THE ENGINEER AS MANAGER: COGNITIVE DIFFICULTIES
AND EDUCATIONAL REMEDIES

by

Mark Ernest Beckham

S.B., Massachusetts Institute of Technology, 1977

Submitted in partial fulfillment
of the requirements for the
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Master of Science
at the
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Signature of Author.
Department of Civil Engineering, July 6, 1979

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ABSTRACT

Data are examined to substantiate the observation that a significant portion of engineers eventually performs a managerial role. A conceptual framework is presented and utilized to review problems engineers may encounter as managers. Possible educational remedies at the undergraduate level are discussed and constraints on educational reform are noted.

Thesis Supervisor: Dr. Frank E. Perkins
Title: Chairman, Department of Civil Engineering
ACKNOWLEDGEMENTS

Several people made immense contributions toward the realization of this study.

The first word never would have been written without the friendship and professorial tutelage of David Major. If I had not known Dave, I would have gone to Harvard College. That would have been a mistake.

Frank Perkins provided invaluable intellectual stimulation for these words as well as patient and productive mentorship while I was an undergraduate. His insistence on ordered thought and communication motivated the development of the concepts presented.

I thank my brothers, Steve and Dave, for the legacy that "nothing is impossible". They have been the explorers and always have had the maps for lands I would like to visit. They pushed me from Oregon to the East. They have been models of achievement and demonstrators of the imperative of determination.

If Joanie sheds any tears over the end of these words, they will not be tears of sadness. I thank her for her understanding in times of stress, encouragement in the face of imminent failure, and accompaniment during countless days in inumerable libraries. I dearly hope the person she never has known--the one without this damn thesis to write--was worth the wait.
My parents, Dow and Anna, have always been the stabilizing force. They have been on the telephone from Coos Bay to Cambridge for six years. They are my continuing models of intelligence, sincerity, and compassion. They have provided the mind and body and unselfishly given free and unending opportunities for development. I am forever grateful for all they have meant to me and hope that I could approach their image should I ever find myself in their role.
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CHAPTER 1: INTRODUCTION

The management side of an engineer's practice is an inseparable portion of his day-to-day activities. Engineers work for managers, functions as managers, and frequently serve in both positions. Most importantly, the past has shown that more engineers have been taking on more managerial responsibilities at an increasing rate.

Focus

"Engineers" relevant to this discussion are distinguished along two dimensions: all engineers regardless of specialty versus civil engineers in particular; all engineers regardless of collegiate background versus engineers with undergraduate education at M.I.T.. These characteristics define four subject populations (Exhibit 1-1). The quadrants represent:

1. all engineers regardless of undergraduate background or engineering specialty
2. all civil engineers
3. civil engineers whose undergraduate education was at M.I.T.
4. all engineers whose undergraduate education was at M.I.T.

Although some data exist on the managerial issues of engineering education and practice for all quadrants, most data deal only with all engineers, regardless of specialty or background. Recognizing this obstacle, the focus herein
Exhibit 1-1

Schematic Representation of Engineers Relevant to this Study

<table>
<thead>
<tr>
<th>Engineering Specialty</th>
<th>All Engineers</th>
<th>Civil Engineers</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Colleges</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>M.I.T.</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
necessarily is on the managerial issues in the practice of all engineers and the implications for formal education. Wherever possible, additional attention is directed to graduates and undergraduate educational programs in civil engineering as well as those of the M.I.T. Civil Engineering Department (MITCED).

In terms of educational alternatives, most effort of this study is focused on formal educational programs at the undergraduate level. There are several reasons behind this orientation:

- a desire to limit the extent of an otherwise unmanageable topic
- the observation that undergraduate education is the only common experience of essentially all engineers
- a belief that the undergraduate years are extremely formative and, hence, impact during this period is highly leveraged over the length of a lifetime career

The Questions

Four principal questions will be considered in this study:

- Does a significant portion of engineers eventually perform managerial activities? (Chapter 2)
- What problems does an engineer face when functioning in the managerial realm? (Chapters 3 through 7)
- What are possible educational remedies at the undergraduate level in view of the problems of engineers functioning in the managerial realm and the different conditions necessary for achievement of particular types of learning? (Chapter 8)
- What are the normative determinants of feasible educational remedies at the undergraduate level? (Chapter 9)
Key Terms

Before preceding further, there are several terms whose meaning should be clarified: "manager", "managerial activities", "learned attributes", and "insufficient" versus "inappropriate" learned attributes.

Visualize the relationships that exist between these concepts (Exhibit 1-2). Verbally, the left chain indicates that "a 'manager' is involved in certain 'managerial activities' which require particular 'learned attributes'-- 'insufficient' and 'inappropriate' learned attributes can cause 'problems'". The corresponding right chain indicates that (1) some managerial activities are performed even when someone works as an engineer, (2) certain learned attributes required to perform managerial work may be part of the learned attributes necessary for engineering work, and (3) insufficient managerial learned attributes as well as application of learned attributes inappropriate for managerial activities may spell "trouble" for the engineer functioning in the managerial realm.

Formally, how should each of these key terms be viewed?

