate Chemical Engineering program began with the following observation that was found many times in research:

That which is currently being emphasized in today's education systems is how to do something. This needs to be modified so that we also teach why things happen. This way, when the graduated student is in a work situation, he can synthesize new knowledge (including how) by splicing basic science whys into a new application.

This leads to the following possible idea.

2 KNOWLEDGE INVOLVED IN UNDERGRADUATE EDUCATION

The factual knowledge of science and applications that need to be learned by undergraduate students resides at a variety of levels of abstraction. These levels range from the pure theory of math to the system level of a chemical plant and beyond. A few example levels are listed in Table B.1 below. To be a

successful chemical engineer, the student must learn knowledge from and about each of the levels.

Level (in increasing complexity)	Examples
pure theory	mathematics and its various branches
basic principle	conservation, equilibrium, path of least resistance
field applications	chemistry, physics, thermodynamics
discipline applications	chemical engineering, human factors
unit application	devices such as reactors and distillation towers
subsystem	porous catalysts, chemical separation systems
system (application)	chemical plant, polymer processing plant
total (micro) system (immediate environment)	city around plant, local and state politics
whole (macro) system (international environment)	international, corporate, country and global politics, logistics

Table B.1 Example Levels Of Science And Application Knowledge

3 REPRESENTATION OF CHEMICAL ENGINEERING KNOWLEDGE STATE SPACE

3.1 THE COMPLEX SPACE OF KNOWLEDGE OF SCIENCE AND APPLICATIONS AND PROCEDURES

The knowledge involved in the science and application facets of chemical engineering is not simple to represent. It is easiest to understand the breadth and interrelationships in this body of knowledge if it is first distilled down into a group of basic principles and then shown how these principles interrelate to form all the applications at different levels of complexity.

While this seems like a reasonable project, attempts at doing this quickly resulted in a disaster with pages of different integrations of levels of principles and applications. Basically, it was found that a small number of phenomenological principles could be combined in a myriad of different ways at a variety of different levels of inter-relational complexity and in a whole scale of

degrees of application involvement to form a space that went well beyond the 3 intended dimensions of phenomenological principles, applications, and level of complexity. Further, it was very difficult to sort out the procedures from this knowledge space and vice versa. In fact, it was this difficulty which first made the author aware that there were actually two different branches of knowledge that he was attempting to represent: tangible and intangible knowledge.

3.2 KNOWLEDGE OF ENGINEERING PROBLEM SOLVING

The extra dimensionality could only be partially explained by the separation of tangible and intangible knowledge. The answer finally originated in a definition from The American Heritage Dictionary.

Engineering: 1. The application of scientific principles to practical ends as the design, construction, and operation of efficient and economical structures equipment, and systems. 2. The profession of or the work performed by an engineer.

According to Hauser, "Engineering is creative solutions and a balancing of objectives." [Hauser 1988] From these two definitions, it was determined that there was another body of tangible knowledge that a successful engineer must hold. This body pertained to the knowledge involved in the creative, balanced, and efficient application of the scientific knowledge above to the solving of problems. In other words, this other body of knowledge contains the procedures that are used by the engineer in his work.

These procedures were found to fall into two categories. The first category contains the procedures used in problem solving. This includes such procedures as are involved in problem formulation, information gathering, making approximations and assumptions (including order of magnitude significance), top down design and bottom up design, system testing and verification, and many others.

The second category contains those procedures involved with the many tools used by engineers. They include the procedures associated with tabulated data (graph and table reading, interpolation, extrapolation, etc.), dimensional analysis, linear programming, computer modeling and simulation, optimization, tradeoff analysis, net present value and other economic tools, communication, and many others. While the tools available to the engineer may change with time, the functions they perform stay basically the same. This means that with time these procedures may change at the syntactic level. The overall procedures, however, remain relatively stagnant or only slowly changing over time.

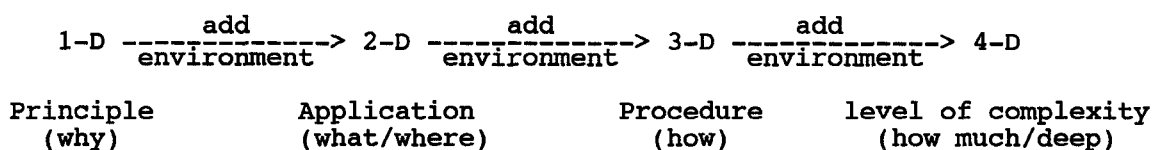
4 4-DIMENSIONAL REPRESENTATION OF KNOWLEDGE STATE SPACE

From this, it was finally determined that there were four basic dimensions that were involved in the representation of the state space of the undergraduate chemical engineering knowledge base. These dimensions are listed in Table B.2.

Dimension	Questions Answered	Knowledge/Object/Concept Orientation
(Phenomenological) Principle:	Why	Symbol Oriented
Application:	What and Where	Requirements Oriented
Procedure:	How	Algorithm Oriented
Level Of Complexity:	How much (level of) or to what depth	Inter-relational complexity (involvement, sophistication, depth of knowledge)

Table B.2 Knowledge Space Dimension Framework

Or, in an increasing dimensional synthesis format:



4.1 PHENOMENOLOGICAL PRINCIPLES

The first dimension contains the basic underlying phenomenological principles involved in the science of the field. The phenomenological principles can be seen as answering the why questions within the engineering knowledge state space, and are usually expressed as symbols on a theoretical level. A simple example is the principle of conservation.

4.2 APPLICATIONS

The phenomenological principles of the first dimension can be combined in various contexts to form all instances of the second dimension, that of applications. Applications can be seen as answering the what and where facets within the state space. A simple example is the principle of conservation combined with the context of chemical reactions to yield the second level

principle of conservation of mass and application of mass balances over a reactor, etc. Instances along the application dimension are usually requirements oriented and give bounds and definition (constraints of application of principle) to the usage of the principles.

These two dimensions can be utilized to represent the whole of the Science and Application Knowledge branch of Engineering Knowledge. However, this representation is impossible to interpret because it lacks the context imparted by the following two dimensions.

4.3 THE DIMENSION OF PROCEDURES

This dimension begins to allow us to understand the state space knowledge representation by answering the questions associated with "how". The information imparted by the answers to this question begins to allow us to see a context of the usefulness of the principles within the mechanisms associated with their contextual application. It is here that we can begin to see that this space is representative of the realm of engineering and not some other discipline. The orientation of this axis is in the form of a nominal listing of algorithms in no particular order other than grouping by similarity.

4.4 THE DIMENSION OF COMPLEXITY

The last dimension deals with the level of complexity of the knowledge. It is obvious that all the knowledge does not exist at the same level of sophistication or involvement. In fact, this dimension can be formulated as a demonstration of the measure of inter-relational complexity between basic principles, applications, and procedure instances in any combination. In more common terms, this is known to us as the abstract term "depth of knowledge".

5 KNOWLEDGE STATE SPACE DIAGRAM

It was with a conceptual understanding of this format of breaking down and understanding the knowledge to be transferred to the students that the state space of Figure 3.2, here reproduced as Figure B.1 was developed. This is not to

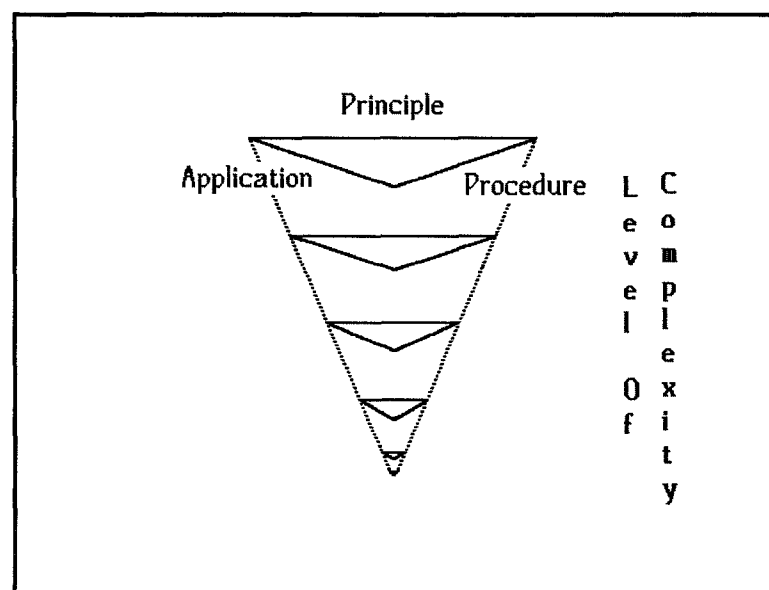


Figure B.1 Knowledge Space Representation

say that the knowledge in this space could not be represented in other forms. It is believed, though, that this form most closely suits the needs of the visions of how this designer views the knowledge.

Using this representation form to show all the knowledge involved in the undergraduate chemical engineering program was considered. The initial attempts at this, however, proved that this is an extremely ambitious and complex project that may itself be equivalent or even exceed the work of an average masters project. In addition, it was decided that it would be very difficult to represent this knowledge state space in a printable form. Thus, this space was left as a representation: one that was invaluable in the understanding of the type, vast breadth, and inter-relatedness (complexity) of the knowledge to be transferred to students in the four years of their undergraduate education.

APPENDIX C

TOPICS

C.1 DISCIPLINE SPECIFIC TANGIBLE KNOWLEDGE

Analysis And Understanding Of ChE Systems

Methods and tools:

- methods of ChE analysis
- methods and involved mathematics of ChE calculations
- units conversion
- energy and material balances
- basic rate laws (reaction, evaporation, diffusion, etc.)
- stoichiometric relations in conversion systems
- setting up of differential reaction equations with boundary conditions.
- analytical and computer methods including symbolic algebra & manipulation & differentiation & integration.

Processing facility and industry concerns:

- chemical process industries from the standpoint of technology, raw materials, products and processing equipment
- operations of major chemical processes and industries combined with quantitative analysis of process requirements and yields

Computers: Usage, Programming, And Engineering

PC introduction, usage and programming in the parallel or student chosen forms of DOS, Mac, Amiga, etc.:

- standard programs (word processing, spread sheet, data base, communications, drawing, etc.)
- canned & modular mathematical and scientific programs or libraries
- programming
- introduction to Object Oriented Programming and windows programming (any language)
- introduction to networks
- survey of current hardware and future trends

Workstation and larger computer usage:

- survey of forms and operating systems
- canned and modular mathematical and scientific programs or libraries
- programming, including parallel
- networks, including Internet, etc.
- survey of current hardware and future trends

Design

Principles of equipment, instrument, and small process design:

- current state of equipment and instrument technology
- current equip/instrument design software (vendor)
- advanced equipment forms for higher conversion, separation, etc.
- equipment chaining to increase conversion, concentrations, etc.
- maintenance concerns in design

Principles of large process and plant design:

- structure of chemical and other related industrial processing plants
- current equipment and instrument design software packages (FLOTRAN, etc.)
- sources and availability of standard process equipment/instrument
- sources and research of current and past design documentation
- functional breakdown
- alternative generation
- tradeoff studies
- process and plant synthesis from functions
- process and plant integration, eg. heat.
- process and plant control strategies
- process and plant control integration / distribution
- maintenance concerns in design
- bid proposal design concerns

Design Project methods:

- analysis of a design objective
- development of criteria
- determination of scope
- development (synthesis) of plant or process strategies and alternatives
- feasibility consideration
- preliminary tradeoff to narrow field
- design completion and first optimization
- final tradeoff study
- system testing
- evaluation
- design documentation, presentation and evaluation

Economics

- overall controlling economics of chemical and other related industrial processing plants
- cost breakdown and totalling
- net present value, future value, annuities, depreciation, etc.
- equip/instrument cost estimation methods
- capital and logistics costs estimation
- profitability / life cycle cost preference
- process and plant cost estimation methods
- capital and logistics costs estimation
- bid proposal economics

Kinetics

- reaction kinetics fundamentals
- reaction rate theory
- homogeneous reactions
- heterogeneous reactions
- single and multiple reaction systems
- equilibrium optimization (forcing the balance)
- catalysis
- electrochemical reactors
- biological reactors
- application to design and operation of reactors
- temperature effects on reactions and reactor design
- correlation of experimental data
- series reactor design principles
- fluidized bed design principles

Laboratory (Process) Experience

Lab experiments to illustrate:

- principles of heat, mass, momentum transport
- unit operation principles in small scale
- evaluation of performance & efficiency
- principles of thermodynamics
- chemical reaction engineering
 - ideal reactor
 - introduction of interplay of mass and heat transfer with kinetics

Exposure to provide:

- experience and understanding in equipment and instrument trouble shooting
- experience and understanding in equipment and instrument maintenance
- further exploration through open-ended projects

Maintenance

- major equipment categories, and summary of their components, advantages/disadvantages with respect to maintenance and maintenance requirements of each
- major instrument categories and summary of their components, advantages/disadvantages with respect to maintenance and maintenance requirements of each
- pumps, compressors, valves, seals
- material conveying systems
- material storage systems
- metal thickness and stress testing, tank and pipe integrity
- pressure release devices
- motor, etc., alignment
- steam traps
- heat exchangers, esp. power and steam systems
- ovens, furnaces, etc.
- heat tracing
- flares and incinerators
- process shutdown and other maintenance periods
- preventative versus as needed maintenance
- maintenance tools and measuring instruments
- empirical methods that really work and save time (requires VERY good industry maintenance source(s)).

Materials

Properties, Applications & Structures Of Materials:

- exposure to commonly used engineering materials (metals, ceramics, polymers, composites)
- basic useful properties of these materials
- material selection for an engineering applications
- molecular structure and microstructure of materials
- relationships between structure and properties
- survey of near and far future materials

Engineering Of Materials & Their Properties (structural, mechanical, chemical, surface, electric, etc.):

- elastic properties
- plastic deformation
- viscoelastic behavior
- chemical resistance
- corrosion
- heat treating
- doping / alloying
- multi-layered materials
- compositing
- survey of how engineering materials are protected from their environments

Mathematics

Advanced Engineering Mathematical And Computational Techniques Commonly Utilized In The Analysis And Solution To ChE Problems. To Include:

- manipulating symbolic equations on computer
- symbolic algebra
- symbolic logic
- fuzzy logic
- ordinary differential equations
- partial differential equations
- integral transforms
- vector algebra and calculus
- La Place and Z transforms
- Fourier series and analysis
- infinite series approximations and methods
- estimation
- iterative order of magnitude analysis
- numerical and statistical methods
- mathematical modeling at various levels
- numerical methods
- dimensional analysis
- data manipulation, including curve fitting
- running integrators, differentiators, averagers
- analog circuits
- amplifiers
- PID and other control equations
- minimum and maximum determination techniques

Optimization

Analysis of chemical processes:

- utilization of mathematical models to represent:
 - transport
 - chemical kinetics
 - etc.

Optimization of chemical processes:

- mathematical model based optimization methods
- minimum and maximum determination and utilization
- equilibrium equation forcing
- evaluation of process alternatives
- statistical methods
- non-linear system optimization
- trend exploitation

Process Control

Process modeling and dynamics:

- formation of physical & mathematical models of the thermal, electrical, mechanical, and chemical components of chemical processes
- Conversion of models to transfer functions.
- dynamic response of systems, including order of system

Control of systems:

- basic control theory
- open and closed loop system response
- control system design
- control system optimization
- statistical process control
- automatically optimizing controllers
- current and future instrument and equipment survey

Safety

Chemical process safety:

- analysis and management of fire and explosion hazards
- control of human exposure to toxic or other hazardous materials
- codes, standards, and regulations
- transportation and disposal of noxious substances
- analysis of drift from clouds, stacks, and flares
- venting of pressure vessels
- hazard evaluation and safety review procedures
- emergency plans for accidents and disasters
- safety in maintenance: design and procedures

Legal safety:

- law suit safety concerns and liability reduction
- plant security
- tradeoff methods in level of safety

Surface And Colloid Science

- principles of surface and colloid science
- principles of measurement and estimation of relevant parameters
- interfacial phenomena in emulsification, catalysis, detergency, etc.
- describing the nature of l/g, l/l, s/l, s/g interfaces
- surface tension: measurement, effects, and principles
- interfacial adsorption
- surface area and particle size determination
- dispersion stabilization / flocculation
- emulsification
- wetting

Thermodynamics

- introduction to thermodynamic meaning and consequences
- introduction to thermodynamic principles
- principle of conservation
- thermodynamic state
- properties of gases, vapors, liquids, solids, mixtures
- state transition, triple point
- phase, chemical, etc., equilibria
- the Carnot cycle
- work, heat, energy
- first, second, and third laws of thermodynamics
- applications to simple engineering systems (such as power plant loops for conservation of energy)
- threshold energies
- production of work from heat.
- thermodynamic analysis of operations
- thermodynamic maximum efficiency, efficiency factors
- equilibrium stage operations
- thermodynamics of chemically reacting systems
- thermodynamic properties of pure fluids and mixtures.

Transport Processes

Fluid Mechanics:

- fluid properties & statics
- flow concepts & basic equations
- viscous effects
- measurement of flow
- closed conduit flow
- packed bed and other ChE systems

Heat (Energy) Transfer:

- steady and unsteady state conduction
- convective heat transfer
- radiation
- design of condensers, heat exchangers, evaporators, etc.