It will be helpful to think of engineers who function in some capacity as "managers" (often indicated, "engineer-managers") as "persons who have achieved professional qualifications but then become supervisors or coordinators of their nominal peers". In more detail, a "manager" is
Exhibit 1-2

Relationships Between Key Terms

the "manager"

"managerial activities"

"learned attributes required"

"inappropriate learned attributes"

"insufficient learned attributes"

"problems"

engineering activities

managerial activities

engineering learned attributes

managerial learned attributes

inappropriate learned attributes

insufficient learned attributes

"trouble" for the engineer-manager
"...that person in charge of a formal organization or one of its subunits. He is vested with formal authority over his organizational unit, and this leads to his two basic purposes. First, the manager must ensure that his organization produces its specific goods or services efficiently. He must design, and maintain the stability of its basic operations, and he must adapt it in a controlled way to its changing environment. Second, the manager must ensure that his organization serves the ends of those persons who control it (the 'influencers'). He must interpret their particular preferences and combine these to produce statements of organizational preference that can guide its decision-making. Because of his formal authority the manager must serve two other basic purposes as well. He must act as the key communication link between his organization and its environment, and he must assume responsibility for the operation of his organization's status system." ²

What are "managerial activities"? What do managers do? These questions have remained essentially unanswered for many years. Usual responses tend to conceal more than they reveal. Tyler Hicks wrote in 1966 that management in an engineering context is

"the organizing, planning, staffing, directing, leading, and controlling of the activities of engineers, scientists, designers, draftsmen, and other technical and non-technical personnel to achieve desired goals in the design, manufacture, construction, operation, or maintenance of a product, device, structure, or machine. Some management specialists define engineering management in terms of five M's -- men, money, materials, methods, and machines."³

Such definitions abound and are essentially restatements of Henri Fayol's words of 1916 that managers plan, organize, coordinate, and control.

What do managers really do? In recent years a particular
group of management scientists has been attempting to provide a more useful description of managerial activities. Henry Mintzberg divides managerial activities into three groups: those concerned with interpersonal relationships, those that deal with the transfer of information, and those that involve decision-making. Mintzberg describes these activities by way of ten roles (Exhibit 1-3). It should be observed that someone functioning in the managerial realm may be involved in elements of several roles at any one time. This approach has been successfully applied to develop managerial activity descriptions such as those in the Bayton and Chapman study Transformation of Scientists and Engineers into Managers (Exhibit 1-4).

The aim herein is to give a broad description of the manager's endeavors. Thus, to the degree that activities correlate with the description, activities from many areas involving engineer-managers may be included: management of the engineering firm, management of the engineering or construction project, and certain work performed while functioning as a specialist.

"Learned attributes" comprise the factual knowledge, intellectual and motor skills, thinking and learning strategies, and attitudes that are acquired by an individual through interaction with his environment. Changes in learned attributes relevant to this study are separate from changes which may
Mintzberg's Description of Managerial Activities

<table>
<thead>
<tr>
<th>Role</th>
<th>General Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interpersonal</strong></td>
<td></td>
</tr>
<tr>
<td>Figurehead</td>
<td>Symbolic head; obliged to perform a number of routine duties of a legal or social nature</td>
</tr>
<tr>
<td>Leader</td>
<td>Responsible for the motivation and activation of subordinates; responsible for staffing, training, and associated duties</td>
</tr>
<tr>
<td>Liaison</td>
<td>Maintains self-developed network of outside contacts and informers who provide favors and information</td>
</tr>
<tr>
<td><strong>Informational</strong></td>
<td></td>
</tr>
<tr>
<td>Monitor</td>
<td>Seeks and receives wide variety of special information (much of it current) to develop thorough understanding of organization and environment</td>
</tr>
<tr>
<td>Disseminator</td>
<td>Transmits information received from outsiders or from other subordinates to members of the organization; some information is factual, some involves interpretation and integration of diverse value positions of organizational influencers</td>
</tr>
<tr>
<td>Spokesman</td>
<td>Transmits information to outsiders on organization's plans, policies, actions, results, etc.</td>
</tr>
<tr>
<td><strong>Decisional</strong></td>
<td></td>
</tr>
<tr>
<td>Entrepreneur</td>
<td>Searches organization and its environment for opportunities and initiates &quot;improvement projects&quot;; supervises project design</td>
</tr>
<tr>
<td>Disturbance Handler</td>
<td>Responsible for corrective action when organization faces important, unexpected disturbances</td>
</tr>
<tr>
<td>Resource Allocator</td>
<td>Responsible for the making or approval of all significant organizational decisions</td>
</tr>
<tr>
<td>Negotiator</td>
<td>Responsible for major organizational negotiations</td>
</tr>
</tbody>
</table>
Exhibit 1-4

Bayton and Chapman's Description of Activities of Engineer-Managers

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budgeting</td>
<td>Budget preparation; justification of the budget; living within budgetary constraints</td>
</tr>
<tr>
<td>Reporting</td>
<td>Organizationally upward and downward (to provide information, to elicit information, to get action); laterally and outside the organization</td>
</tr>
<tr>
<td>Staffing</td>
<td>Personnel selections, training and retentions</td>
</tr>
<tr>
<td>Supervising</td>
<td>Directing work of others; personal counseling of subordinates; coordinating efforts of those outside one's own authority</td>
</tr>
<tr>
<td>Planning</td>
<td>Long range; scheduling and work layout; developing scheme to accomplish objective</td>
</tr>
<tr>
<td>Policy-Making</td>
<td>Establishing policies and procedures</td>
</tr>
<tr>
<td>Representing the Organization</td>
<td>At higher echelons; professional or public meetings, liaison with other agencies or groups</td>
</tr>
<tr>
<td>Consulting</td>
<td>Assisting other groups or organizations by virtue of technical or administrative knowledge</td>
</tr>
<tr>
<td>Program Assessment and Evaluation</td>
<td>Critically reviewing projects and programs for ultimate action by a higher authority</td>
</tr>
<tr>
<td>Fire-Fighting</td>
<td>Meeting unexpected day-to-day problems</td>
</tr>
</tbody>
</table>
occur because of maturation. Learned attributes and their relevant application are discussed further in Chapter 3.