Mass Transfer:

- steady & unsteady state molecular diffusion
- inter-phase transfer
- simultaneous heat and mass transfer
- boundary layer theory
- mass transfer and chemical reaction
- design applications in humidification, gas absorption, distillation, extraction, adsorption, and ion exchange

Theoretical similarities and differences between the principles of:

- heat (energy) flow and exchange
- mass flow and exchange
- momentum flow and exchange

Unit operations principles:

- stagewise transfer operations
- continuous transfer operations
- co- and counter-current flow and transfer
- analytical and computer staged and finite element modeling

Basic principles and respective equipment involved in:

- distillation
- gas absorption
- diffusion and doping
- humidification
- leaching
- liquid extraction
- mixing and micro-mixing

Other Topics

- blue print reading
- materials handling, transporting, and packaging
 - bulk, parceled
 - liquid, solid, gas
 - suspensions
- startup / shutdown
 - intermediate material handling
 - dynamics
 - timing and criticalities (esp. with heat recovery systems.)
- technical writing and other forms of communication
- cryogenic systems basics
- knowledge engineering

Support Tangible Knowledge

- Principles Of Electrical Engineering
- Introduction to Statics
- Introduction to Mechanics

Specialty Areas

Biochemical Engineering:

ENCH 482 Biochemical Engineering
ENCH 485 Biochemical Engineering Laboratory
ENCH 468 Research (1) recommended if 485 is taken

Polymers ("Applied Polymer Science"):

ENCH 490 Introduction to Polymer Science
ENCH 492 Applied Physical Chemistry of Polymers
ENCH 494 Polymer Technology Laboratory recommended if 490 or if 492

Chemical Processing:

ENCH 450 Chemical Process Development

Processing Analysis and Optimization:

ENCH 452 Advanced Chemical Engineering Analysis
ENCH 453 Applied Mathematics in Chemical Engineering
ENCH 454 Chemical Process Analysis and Optimization

C.2 BACKGROUND TANGIBLE KNOWLEDGE

CHEM 103, 113:	General Chemistry I, II	(4,4)
PHYS 161:	General Physics	(3)
MATH 140, 141:	Calculus I, II	(4,4)
ENES 101:	Intro Eng Science	(3)
ENES 110:	Statistics	(3)
ENGL 101:	Introduction to writing	(3)
MATH 241:	Calculus III	(4)
PHYS 262:	General Physics	(4) (includes lab)
MATH 246:	Differential Eqns for Sci & Eng	(3)
PHYS 263:	General Physics	(4) (includes lab)

C.3 INTANGIBLE KNOWLEDGE

- Intangible knowledge such as:
 - management knowledge and skills
 - communication skills: written, verbal, presentation, demonstration, instruction
 - ability (experience) in teamworking
 - ability (experience) to work in inter-disciplinary teams
 - ability (experience) to work independently
- Improve the student's ability to work just as effectively in inter-disciplinary teams as an individual.
- Improve the understanding, appreciation and incorporation of long range goals.
- Improve the student's knowledge, experience, and understanding of management.
- Improve the student's understanding of leadership and follower roles, including management, authority, responsibility, accountability, and the dissemination of these factors.
- decision-making knowledge, theory, and experience
- how to teach themselves (new or as needed info.!)

C.4 INTERDISCIPLINARY CONCERNS

- broad-based
- includes knowledge of a qualitative nature, especially knowledge in other disciplines
- emphasizes qualitative cause and effect analyses of technical, organizational, and social systems based on phenomenological or similarity principles
- encourages the students to develop, consider, and maintain higher level inter-disciplinary relationships in complex systems while working on their own small part of the system
- provides the breadth of knowledge, dynamic mindset, and other facilities necessary to quickly consolidate and move from one area of a project and then to likewise quickly pick up another area in the same or a different project at any time

- in order to facilitate inter-disciplinary movement, emphasizes a more generally applicable knowledge than is available in today's specialization dominated education
- allow for specialized focus students to still have large general knowledge education (Have a large need to figure out some way to continue and improve specialization and still allow inter-disciplinary working capabilities.)
- allows the student to build an extensive quantitative knowledge database in his area of specialization (if any), in his general discipline, and in other technical matters. This will be necessary for quantitative cause and effect analysis when the depth of the project does not warrant qualitative tradeoff studies.

APPENDIX D

UNDERGRADUATE COURSE SEQUENCE

FRESHMAN

4	Calculus For Engineers I
4	General Chemistry I & Lab
3	Computer Usage And Programming I
3	Introduction To Engineering Science

14

4	Calculus For Engineers II
4	General Chemistry II & Lab
3	Computer Usage And Programming I
3	Practical Statistics and Probability

14

SOPHOMORE

3	Differential Equations For Engineers
4	Organic Chemistry I & Lab
4	Physics For Engineers I & Lab
3	Introduction To Technical Writing

14

3	Applied Mathematics In ChE
4	Organic Chemistry II & Lab
4	Physics For Engineers II & Lab
3	Analysis And Understanding Of ChE Systems

14

JUNIOR

4/7	Thermodynamics
4	Transport Processes I
3	Mathematics
3	Physical Chemistry I
2	Physical Chemistry Lab
1/3/6	Engineering Materials

17 (minimum)

4	Transport Processes II
3	ChE Laboratory I
3	Physical Chemistry II
1/3	Process control
3	ChE Elective or Substitution (Materials II, Thermodynamic II, Safety)

14 (minimum)

SENIOR

3	Design & Econ Of ChE Equipment & Processes
3	Kinetics And Reactor Design
3	ChE Laboratory I
1/3	Safety
1	Other Topics
3	ChE Elective or Substitution (Materials II, Thermodynamic II, Transport III, Process control, Safety, Colloids, etc.)
3	ChE Elective

17 (minimum)

4	Design & Econ Of ChE Processes & Plants
1/3	Surface And Colloid Science
1/3	Optimization
1/3	Maintenance Of Chemical Systems And Plants
3/12	Basics Of Civil, Computer, Electrical, Mechanical And Software Engineering
3	ChE Elective

13 (minimum)

APPENDIX E

SEMANTIC AND SYNTACTIC KNOWLEDGE

(Also see the books by Shneiderman and Ellis)

Semantic Knowledge

"Knowledge about concepts." [Shneiderman 1987] Semantic knowledge is structured knowledge that is paradigm (an example or model) and algorithmic based. This can be further broken down into the more basic level of principles, which are schemata independent, and the more complex level of applications, which are examples of schema. This is shown in Figure E.1, which is modified from Shneiderman, p. 43. Semantic knowledge can be obtained by analytical learning and is relatively stable in memory.

Syntactic Knowledge

"Knowledge about device-dependent details." [Shneiderman 1987] Syntactic knowledge pertains to arbitrary and usually unlinked knowledge about the details of a particular application and/or procedure. In our knowledge space, it is often empirical. Syntactic knowledge needs to be rote memorized and is easily forgotten unless rehearsed or linked to a more permanent concept.

Both of these knowledge forms can reside in long-term memory.

Chunking

Chunking is the cognitive process of converting multiple units, usually of syntax, to one related group or item of semantic or possibly more basic syntactic knowledge to compress its volume. This is most often—but not exclusively—spoken of when referring to the operations of working memory (also called short-term memory).

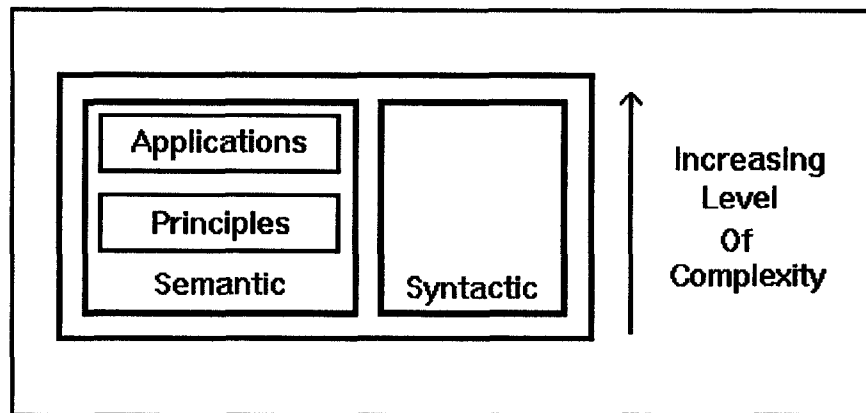


Figure E.1 Model Of Syntactic & Semantic Knowledge

A Learning Mechanism

Knowledge learning is a process of increasing conceptual understanding, usually realized by learning relationships. Usually, this is a process of accumulation and conversion of small amounts of syntactic information into the boundaries of an application (schema), which is then chunked into principles for better memory and storage. As such, it is inappropriate to attempt to teach basic principles or theories without first giving a relative application or less specific principle schema that is easily identified by the student.