Finally, problems an engineer-manager encounters result from "insufficient" or "inappropriate" learned attributes. For particular managerial activities, learned attributes may be insufficient to facilitate (1) effective and efficient performance, (2) recognition of one's own insufficiencies and identification of appropriate improvement or sources of outside advice, (3) necessary learning (e.g., lack of prerequisites). Similarly, learned attributes appropriate for engineering activities may be inappropriate for certain managerial activities. The engineer-manager, however, may have no learned alternative.

Methodology

This study is applied in nature. Methodology is based on collection of existing data which are central to the issues addressed.

The questions posed earlier indicate that identification of possible changes in undergraduate educational programs is a goal of this study. An "ideal" study which works toward that goal probably would appear similar to the process indicated in Exhibit 1-5. Several problems are immediately apparent.

First, the scientific method would suggest many iterations through the cycle in Exhibit 1-5. For reasons of time, money, and institutional and societal constraints, this is not
Exhibit 1-5

An "Ideal" Study of Curricular Change

identify educational objectives

identify a subject
population of graduates
and their particular
curricula

examine graduates to
determine problems

do problems indicate
objectives of undergraduate
curricula are being achieved? yes
no

assign problems to
particular characteristics
of curricula

identify possible
changes and order
of implementation

change curricula

stop
practical.

Second, it is difficult, if not foolhardy, to formulate a general set of objectives for all undergraduate engineering education. Additionally, it is often difficult to articulate accurately the educational objectives of a particular institution.

Third, it is difficult, if not impossible, to control the many factors which can affect the relevancy of data. For example, problems that graduates currently face can result conceivably from extinct curricula. Thus, employing such data to guide the change of current educational programs could be questionable. Additionally, students begin their undergraduate educational experience with differences in intellect and personality.

Fourth, data in many instances are not directly applicable or are deficient in other respects.

The methodology employed herein is definitely less rigorous than the ideal. However, it hopefully achieves in practicality what it lacks in rigor. The steps followed are generally,

- define and discuss problems that graduates may encounter
- suggest how these problems may be tied to particular insufficient or inappropriate learned attributes
- suggest possible alterations of the educational experience now available
Data utilized herein are subject to important limiting conditions:

1. Data are used to illustrate situations graduates may encounter

2. Data are generalizable from broad classes of engineers to specific classes based on the assertion that certain results of engineering educational programs are similar across specialties and institutions

3. Data are used only if (a) no evidence of its disconfirmation is available and (b) disconfirmation seems unlikely

4. Quantitative data are used wherever possible. Elsewhere, discussion is accompanied by testimony of individuals believed capable of "expert" opinion

5. Before implementation of any action implications of this study, original situation-specific analysis should be executed to verify key conclusions

Managerial activities are discussed, but no attempt is made rigorously to map learned attributes and their associated problems directly onto managerial activities. The focus is on the "trouble spots" in learned attributes of engineer-managers. In view of the many paths that graduates may follow, attention is restricted to those problems believed most fundamental to engineer-managers. The isolation and definition of these trouble spots are performed through reference to many sources.

**Study Objectives**

The objectives of this study are as follows:
(1) Address the four principal questions posed

(2) Develop reasoning, evidence, and conclusions so as to communicate to engineering educators and educational administrators (including those in civil engineering in general as well as those of the MITCED)

(a) the dimensions of problems graduates may encounter in the managerial realm

(b) possible educational solutions at the under-graduate level

(c) a conceptual framework to order issues for future discussion
Chapter 1: Endnotes


CHAPTER 2: ENGINEERS TO MANAGERS

Undergraduate engineering curricula are often restricted to principally technical studies. If an engineer must be competent in areas other than technical, this type of education may be insufficient or inappropriate over the long term. In view of the frequently discussed tendency of engineers to function in the managerial realm, does a significant portion of engineers eventually perform managerial activities?

There are two ways to address this question. First, one may examine whether a significant portion of managers has an engineering background. Second, one may examine whether a significant portion of engineers moves into positions involving managerial activities. Although the second approach is more definitive, both are explored and presented.

Managers Who Are Engineers

In 1952 the National Society of Professional Engineers surveyed more than 200 companies to gather data on issues relevant to engineer-managers.¹ Results pertaining to the portion of executives with training in engineering are displayed in Exhibit 2-1. Observe that

- 15% of those companies reporting noted that all their executives had an engineering or technical background
- Essentially all companies reported some executives with an engineering or technical background
Exhibit 2-1

% of Executives with Engineering or Technical Background (1952)
. On average, 20% to 25% of executives studied had an engineering or technical background

These observations are valid for one point in time: 1952. How has the portion of executives with engineering or technical background changed over time? Two studies on "Big Business Executives" address this question: a 1955 study by Mabel Newcomer and a 1964 sequel by Jay M. Gould. Pertinent results are displayed in Exhibit 2-2. The portion of executives with an engineering or technical background has grown dramatically over time. Additionally, Gould estimates that in 1980 more than 50% of top executives will have an engineering or technical background.

It seems reasonable to conclude that a significant portion of people in managerial positions has an engineering or technical background.

Engineers Who Become Managers

Several studies have been performed to describe the movement of engineers into managerial positions. Data from sources known reliable are displayed in Exhibit 2-3.