APPENDIX F

CBT Workstation Concepts

- 1) **Uses Of CBT In The New Education System:**
 - 1) manipulatable application examples
 - 2) extra help
 - 3) can allow resources for student motivated in a particular subject to learn beyond that minimum given in class
 - 4) hypothesis testing
 - 5) instill high levels of interest and enthusiasm which can spark the incentive for extra learning
- 2) **Possible Formats For CBT System:**
 - 1) pc applications with each book, class, etc.
 - 2) computerized simulations for lab applications
 - 3) computerized simulations for application demonstrations
 - 4) encompassing workstation
 - 5) multimedia presentations, possibly even interactive, which teach a particular subject
- 3) **Dynamic Workstation Concepts:**
 - 1) develop workstation which can also be used later when practicing real profession
 - 2) make dynamic programs so that each semester improves and/or expands over the previous capabilities
 - 3) would also allow seamless tie-in with other useful programs such as MATHCAD, MATHEMATICA, graphics packages, word processing, spread sheets, communications, statistics, etc.
 - 4) encourage students, graduates, class projects, etc., to write/improve objects for this system. BS, MS, and PhD projects/theses should be encouraged to include this kind of work (can even include joint projects, giving CS grads, etc., projects to do for their theses). This kind of project would represent a more real world example of work and teamwork.
 - 5) Might consider making this expansion of capabilities a second project requirement. Eg. Require classes, thesis and workstation improvement project as prerequisites for graduation.
 - 6) Graduating students can take the current workstation software as limited shareware with them into the workforce when they graduate. This results in the following thoughts:
 - 1) makes these graduates much more placable / employable / desirable / in demand because of the tools they bring with them
 - 2) this would help the graduates get to productive work faster, decreasing a company's worker startup costs and allowing quicker break-even
 - 3) will infiltrate the commercial world with both UMD reputation, products, standards, and possibly start an engineering workstation revolution
 - 4) could aid in placement with company pledging of hardware and education funds in exchange for summer, coop, or post graduate work
 - 5) limit software use to about 5 (?) years and personal use only. This would

allow the opportunity for a significant revenue source for the university as graduate employing companies only can purchase the rights for other copies of the SW and/or continued use and/or upgraded SW (this increases the worth of graduates and keeps the university from becoming a business).

- 6) would result in an integrated workstation, which is most productive as a tool
 - 7) can cause very healthful competition (as long as interface is similar) between hardware, and other sources of SW, including other universities which would be forced to update and upgrade their current education systems.
 - 8) Can cause students to want to get involved in the form of their own education and the creation of their productive future.
 - 9) Can cause students to dump an "it cannot be done attitude" and instead instill a search out and/or create tools / industries, etc., mentality.
 - 10) Can begin the inevitable process which will bring all engineering disciplines (except for specialists which would be scientists, not engineers) back together into a singular practice of creative problem setup and solution design, instead of analytic problem solving with the aid of a large, integrated, and possibly intelligent engineering database and an appropriate database of well-formed problem solvers (mathematical, etc.) automatically linked to the appropriate system HW, SW and PeopleWare synthesis facilities.
 - 11) The desire to design more efficient, more natural, more comprehensive workstations would lead to more enlightened and pointed (useful) study of the current and optimum methods of engineering practices.
 - 12) Will eventually bring about an advanced engineering tool: the educated, intelligent workstation, available for human use and direction.
 - 13) Could eventually bring about a desire for increased connectivity even to globally integrated workstations (networked, not singular processed) which would improve by orders of magnitude the efficiency and usefulness of technology and science transfer
 - 14) This type of system would ease the transference of a job from one group or individual to another, as all the work is still there and the workstation will be able to remember the sequence of the work, preserving the thought patterns and progressions.
 - 15) Such a system will be developed by its users who can and will disseminate knowledge of the tools with their passage through their professions instead of keeping everything proprietary and secret.
- 7) Can stimulate very healthful competition between universities that would then be forced to update and upgrade their education systems continuously. This competition could possibly move U.S. education to long-term world superiority (services increasing importance and increasingly important for new products to balance trade deficit, decreasing product production / population required ratios, etc.).
 - 8) Can cause students to get involved in their own education as well as give them the motivations, desires, and other practices of self-education as needed for a given project.
 - 9) CBT and dynamic processing systems! (Tools and knowledge base and application examples and problem examples as extra help / extra learning) Can also make this a workstation tool that can then be later taken into the workplace. Can include future training of new capabilities, etc., by the new designers, that of the current students (!), which is a learning and experience for the students and the ChE's.

4) **Workstation Logistics:**

- 1) currently, equivalent to a 486/small SPARC/Sun system. (e.g. keep below \$10K)
- 2) centralized knowledge base (probably object oriented and/or hierarchial) with centralized interface, etc.

5) **Benefits Of Computer Based Training:**

- 1) great as a tool to demonstrate how a phenomenological principle is applied to a specific example once the principle of why has been properly understood.
- 2) can also remove the confusion about subjects due to mathematical or physical details behind the demonstration which otherwise may not be considered the main emphasis
- 3) can keep teaching consistent.
- 4) can keep teaching improving with time
- 5) can make learning even easier by introduction of direct manipulation and touchscreens or mouse manipulation for direct correlation to tangible semantics (bypasses syntactic because of previous complete links in memory). See Figure 5.11, p.203 of Shneiderman book.
- 6) can best teach phenomenological method with what will be the engineer's most useful tool in his/her actual careerwork: the integrated workstation
- 7) workstation can allow for better self-paced learning or extra-curricular browsing (especially for hypertext based systems) in areas of student's interest / focus
- 8) workstation can better allow for simultaneous specialization and basics learning by learning basic principles from examples within the specialization
- 9) can be the needed seed or catalyst to boost ChE into a new generation of growth, application and efficiency
- 10) makes conversion to Object Oriented Programming practices much more simple, straight forward, and natural
- 11) Can introduce CBT in and as tool modules, as they offer a tremendous appeal, variability, and adaptability with only major initial costs. Further, these costs can easily be defrayed by utilizing the programming and ideas of advanced and normal students to design and implement these tools, simulations, and other educational modules that they feel themselves or others can utilize. This encourages over-viewing, problem skills development, computer tool building, a helping mentality (instead of a competitive attitude), updating, refining, "full-team-teaching", computer usage, and numerous feelings of being useful and worthwhile.
- 12) Education programs need to be more personalized yet consistent.
- 13) Maybe these programs do not need to be so standard. They might do better if they were different for different people.
- 14) Due to the resulting need for increased numbers of instructors, this can only lead to CBT.

6) **Drawbacks Of Computer Based Training:**

Need to study the motivation and learning process in students to determine best paths and balances between computer demonstration and human instruction and the types of students where each has its greatest benefit.

Conclusion:

"Such an interplay between computer tools for demonstration and human instruction for the understanding of fundamental principles is what modern (and future??) engineering education should be about..." [Asbjornsen 1991]

APPENDIX G

Mathcad DEMO PROGRAM

This appendix shows just how far mathematical manipulation programs have advanced in the last few years. These programs are now both very powerful and very easy to use. This demo of the latest version of this popular program, Mathcad 3.0 -- for Windows 3.0 demonstrates this.

It is the opinion of the author that students and instructors in the undergraduate Chemical Engineering program can benefit tremendously from the utilization of programs like this. The author would have gone to great lengths to obtain such a program when he was in such an undergraduate program.

With the increase of personal computers and laptop computers, this form of program will become even more popular. This is because personal copies, available in the bookstore at discounted student prices, are much more convenient to access than similar programs such as MACSYMA and MATHEMATICA which are normally run on networks or workstations.

Demo and full programs are available in a variety of forms:

- PC Mathcad 3.0 (MS Windows version)
- PC Mathcad 2.5 (DOS version)
- PC Mathcad 2.0 (Macintosh version)

and each of these forms are available at student discounts. In addition, application packages are available for various science and engineering applications. Page 157 lists the topics which are supported in the Chemical Engineering package. For demo programs or other information, call 1-800-MATHCAD!

Mathcad®

How Mathcad Simplifies Math for Teachers and Students

Mathcad makes mathematics accessible, interesting, creative, and powerful for anyone using a computer to teach or solve problems. Mathcad's live document interface™ combines math, text, and graphics all on one screen—providing an easy transition from a calculator, blackboard, or pencil and paper. It allows teachers and students to express mathematical concepts and models in real math notation and to easily combine the math with text, plots and tables. The end result has the appearance of a page from a textbook, yet all the information is live and interactive, allowing the student and teacher to change assumptions and try "what-ifs".

Enhances lectures. Since the live document interface works like an electronic blackboard, Mathcad can be used in place of the blackboard with a flat panel projection device and an overhead projector. Teachers can demonstrate concepts and involve students interactively to visualize different solutions. By changing variables and assumptions, students can immediately see the new results as numbers, tables, or plots. Problems can be developed spontaneously, or prepared in advance and stored as easily recalled files.