Certain observations can be made for all engineers, regardless of specialty or background:

. Between 50% and 60% of engineers eventually move into principally management oriented positions

. Between 80% and 90% of engineers eventually have some managerial responsibility

25
Exhibit 2-2

% of Top Executives with Engineering or Technical Background in 500 Largest U.S. Non-Financial Corporations
Exhibit 2-3

% of Engineers Functioning in Management

- principally management oriented
- any supervisory responsibility

1969 Engineers Joint Council study (all engineers)

1978 Auburn University study (AU civil engineers)

1971 M.I.T. study (M.I.T. engineers)

1955 Univ. of Cal. study (UOC engineers)

1939 M.I.T. study (M.I.T. engineers)

1964 Stevens Institute of Technology study (all engineers)
The trend of "engineer to manager" has been accelerating:
--in 1939 approximately 10% of engineers sampled were principally managers 10 years after graduation (M.I.T. study4)
--in 1978 approximately 50% of engineers sampled were principally managers 10 years after graduation (Auburn University study9)

Exhibit 7-3 also facilitates assertions on civil engineers in general as well as M.I.T. civil engineers:

. Based on one sample of civil engineers (Auburn University9), it appears that civil engineers in general move into managerial positions at least as rapidly and as extensively as other engineers

. Generalizing from data on M.I.T. engineers and civil engineers from another institution, it appears probable that M.I.T. civil engineers move as rapidly as other engineers into managerial positions

Conclusions

A significant portion of engineers eventually performs managerial activities. Several observations substantiate this conclusion:

. Possibly half of executives have an engineering or technical background

. At least 80% of all engineers eventually perform some managerial function and at least 50% eventually function principally in a managerial role

. At least 60% of all engineers have some managerial responsibility within five years after finishing undergraduate study

If these observations are valid, the intent and substance of
undergraduate educational programs should be designed with this in mind.
Chapter 2: Endnotes


5. "What Engineers are Doing 6-30 Years After Graduation", Power Engineering, August 1955, p. 100.

6. Basil J. Candela and Frederick J. Gaudet, "Do Engineers Make Good Managers?", Factory, March 1964, p. 82.


CHAPTER 3: A CONCEPTUAL FRAMEWORK FOR WHAT IS LEARNED

How does an engineer-manager mentally process what is known or what is learned? Conscious as well as unconscious processes exist, both of which are important.

What does an engineer need to know in order to function in the managerial realm? Exhaustive enumeration is not possible. The approach taken herein is to focus on the exceptions--those classifiable bits of knowledge which become obvious requirements once their need causes a problem.

What conditions must exist for specific learning to occur? Conditions both internal and external to the learner must exist. Conditions necessary for learning which involves unconscious processes may be much more difficult to specify than conditions necessary for conscious learning.

Why does an engineer-manager encounter problems? Problems result from insufficiency, inherent inappropriety, or inappropriate application of what is learned.

The Concepts

Use of a conceptual framework is often valuable in problem-solving. A conceptual framework is imperative where reasoning must be clearly and cogently communicated:

"In nearly all problem solving there is a universe of alternative choices, most of which must be discarded without more than cursory attention. To do otherwise is to incur costs beyond the value of any solution and defer decision beyond the time horizon. A frame of
reference is needed to screen the intuitive selection of assumptions, relevance of data, methodology and implicit value judgments. That frame of reference is the concept."

--Bruce D. Henderson
President
Boston Consulting Group

This study is no exception to the need for concepts. The four concepts utilized have been borrowed from the literature and used intact, borrowed from the literature and revised, or created from independent thought: a model of cognitive processes (revised/created), a categorization of what is learned (borrowed), an outline of conditions necessary for learning (borrowed), and a model associating problems with certain conditions of what is learned (created).

**Cognitive Processes**

The dictionary defines "cognition" as "the act or process of knowing including both awareness and judgment." Henry Mintzberg writes,

"Managers use the word judgment to refer to thought processes that work but are unknown to them. Judgment seems to be the word that the verbal intellect has given to the thought processes that it cannot articulate."\(^2\)

Mintzberg continues,

"The managers' programs--to schedule time, process information, make decisions, and so on--remain locked deep inside their brains. Thus, to describe these programs, we rely on words like judgment and
intuition, seldom stopping to realize that they are merely labels for our ignorance."4

Finally, Mintzberg adds,

"The mystification of conscious behavior is a favorite ploy of those seeking to protect a power base (or to hide their intentions of creating one); this behavior helps no organization, and neither does forcing to the realm of intuition activities that can be handled by analysis."5

Indeed, there seem to be things that are "known" and can be articulated consciously as well as those that are equally "known" but cannot be consciously articulated. Numerous adjectives are applied to describe processes and knowledge in each state:

- explicit versus implicit
- conscious versus unconscious
- light versus dark
- analytic versus intuitive
- intellectual versus gestalt
- serial versus relational
- argument versus experience
- verbal versus spatial

Processes or knowledge in the former state can be experienced when verbalized or articulated in conscious thought. Processes or knowledge in the latter state can be experienced only through performance or transference to and verbalization in the
The distinction between conscious awareness and intuition is helpful when coupled with two other bodies of knowledge: the "information-processing theory" of learning and thinking and knowledge from neurology and psychology concerning the specialized functions of the hemispheres of the brain.

The information-processing theory of learning postulates certain structures in the central nervous system that transform "inputs" to "outputs" in a manner analogous to a computer. An arrangement of such structures which allows for the existence of both conscious and intuitive domains is illustrated in Exhibit 3-1. This is essentially an illustration of what may go on within the learner's or thinker's head.

Referring to Exhibit 3-1, the environment affects the "receptors" (the senses) and information is then accepted by a "sensory register". Information is coded by the sensory register and remains there for only a fraction of time before being dispatched to conscious or unconscious "short-term memory". Short-term memory has a limited capacity and persistence is a matter of seconds (although persistence can be extended through the process of "rehearsal"). If information is to be remembered it is transformed once again and enters long-term memory. The information-processing theory holds that long-term memory is permanent and that failure in ability to recall is a result of "not finding" the information. The conscious and unconscious processors transform information via...
Exhibit 3-1

Cognitive Processes

what is known can be articulated
what is known cannot be articulated

long-term consciously retrievable memory
long-term unconsciously retrievable memory

short-term memory conscious processor unconscious processor short-term memory

sensory register

effectors

receptors

environment
executive control routines and "expectancies" as well as problem-specific programs or "skills". Action occurs through direction of the effectors (limbs, muscles, etc.).

Now, is there any evidence that there are in fact structures involved in conscious and unconscious/intuitive processes? Evidence of such structures is reported by Robert Ornstein in his book *The Psychology of Consciousness*. As alluded, the evidence concerns information from psychology and neurology describing the specialized functions of each hemisphere of the brain.

If in fact the hemispheres can be characterized as conscious/analytic and unconscious/intuitive, what are the specialties that each has been observed to display? Mintzberg has summarized Ornstein's data:

"In the left hemisphere of most people's brains (left-handers largely excluded) the logical thinking processes are found. It seems that the mode of operation of the brain's left hemisphere is linear; it processes information sequentially, one bit after another, in an ordered way. Perhaps the most obvious linear faculty is language. In sharp contrast, the right hemisphere is specialized for simultaneous processing; that is, it operates in a more holistic, relational way. Perhaps its most obvious faculty is comprehension of visual images..."

"What does this specialization of the brain mean for the way people function? Speech, being linear, is a left-hemispheric activity, but other forms of human communication, such as gesturing, are relational rather than sequential and tend to be associated with the right hemisphere..."

"Now, scientists have further found that some common
human tasks activate one side of the brain while leaving the other largely at rest. For example, a person's learning a mathematical proof might evoke activity in the left hemisphere of his brain, while his conceiving a piece of sculpture or assessing a political opponent might evoke activity in his right...

"Some people--probably most lawyers, accountants, and planners--have better developed left-hemispheric thinking processes, while others--artists, sculptors, and perhaps politicians--have better developed right-hemispheric processes. Thus an artist may be incapable of expressing his feelings in words, while a lawyer may have no facility for painting. Or a politician may not be able to learn mathematics, while a management scientist may constantly be manipulated in political situations...

"Now, reflect on this for a moment. There is a set of thought processes--linear, sequential, analytical--that scientists as well as the rest of us know a lot about. And there is another set--simultaneous, relational, holistic--that we now little about. More importantly, here we do not 'know' what we 'know' or, more exactly, our left hemispheres cannot articulate explicitly what our right hemispheres know implicitly...

"Maybe 'he has good judgment' simply means 'he has good right-hemispheric models'."8

Finally, it is inferred that the conscious domain is specialized to assimilate ordered thoughts (e.g., concepts, theories, language) and the intuitive domain is specialized to assimilate unordered experience (e.g. painting, negotiating, leading). Note that the construction of Exhibit 3-1 implies that there is some relationship possible between the conscious and intuitive domains. At least three possible interactions are apparent.

First, concepts and skills such as geometric postulates
and methods of logic are usually acquired through the conscious
domain. However, repetitive drill in application can result
in their becoming "internalized": the underlying principles
can now be applied with more dependence on intuitive relation-
ships and less on conscious analysis. An engineer has noted,

"While I was in civil at Princeton I really had the
basic structures problems internalized--they were in
many cases virtually intuitive."

--Michael Porvaznik
Consultant
formerly with Water Resources Engineers, Inc.

Thus, acquisition of analytic tools potentially can have impact
on the intuitive domain.

Second, a relationship developed and utilized in the
intuitive domain may surface and be articulated in the con-
scious domain. As a possible example, an accountant has noted,

"In the fiscal year ended last June 30, SCM reported
'record' earnings per share of $3.75, up from $3.70
the year before. Experience suggests that such slim
margins of year-to-year improvement are frequently
accompanied by interesting and/or unusual accounting.
Examination of the SCM annual report and 10-K did
provide some such examples. It is possible to con-
struct revised figures respectively of $2.00 and
$4.46." (emphasis provided)

--Lee J. Seidler
Professor of Accounting
New York University

Third, learning locked in the intuitive domain may be
"known" but "not known": What is known intuitively may be
articulated only through conscious observation of performance which utilizes the intuitive knowledge. A ballet instructor has noted,

"Most all who come here have fine bodies and good coordination, and they quickly learn the positions in the book sense. But first-class work can only be done by those who can shed their inhibitions... Some have 'it'; some don't. I don't pretend to understand it, even though I can recognize it quickly." (emphasis provided)

Additionally, a student may learn implicitly through solution of numerous problems that an effective strategy is to "suspend judgment, don't jump to a final conclusion but try many". This may be repeatedly, intuitively employed to guide the solution of novel problems. This strategy may be inferred by an outside observer or inferred by the possessor of the strategy through conscious analysis of behavior.

In sum, the value in articulating this model of cognitive processes is twofold. First, it provides a model which can be exercised while the categories of "what is learned" are discussed. "What is learned" constitutes the "data" and "programs" of cognitive processes. Second, it points up the importance of the conscious as well as the intuitive domains.