A laboratory tool for exploration and group learning. Mathcad is an excellent way for students to explore and discover—either on their own, in groups, or in conjunction with lectures. Problems can be solved competitively between groups or as part of homework and individual study, greatly enhancing the student's involvement and learning experience.

A tool for homework. The live document interface lets teachers produce homework problems or tests as finished documents—combining math (in real math notation), text, tables and plots. When the student uses Mathcad to complete the work, the learning experience is greatly enhanced by the live document interface. It permits him or her to try numerous "what-ifs" by changing variables and assumptions. When complete, the student can easily generate a printout of the finished assignment.

Improves classroom productivity. Mathcad helps students break through the tedious parts of math and quickly move on to deeper underlying concepts and causes. Motivation and comprehension increase at all skill levels. Teachers who have introduced Mathcad into their classroom find that they now cover twice as much material at a significantly greater level of understanding.

A problem-solving tool. Given Mathcad's origins as a technical professional's tool, it's specifically designed to help the user apply math to real world problems. Mathcad has been proven in both academic and professional life. A student's time investment in Mathcad will increase in value as he or she enters professional life and applies Mathcad on the job. Mathcad is used with equal success by students in high school and scientists at national laboratories because of the easy-to-use live document interface. The only distinction between these two types of users is the number of features they access.

Mathcad can also be used for teaching and learning across the curriculum, in such areas such as math, engineering, physics, and economics. The ability to mix math, text and graphics in the live document in addition to Mathcad's ability to handle units of measure such as length, time, mass

MathSoft

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Fax 617-577-8829

Maximum power on a minimum of hardware. Mathcad packs a lot of computational power into a package that requires a minimal hardware environment. It operates well on less powerful machines and also supports all industry standard printers and graphics display devices.

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Call 800-MATHCAD to order or for more information.

To order Mathcad at special educational pricing, call our toll-free number, or use the order form on the reverse side. Mathcad is also available at university bookstores at special pricing. If it's not available there, just give us a call.

A few of the reviews...

"I have used Mathcad as a teaching tool for several years and have found that Mathcad empowers teachers to cut through the chaff to get to the core of mathematics. Mathcad enables students to explore, because with Mathcad, students are not consumed with the tedium of calculation and are free to experiment."
Benjamin Levy, Math Teacher, Beverly High School, Massachusetts

"This is the second year that I have used Mathcad as a 'required' text in my undergraduate course and I have had good success with it. Students are turning in better exercises and the comprehension level is up. However, it is no less work for the students than before because I have expanded the exercises to broaden their experience."
Lee C. Wensel, Professor, UC Berkeley, California

"As a final year engineering degree student, I find your software an invaluable aid to my studies, and it is obvious from its features and capability that a great deal of care and attention to detail by MathSoft, Inc. went into Mathcad's development — I still remain amazed at what Mathcad can perform."

The Mathcad 3.0 Demonstration

Congratulations. The math problems you need to solve are about to get a whole lot easier.

To give you a chance to try Mathcad 3.0, we've created this demo version of Mathcad. It has nearly all the features you'd find in Mathcad 3.0, along with some example documents and excerpts from Mathcad's Electronic Handbooks.

You'll be calculating and graphing like a pro in no time. You don't need to be an expert to use Mathcad, but it won't be long before you start to feel like one.

Mathcad 3.0 for Windows is a simple but powerful tool for doing numerical calculations, symbolic math, graphing, and documentation — everything you need to solve the math problems you deal with everyday. And it's not hard to learn, either.

Mathcad combines the "what-if" capabilities of a spreadsheet with the WYSIWYG interface of a word processor. This creates Mathcad's unique *live document interface*™. With Mathcad, you can type equations on the screen exactly the way you see them in a book. But Mathcad equations do more than look good on the screen. You can use them to actually do calculations.

Like a spreadsheet, as soon as you make a change anywhere in your document, Mathcad's *live document* goes straight to work, updating results and redrawing graphs. With Mathcad, you can easily read data from a file and do mathematical chores ranging from adding up a column of numbers to evaluating integrals and derivatives, inverting matrices and more. In fact, just about anything you can think of doing with math, you can do with Mathcad.

Like a word processor, Mathcad comes with a (what-you-see-is-what-you-get) interface, multiple fonts, and the ability to print your document on any Windows supported printer. This, combined with Mathcad's live document interface, makes it easy to produce up-to-date, publication quality reports.

Like a technical library, Electronic Handbooks provide a wealth of information you can paste directly into your document.

A brief introduction

Before you start, there are a few things you should know about Mathcad:

Mathcad's interface is based around the idea of a document. Type definitions and calculations into the document, and Mathcad shows them on the screen in standard mathematical notation. Mathcad reads documents the same way you do

from left to right, top to bottom.

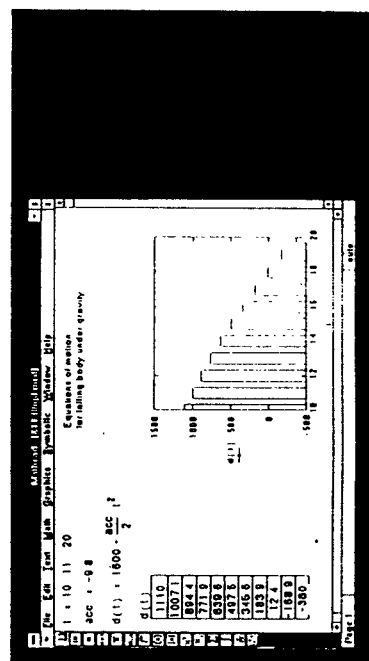
Mathcad can find solutions symbolically — simplifying complicated expressions, for example — and numerically.

You can put text anywhere on the screen using the entire array of Windows fonts. Outside equations, Mathcad behaves a lot like a word processor.

Mathcad's graphics features are easy to use — just put a graph anywhere you want on the screen, and fill in the blanks. Mathcad can plot anything from simple line graphs and curves to complicated surface plots.

Mathcad comes with Electronic Handbooks full of useful formulas and data you can paste right into your documents.

Finally — Mathcad 3.0 has been completely rewritten to take advantage of the Microsoft Windows 3.0 graphical environment. As a Windows application, Mathcad sports Windows' intuitive graphical features: pull-down menus, pointing and clicking, on screen fonts, and more. You can even use Windows to paste Mathcad equations or graphs into your favorite word processor — or vice versa!



Getting Started

To run this demo version, you'll need an 80286,

80386, or 80486-based IBM-compatible computer and:

- A mouse supported by Microsoft Windows. A hard disk with 3MB free space
- A 1.2 MB 5 1/4 or 720KB 3 1/2 floppy drive. MS-DOS or PC-DOS version 3.1 or later.
- A monitor and graphics card compatible with Windows. At least 2MB of RAM

To use Mathcad 3.0 as a full product, you'll need Windows 3.0 installed on your computer. If you don't have Windows 3.0, this demo version will install a slimmed-down demo version of Windows so you can try out Mathcad.

Installing the demo

To install Mathcad, make sure you are in DOS. Exit Windows if necessary. Then:

Place the disk marked "Program 1" in the floppy disk drive

- 1. Type the drive letter followed by a colon (:) to make the installation drive active. For example, type A:[_] if you've placed the disk in drive A.

Type **install** and follow the on-screen instructions.

- 2. If you already have Windows 3.0, this installation will then start Windows for you. If you don't have Windows 3.0, this installation automatically installs and starts a slimmed-down version of Windows 3.0 on your computer.

Notations and conventions

Throughout this booklet, **Bold** Courier represents keys you should type. You don't need to type spaces in equations. Mathcad puts them in for you.

All mouse clicks refer to the left mouse button.

Special keys are shown in brackets. Function keys and other special keys are enclosed in brackets. For example, [F 9] is a function key; [Bk sp] is the Backspace key.

Starting the demo

Once Windows is running, you can start this demo version of Mathcad.

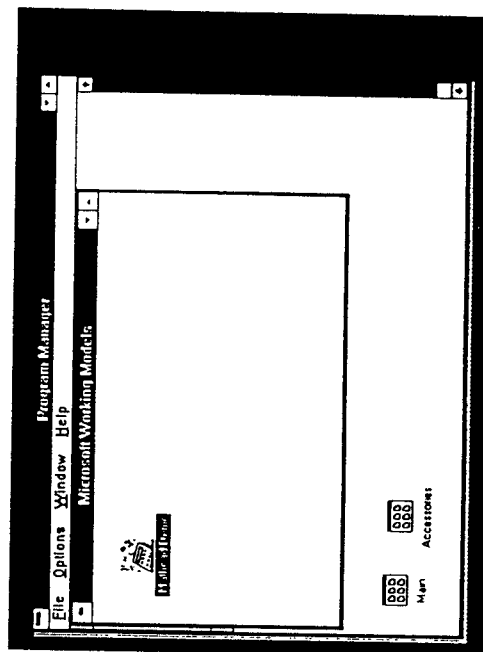
If the Program Manager window isn't already visible on your screen, double-click on it to open it up. You should see the Program Manager window, with icons:

For the purposes of this demo, you may need to change a setting in the Program Manager. You'll see the Options menu. If there's already a check next to Minimize on Use, you're set; just click again to close the menu. If not, choose.

To open the program group that contains the Mathcad demo, double-click on the **Microsoft Working Models** icon. You should see the Mathcad icon (a calculator with symbols floating around it) in the **Microsoft Working Models** window.

To start Mathcad, double-click on the Mathcad icon. A Mathcad window opens on to an empty document. You can exit the Mathcad demo at any time choosing **Exit** from the **File** menu. To exit Windows, press (Alt) (F 4)

Double-click here to start the demo.



Learning to use Mathcad

To make it easy to learn Mathcad, we've provided some demonstration screens. To see these screens, choose **Getting Started** from the **Help** menu.

It's easiest to learn to use Mathcad if you can see the Mathcad window and the demo window at the same time. Here's an easy way to do this:

Minimize all windows except the Mathcad and demo windows. To do this, click on the down arrow button at the upper right corner of each window.

Press **(Ctrl)[Esc]** to open the Task Manager window.

Click on the "Tile" button.

When you do this, the Program Manager arranges the two open windows side by side so that you can see both windows at once. The picture on the next page shows the Mathcad and help windows tiled this way.

"Getting Started" contains simple instructions on how to use Mathcad. Just follow the instructions and you're on your way.

To reveal more of a window, scroll it. You can either click in the demo window and press **(PgDn)**, or use the scroll bar.


At the end of each demo screen is a list of underlined topics. Click on one of these topics to go to its demo screen.

To leaf through the demo screens in order, click the "Browse" buttons. To find information on a specified topic, click on the "Search" button, choose a topic, and then choose a Help screen from the list in the bottom of the dialog box.

Using Help to learn Mathcad

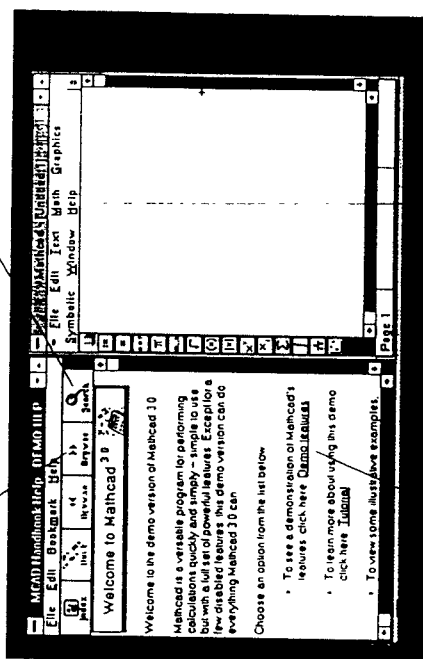
You'll find Mathcad's context-sensitive help system invaluable for learning Mathcad. You can get help on many operators, functions, menu items and even error messages. Just click on whatever you want help on and press **[F1]**. Mathcad jumps directly to the relevant help screen.

Try browsing through the help system to get an overview of Mathcad's features and how to use them. This demo version has everything Mathcad has except symbolic calculations, the ability to save and print documents, the ability to use the clipboard, and the ability to create documents larger than a page. Choose **Index** from the **Help** menu to get into Mathcad's help system.

Before you go on to the next example, click the  button on the upper right corner of the window to enlarge it.

Click here to view additional screens.

Click here to search for a particular topic.



Choose **Index** from this menu to access Mathcad's on-line help system. Or choose **Open Handbook** to access Mathcad's Electronic Handbook.

Click on the green underlined text to go to a screen or paste something into the document.

Mathcad documents come alive

On the next page is a typical Mathcad document. To see this document on your computer, choose **Open Document** from the **File** menu, then double-click on the file tank.mcd.

In this window:

Mathcad reads the document from left to right, top to bottom, just as you would expect. A " := " represents a definition, while = by itself asks Mathcad to calculate and display a result.

You can put text comments anywhere in the document.

You can use units on any quantity. Mathcad knows about common unit systems and keeps track of dimensions, converting results to whatever units you specify.

You can paste illustrations from other Windows applications right into Mathcad.

Go ahead and make some changes in this document. Here are some ideas to get you started:

Click on the 8 in the definition of a . Use [BkSp] to delete it. Then type in a new value. Press [F9] or click outside the definition and Mathcad updates the result instantly.

Click on "kg" at the bottom of the document. Use [BkSp] to delete it. Then type in another unit: "lb" or "gm" for example. Click outside the equation and Mathcad converts the result.

Try changing the specific gravity of seawater (1.028) to a new value. Click on the 8 and use [BkSp] to delete the old value. Then type in a new value.

Try changing the font of some text. Click the mouse in the middle of some text. Keep the mouse button pressed and drag the mouse. Mathcad highlights the selected text as you drag the mouse. Let go of the mouse button and choose **Change Font** from the **Text** menu.

Try dragging the picture to a new spot. Move the pointer near the picture, press and hold down the mouse button and drag the mouse until the dashed line encloses the picture. Then move the pointer inside and drag the picture.

Redefine variables to update calculations using new parameters.

Paste graphics and text from any Windows application using the clipboard

Place text in any font, size or style anywhere in the document

Built-in units include MKS, CGS, and US customary

The example files

The Mathcad demo version comes with several interesting example files. You can open any one of these, examine it, and even make changes and observe the results. With Mathcad's *live document interface*, you immediately see the effects of any changes you make.

To open a document, choose **Open Document** from the **File** menu. Then double-click on the document you want to see.

You can see an annotated list of these files by clicking on "Examples" on the first Getting Started screen.

Electronic Handbooks at the click of a button

Mathcad comes with its own on-line reference system as well. Mathcad's Electronic Handbooks make hundreds of useful formulas, data values and diagrams available in your document at the click of a button.

You'll never again have to pore through stacks of reference books to find that one crucial formula. Mathcad's Electronic Handbooks are fully indexed. You won't even have to write it down — Mathcad can paste formulas, data values and diagrams right into the document.

To open a handbook:

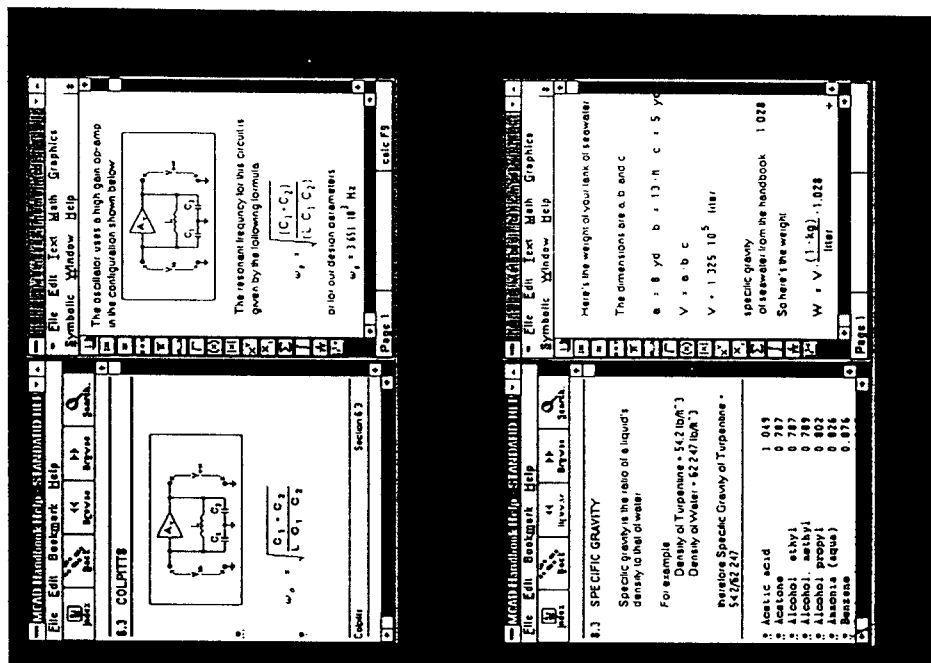
- ☐ Choose **Open Handbook** from the **Help** menu.
- ☐ Double-click on "standard" in the scrolling list. This opens up the Standard Handbook
- ☐ To make your screen look like those on the next page, press [Ctrl][Esc] and click on the "Tile" button
- ☐ Go ahead and browse through the handbook. Click on a topic in the index or click on the "Search" button. If you see something you want to paste into your document, just
- ☐ Click in the document window, then
- ☐ Click on the "_" beside whatever you want to paste.