The Categories of What is Learned

Many educational researchers have made contributions toward a "taxonomy of learning" (simply, a categorization of what is learned): Arthur Melton$^{12}$, B. S. Bloom$^{13}$, R. E.
Hilgard\textsuperscript{14} to name a few. The categorization found most useful is that of Robert Gagné.\textsuperscript{15} "What is learned" is referred to as an individual's "learned attributes". Gagné observes five types of learned attributes: factual knowledge, intellectual skills, cognitive strategies, attitudes, and motor skills.\textsuperscript{16} In terms of the previous model, cognitive strategies and attitudes determine "how the cognitive system runs". Intellectual skills determine "what problem-specific programs are available". Factual knowledge constitutes the "data" of thought. (Motor skills are not discussed herein.) These four learned attributes are keys to chapters to follow.

Factual knowledge is an organized body of information where the words have meaning for the possessor of the information. Examples include "engineers often move into management", "M.I.T. is located in Cambridge, Massachusetts", "\pi \text{ is approximately } 22/7", "M.I.S. means Management Information System". Factual knowledge serves several purposes. First, it is often a prerequisite for further learning (e.g., it is helpful to know the names of basic accounting statements as background to understanding accounting). Second, it includes certain practical information necessary for everyday life (e.g., "I must remember that John Adison in marketing doesn't understand my linear programming approach to resource allocation"; "my social security number is..."). Third, it functions as a vehicle for thought in novel problem-solving (e.g., a basic description of
the theory of entropy may provide a stimulating analogy for
the solution of an economic problem). Fourth, broad factual
knowledge often permits the generalization of skills between
fields of endeavor (e.g., application of dynamic programming
to transportation problems as well as manufacturing plant
scheduling).

Intellectual skills provide the learner certain means of
interacting with his environment: mathematical skills, lan-
guage skills, interpersonal skills, etc. In essence, such
skills constitute "knowing how" versus the "knowing that" of
factual knowledge. Gangé divides intellectual skills into
several sub-categories and orders these sub-categories
according to the complexity of mental operations involved. He
notes that each simpler skill is a prerequisite for learning
more complex skills. Acquisition of an intellectual skill
can be demonstrated through performance. Thus, the various
sub-categories are illustrated as follows:

. Discrimination=ability to distinguish printed b's
   from d's

. Concrete Concept=ability to identify the spatial
   relation "below"

. Defined Concept=ability to classify a "city" by
   using a definition

. Rule=ability to demonstrate that water changes
   state at 100 degrees centigrade

. Higher-Order Rule=ability to generate a rule for
   predicting rainfall, given con-
   ditions of location and terrain
Intellectual skills function as the prerequisites of further learning as well as the tools of problem-specific thinking and action. To distinguish intellectual skills, particularly from cognitive strategies, Gagné notes the following:

"Perhaps the best general word to denote the kind of capabilities that intellectual skills imply is demonstrating. If the individual has learned an intellectual skill, he can demonstrate its applicability to one or more particular instances of the class of phenomena to which it refers."

As a final note, demonstrating an ability to classify learned attributes according to Gagné's taxonomy is evidence of an acquired intellectual skill.

Cognitive strategies are internal capabilities which facilitate and direct learning, retention, and thinking. Examples often cited but not titled as cognitive strategies include creative acts of problem-finding, problem-definition, general detection of irrelevant information, and problem-solving (i.e., judgment, intuition, creativity). Gagné notes the following characteristics of cognitive strategies:

"Their nature can perhaps best be illustrated by contrasting them with intellectual skills. Intellectual skills are oriented toward aspects of the learner's environment; they enable him to deal with numbers, words, and symbols which are 'out there'. In contrast, cognitive strategies govern the learner's own behavior in dealing with his environment; they are, in a sense, 'in there'. The learner uses a cognitive strategy in attending to various features of what he is reading; what he learns may be an intellectual skill or information. He uses a cognitive strategy to select and 'code' what he learns, and another strategy for re-
trieving it. Most importantly, he uses cognitive strategies in thinking about what he has learned and in solving problems. Cognitive strategies are ways the learner has of managing the processes of learning (as well as retention and thinking)."18

Gagné adds the following distinctions of cognitive strategies:

"Rather than being oriented to specific kinds of external content, such as language or numbers, cognitive strategies are largely independent of content and generally apply to all kinds."19

The generation of a new approach to thinking about management education for engineers is evidence of a cognitive strategy or set of cognitive strategies at work.

In view of the central position of cognitive strategies in the taxonomy of learned attributes one might expect to find them high on the list of developmental objectives of educational institutions. Unfortunately, they often take a "back seat" to the development of the other learned attributes. Gagné observes,

"Emphasis is frequently given in educational writings to the desirability of cognitive strategies as educational outcomes. For example, 'learning to learn' and 'learning to think' are often cited as educational goals of high priority. At the same time, it is not evident that there has been a substantial commitment to instruction having these aims in the schools."20

The lack of emphasis on the development of cognitive strategies probably results from the difficulties of distilling, articulating, and transmitting cognitive strategies. First, they
are often not verbally articulated and labelled as cognitive strategies. Second, they develop over a period of time, not all at once. Third, conception of a single course to "teach a student to learn" or "teach a student to think" is difficult if not impossible.

Attitudes are "acquired internal states that influence choice of personal action."\textsuperscript{21} Attitudes have many effects. People form attitudes concerning how they should treat others, attitudes concerning preferred activities, and, potentially, attitudes influencing employment of particular skills and cognitive strategies.

Finally, it should be noted that this categorization of learned attributes applies to both the conscious and intuitive domains. Since, the intuitive domain is not easily pondered, this may be a difficult construct to accept. It is, however, a productive viewpoint.

Additional Thoughts Concerning the Categories of Learned Attributes

Internalization of the taxonomy presented is valuable but possibly difficult. In order to minimize confusion, three terms should be explored: "intellectual activities", "mind-sets", and "problem-solving".