Whatever Mathcad pastes, whether it's a diagram, a formula or a data value, becomes a part of your document. You can edit it, move it around or print it.

If a formula's not in the form you need, use Mathcad's symbolic features to transform it. Although symbolic features have been disabled in this demo, Mathcad 3.0 lets you simplify, expand, factor, differentiate, integrate, solve for a variable, even compute a Taylor series.

If a data value isn't in the units you need, backspace over the units and type new ones in. Mathcad performs the necessary conversions automatically.

If a diagram is too big or too small, you can resize it. Or you can paste it from Mathcad to any graphics editor to customize it for your application.



Click on an asterisk to paste from the Handbook into the document

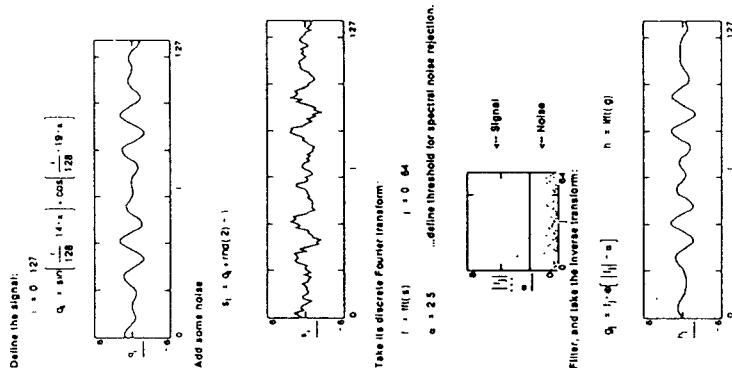
FFTs make signal processing a snap

The next page shows a printout from a document that does some signal processing — removing noise from a signal.

This printout shows some of Mathcad's sophisticated, yet easy to use mathematical features and file I/O capabilities.

- Mathcad reads data from other sources. In this document, the source data for the signal comes from data collected in an experiment.
 - Mathcad includes a full complement of sophisticated functions, including the FFT (Fast Fourier Transform), Bessel functions, statistical functions, and functions for eigenvalues and vectors.
 - The "vectorize" operator, appearing as an arrow, speeds up computation by letting you do parallel processing.
 - Plots are easy — just fill in the blanks.
- This sample file is on your hard disk. Go ahead and make some changes in it. Choose **Open Document** from the File menu, and load the file `fftfilt.mcd`. Here are some ideas to get you started
- Try changing `a`. As you decrease `a`, the filtered signal gets progressively noisier.
 - Click in either graph, then choose **Format Graph** from the **Graph** menu. Try changing some of the parameters of the graph.
 - Decrease the signal-to-noise ratio by changing `rnd(1)` to `rnd(10)`. The filtered signal will again get progressively noisier.
 - Try plotting just the noise component. Replace `s` with `q - s`. Use the left bracket key (`[`) to type subscripts

FILTERING A NOISY SIGNAL WITH FFT



Iteration

Mathcad is a tool for financial analysis as well as science and engineering. The document on the facing page performs a variety of calculations for mortgage analysis. This document shows:

- Range variables. These are variables with many different values. Use them to perform hundreds of calculations with a single equation.
- The summation operator. Mathcad supplies dozens of basic and advanced math operators including integrals and derivatives. Just click in the palette on the left side of the window to insert them into your document.
- Multiple fonts. You can use any Windows fonts for math or text. This document demonstrates bold and roman Helvetica in two different sizes.

A sample file similar to this one is on your hard disk. Go ahead and make some changes in it. Choose **Open Document** from the File menu, open the file mortgage.mcd. Here are some ideas to get you started.

- Change the annual percentage rate APR or the loan amount and see its effect on the payments.
- Adapt the document to a car loan. Set last to 4 or 5 and change **House_price** and **Down_pmt** to 15000 and 3000

The full version of Mathcad 3.0 comes with extensive symbolic math capabilities, a comprehensive handbook, full clipboard and printer support, and the ability to create documents much larger than a page. Feel free to make copies of these disks and this pamphlet to distribute to your friends and colleagues. Just make sure you copy all the files on all the floppy disks when you do

HOME MORTGAGE CALCULATIONS

Set up parameters of loan.

$\text{House_price} = 120000$ $\text{Down_pmt} = 10000$

$\text{Loan_amount} = \text{House_price} - \text{Down_pmt}$

$N = 15$ (number of years)

$M = 12 \cdot N$ (term of loan)

$\text{APR} = 10$ (annual percentage rate)

$i = \frac{\text{APR}}{12}$ (interest rate per month)

Compute the monthly payment.

$$\text{payment} = \frac{\text{Loan_amount} \cdot i \cdot (1+i)^M}{(1+i)^M - 1}$$

$\text{payment} = 1074.61$

Now compute payments through term of loan.

$$j = 1 \dots M$$

To compute monthly balances, start with **Loan_amount** and each month add interest, subtract payment.

$$\text{balance}_0 = \text{Loan_amount}$$

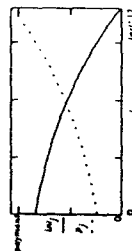
$$\text{balance}_j = \text{balance}_{j-1} \cdot (1+i) - \text{payment}_j$$

Compute principal and interest in each payment.

$$\text{int}_j = \text{balance}_{j-1} \cdot i$$

$$\text{pr}_j = \text{payment} - \text{int}_j$$

Plot interest and principal paid each month ...



Note that at first, payments are mostly interest. The curves cross when payments consist of equal parts of principal and interest.

Compute total interest paid:

$$\sum_{j=1}^M \text{int}_j$$

$$= 9463.54$$

$$\sum_{j=1}^M \text{pr}_j = 9463.54$$

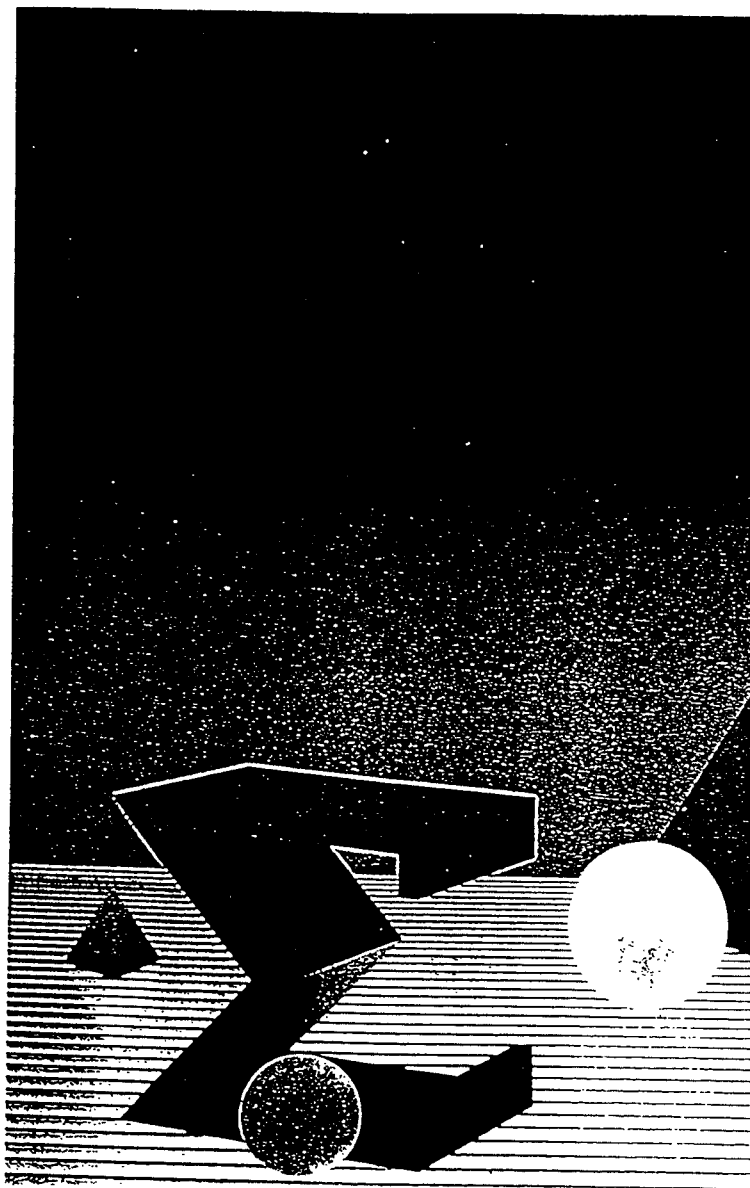
$$\sum_{j=1}^M \text{pr}_j = 9463.54$$

Useful formulas

$$\sum_{j=1}^M \text{pr}_j = 9463.54$$

$$\sum_{j=1}^M \text{int}_j = 9463.54$$

Mathcad® Applications Packs



10

Chemical Engineering

Thermodynamics

Determination of Equilibrium
Composition

Heat of Reaction

Heat of Formation

Steam and Furnaces

Steam Properties

Furnace Performance

Phase Equilibrium and Distillation

Binary Phase Diagrams for VLE

Isothermal Flashing

Sizing of Distillation Column Internals

Transient Heat Transfer

Transient Heat Conduction

Heat Exchangers

Outside Film Heat Transfer Coefficient

Inside Film Heat Transfer Coefficient

Agitated Vessel Film Heat Transfer
Coefficient

Clean Overall Heat Transfer Coefficient

Design Overall Heat Transfer Coefficient

Fouling Factor

Reactor Design and Kinetics

Rate Expression from Differential Method

Reaction Rate Equation Integral Method

Isothermal Batch Reactors

Sizing of CSTR

Non-Adiabatic Plug Flow Reactor

Effectiveness Factors

Fluid Flow

Flow Pattern Identification

Two-Phase Flow Systems

APPENDIX H

LEARNING & FORGETTING CURVES AND COGNITIVE LOAD

The following portion of this appendix is reprinted with permission from NCOSE and the author. [Asbjornsen 1991]

3.1. Human factors in teaching

A few very simple human factors have a great impact on the teaching and learning process. First, one has to realize the students' learning and forgetting curves illustrated in Figure H.1 Those curves may be simplified by exponential models [Asbjornsen 1990a]:

- Learning to a level L_o from scratch: $L = L_o(1 - \exp(-t/\tau_l))$ (1)
- Forgetting from a level L_o of full understanding: $L = L_o \exp(-t/\tau_f)$ (2)

The time constants of learning τ_l and the time constant of forgetting τ_f are very individual, but they are generally dependent on how a subject has been introduced. They are also dependent upon the interest and motivation for the subject. In general, those time constants are empirical and may only be obtained over several years of experience by a faculty. This hinges again on the encouragement from the university to the teaching function, which unfortunately is low in most cases. The sequence of introduction of subjects should really take

learning and forgetting curves into account, even in a qualitative sense, but they seldom are.

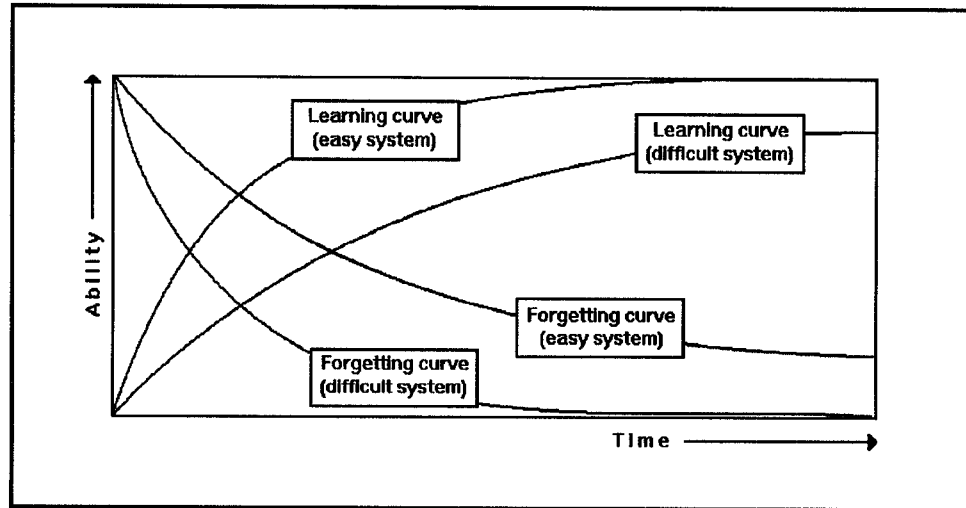


Figure H.1 Learning And Forgetting Curves

Secondly, one has to realize that there is an interesting correlation between amount and quality of information presented and the degree of confusion among the students [Asbjornsen 1976; 1989; 1990a]. This correlation was first introduced for operation in a large control room [Asbjornsen 1976], but they are equally well adaptable to the engineering education, as illustrated in Figure H.2. Even the confusion phenomenon may be modeled by a simple bucket curve. The qualitative explanation of the curve is simply that too little information leads to lack of complete understanding, and too much information chokes the ability to overview and understand:

- Level of confusion: $C = C_0(ai^{-\alpha} + bi^{\beta})$ (3)

where the optimal amount of information presented, leading to the least confusion, is simply:

$$i_{\text{opt}} = [\alpha a / (\beta b)]^{1/(\alpha + \beta)} \quad (4)$$

The parameters a , b , α , and β are empirical coefficients and the level of confusion C_o may be measured as the frequency of errors made. Those parameters are indeed dependent upon the quality of presentation of the

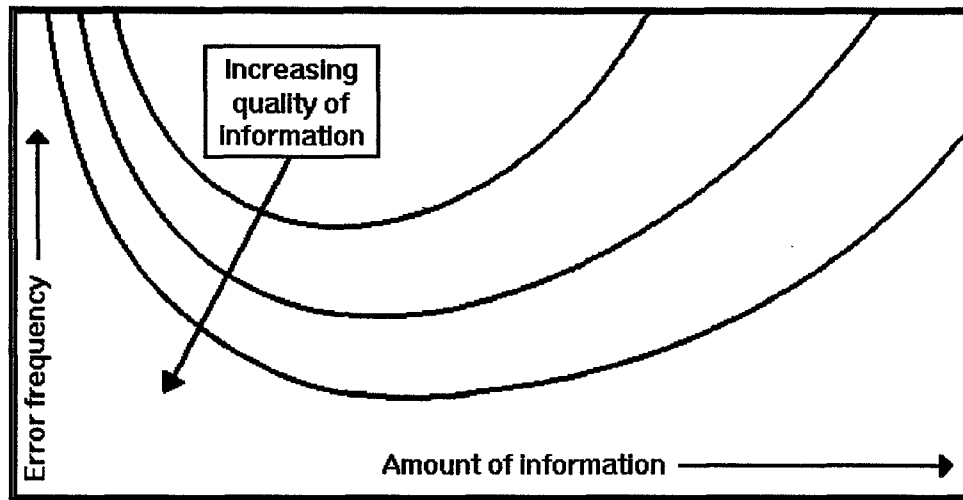


Figure H.2 Level Of Confusion In The Learning Process

information which may be used to improve the learning process from one class to the next. The problem here arises, namely the stochastic nature of the class background for a given course. Such variations require several classes and experiments to reveal significant trends. The willingness of a given class to enter such experiments depends highly on their confidence in the instructor, which also varies tremendously from one class to the next.

The learning process is very dependent upon the culture of a university. If the university traditions typically have a research emphasis, where grants and research publications are given overwhelming appreciation in specialized areas, the enthusiasm for teaching and learning is usually suffering. Systems engineering education, even at a graduate level, is typically not a research area, and that education will suffer from such a culture also.

--- End Reproduced Section

We are not always limited to acceptance of cognitive load as a limiting factor of the content of a particular subject. There are a number of ways that the cognitive load of a particular topic can be reduced, thus making learning easier and thus more possible.

For example, animation and structuring of the information into commonly recognized structures--such as trees, cyclic structures, etc.--can allow an increase in an individual's potential to perceive and process vast amounts of new or foreign data or information. This mechanism decreases cognitive load from normal methods because some of the data entry work is shifted to the unconscious perceptual system, which frees more of the conscious mind for higher level cognitive processing. [Clarkson 1991] This can be further used to advantage with the creation and use of animated mental models in the storage of this material in memory. This not only reduces the cognitive load less in its use,

but also makes recall easier in the future due to the added integration of the contextual key. The key to the successful use of this method in teaching is in the introduction and representation of the data or information in these formats.

Another way to decrease learning based cognitive load is to increase the frequency at which data becomes stored in long-term memory. One way this can be facilitated is by the inclusion of the opportunity for students to move quickly from learning to using. This reduces the total learning load size before a particular portion of that load is utilized, thus most often transferring that portion to long-term memory. In the extreme, however, too frequent storage can result in the stored data becoming too small in context. This would have the effect of breaking up the contextual bonding between the individual data chunks, thus decreasing its retention time.

Lastly, there seems to be some correlation between cognitive load and the level of abstraction of data. Specifically, for most persons, the more abstract a piece of data is, the larger its relative cognitive load in memory. This can be reduced by teaching and keeping peripheral context attached to highly abstract data. This possibly has the effect of increasing the percentage of assimilation of the abstract data, thus increasing the relevance of the data to a particular schema and thus its overall memorability.

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