There are a variety of words often associated with such titles as "abilities" or "skills": analyze, synthesize, evaluate, create, calibrate, design, itemize, detect, enumerate,
identify. It is suggested that these are merely terms which refer to "intellectual activities" whose performance employs one or more learned attributes. Thus, successful performance of the particular activity requires acquisition of certain learned attributes. Alternatively, successful performance of a particular activity demonstrates that certain learned attributes have been acquired.

It is often suggested that people can acquire a "mind-set". Examples suggested include the "mind-set of an engineer", the "mind-set of a manager", or the "mind-set of a social worker". It is asserted that if such mind-sets do exist, they result from some common set of experiences of the reference group. In turn, this common set of experiences produces a common set of potentially identifiable learned attributes. The learned attributes then are responsible for behavior which is attributed to a particular "mind-set". It is further asserted that examination of learned attributes subsumes an examination of mind-sets.

"Problem-solving" is often a confusing term because it can refer to two types of intellectual activities. First, "problem-solving" can refer to the mechanical application of a known principle (e.g., solving a geometry problem). The principal learned attribute employed in this case is an intellectual skill. Second, "problem-solving" can refer to attacking a novel problem where no rule exists to completely and
mechanically guide action. The principal learned attribute employed in this case is a cognitive strategy (although intellectual skills may be used periodically as tools of analysis with the results used to guide the solution of the novel problem).

The Conditions of Learning

In order to recommend educational system design which addresses acquisition of particular learned attributes, the different conditions under which learned attributes are actually learned must be examined. Gagné has considered each learned attribute in detail. His observations are summarized in Exhibit 3-2.

It should be noted that the factors enumerated are the external conditions required for learning. Additionally, internal conditions must be satisfied: establishment of those learned attributes that are prerequisites for acquisition of the desired learned attribute.

Finally, note that the conditions Gagné outlines are primarily, but not exclusively, for development in the conscious domain. What is important to realize is that explicitly structuring conditions for development of the intuitive domain is difficult. Testing for the attainment of intuitive learning is also difficult.
### Exhibit 3-2

**The Conditions of Learning**

<table>
<thead>
<tr>
<th>Learning Objective</th>
<th>Critical Learning Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factual Knowledge</td>
<td>1. Activating attention by variations in print or speech</td>
</tr>
<tr>
<td></td>
<td>2. Presenting a meaningful context (including imagery) for effective coding</td>
</tr>
<tr>
<td>Intellectual Skill</td>
<td>1. Stimulating the retrieval of previously learned component skills</td>
</tr>
<tr>
<td></td>
<td>2. Presenting verbal cues to the ordering of the combination of component skills</td>
</tr>
<tr>
<td></td>
<td>3. Scheduling occasions for spaced reviews</td>
</tr>
<tr>
<td></td>
<td>4. Using a variety of contexts to promote transfer</td>
</tr>
<tr>
<td>Cognitive Strategy</td>
<td>1. Verbal description of strategy</td>
</tr>
<tr>
<td></td>
<td>2. Providing a frequent variety of occasions for the exercise of strategies, by posing novel problems to be solved</td>
</tr>
<tr>
<td>Attitude</td>
<td>1. Reminding learner of success experiences following choice of particular action; alternatively, insuring identification with an admired &quot;human model&quot;</td>
</tr>
<tr>
<td></td>
<td>2. Performing the chosen action; or observing its performance by the human model</td>
</tr>
<tr>
<td></td>
<td>3. Giving feedback for successful performance; or observing feedback in the human model</td>
</tr>
</tbody>
</table>

47
Why Do Problems Occur?

Desirable human response to a stimulus situation can be thought of as composed of several, often unconscious, phases:

1. accurate appraisal of learned attributes required to respond to the situation
2. accurate appraisal of learned attributes possessed by the individual (and required by the situation)
3. application of appropriate learned attributes to task performance
4. application of appropriate learned attributes to ignorance resolution (to learn or to select and utilize problem-specific advice)

Unfortunately, problems in each phase can and do occur. The result is undesirable behavior. Conditions that produce problems as well as desirable results are detailed in Exhibit 3-3. It is not important to fully trace each path in Exhibit 3-3. What is important is to realize that problems are due to the inherent inappropriety, insufficiency, or inappropriate application of learned attributes:

- Learned attributes can be inherently inappropriate for accurate situation-appraisal or self-appraisal
- Learned attributes can be insufficient for accurate situation-appraisal or self-appraisal
- Learned attributes can be insufficient for effective and efficient task performance
- Learned attributes can be insufficient for effective and efficient ignorance resolution
- Learned attributes can be inappropriately applied (largely a result of the above deficiencies)
Problems Due to Learned Attributes

<table>
<thead>
<tr>
<th>appraisal of situation</th>
<th>appraisal of self</th>
<th>probable action</th>
<th>probable outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>to determine learned</td>
<td>to determine learned</td>
<td>apply A LA</td>
<td>OK</td>
</tr>
<tr>
<td>attributes required</td>
<td>attributes possessed</td>
<td>apply IS / IA LA</td>
<td>problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>do nothing</td>
<td>problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>resolve ignorance</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>apply IA LA</td>
<td>problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>apply IS / IA LA</td>
<td>problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>do nothing</td>
<td>problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>resolve ignorance</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>apply IA LA</td>
<td>problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>apply IS / IA LA</td>
<td>problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>do nothing</td>
<td>problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>resolve ignorance</td>
<td>OK</td>
</tr>
</tbody>
</table>

Key:

AD=accurate determination
ID=inaccurate determination
S=sufficient
I=insufficient
A LA=appropriate learned attribute
IS LA=insufficient learned attribute
IA LA=inappropriate learned attribute
Observe again that learned attributes may exist in the consciousness or intuitive domains. The particular problems associated with each category of learned attribute are detailed in Exhibit 3-4. Appreciation of the types of learned attributes as well as the general areas of potential problems will greatly assist interpretation of the results of chapters to follow.

Wrap-Up

A conceptual framework now has been developed through analysis and intuition. The next steps are to use it intuitively to screen relevant data, analyze the results, and intuit possible educational change in light of analysis.
### Exhibit 3-4

**Problems with Learned Attributes that Lead to Undesirable Behavior**

<table>
<thead>
<tr>
<th>possible status of learned attribute</th>
<th>inherently inappropriate</th>
<th>insufficient</th>
<th>inappropriate application</th>
</tr>
</thead>
<tbody>
<tr>
<td>factual knowledge</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>intellectual skill</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>cognitive strategy</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>attitude</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 3: Endnotes


18. Ibid, p. 64.


22. Ibid, p. 93.
CHAPTER 4: FACTUAL KNOWLEDGE

Factual knowledge serves several purposes for the engineer-manager. It is utilized to assess situations to determine

. which problems may be encountered
. which knowledge, skills, and strategies are applicable

It is utilized to perform in situations which require

. functional, problem-specific knowledge on which to base problem-solving
. knowledge to facilitate the transfer of intellectual skills between problem classes
. broad factual knowledge necessary for creative thought

It is used to learn or to resolve ignorance through other means. For this activity factual knowledge provides

. prerequisite knowledge for further learning
. information concerning the factual knowledge, intellectual skills, and cognitive strategies possible to learn
. information concerning sources of learned attributes (e.g., particular books, libraries, schools, individuals, etc.)
. information concerning sources of problem-specific advice (e.g., environmental experts, personnel consultants, financial advisors, particular peers, etc.)

Factual knowledge exists in both the conscious and intui-
tive domains. Particular factual knowledge of the engineer is often of value to the engineer-manager. However, it is possible to identify areas of factual knowledge that may spell trouble for the engineer-manager. Problems result from inherently inappropriate or insufficient factual knowledge.

Conscious versus Intuitive Factual Knowledge

Based on the discussion of cognitive processes, it is inferred that factual knowledge exists both in the conscious and intuitive domains. It is further inferred that (1) knowledge in the intuitive domain is not readily attained through conscious effort and (2) such knowledge normally is not articulated. Robert Heinsohn of Pennsylvania State University illustrates the distinction between knowledge in the two domains through his discussion of "knowledge and understanding":

"To learn is to acquire both knowledge and understanding. There is an important distinction between these terms. Knowledge is information, abstractions of reality which may be accumulated and transferred as facts and principles. Understanding, on the other hand, is meaning, a perception of the full nature of the reality. In engineering the distinction is often lost or blurred. I believe there are aspects of education which can be learned as knowledge; there are other aspects which can only be conveyed as understanding."\(^1\)

Value of the Engineer's Knowledge in the Managerial Realm

The factual knowledge engineers accumulate through their technical education and employment experiences is widely
recognized as valuable to an engineer-manager. It has been observed that this knowledge is helpful in understanding and solving managerial problems in technical organizations or with technical products. Additionally, such knowledge assists managerial communications involving technical subjects.

"Engineers have been responsible for the steady advance of industrial technology, and it is natural that many of them have assumed positions of leadership. The complex and highly technical activity of many new industries can scarcely be directed by men without engineering training."

--How to Improve Engineering-Management Communications
NSPE report²

"There are few senior jobs in industry where decisions do not involve a knowledge of technological as well as managerial factors."

--P. G. Forrester
Director
Cranfield Technical Institute³

"In any manufacturing industry, a substantive knowledge of the technological base of the industry can be most important, and this occurs not only in the obvious areas such as production, but also in marketing and finance."

--Robert E. Machol
Professor of Management
Northwestern University⁴

Some observers see this position of the engineer as a unique opportunity as well as a definite responsibility. J. Douglas Brown of Princeton University observes,
"The profession of engineering must seize the initiative in acting as a bridge between science and human needs. The scientist is not asked to apply his findings through design. The businessman or politician does not know what science offers or how to apply it."

Inappropriate Factual Knowledge

Presumably, a conscious effort is made in education to avoid transmission of inappropriate factual knowledge. However, inappropriate factual knowledge can be imparted in an indirect or implicit manner. When this occurs, inappropriate actions may occur or inappropriate attitudes may form. In view of the difficulty of consciously identifying and articulating this knowledge, it is hypothesized that inappropriate factual knowledge most often is captured in the intuitive domain in the form of inappropriate relationships.

Transmission of incomplete information in the educational process can be equivalent to imparting inappropriate knowledge. A graduate of the MITCED has observed the inappropriate attitudes that may form from such knowledge:

"For four years, we had been told that we were being educated to solve problems that hadn't been thought of yet, we were given the tools to tackle anything --we could work with no data, or tons of it. There was no sense of humility; armed with systems analysis, we could take on anything."

--Richard M. Males, M.I.T. '63
Engineer
W. E. Gates and Associates, Inc.
Actions based on such inappropriate information may mean disaster for the engineer-manager who attempts to use conscious, systematic techniques to solve all problems.

Accumulated inappropriate information may incorrectly guide learning activities. One observer notes,

"Engineers often regard management as a skill somewhat as they regard glass blowing, to be learned only in the doing...They ignore the progress that education for management has made in both teaching and research and are unaware that many problems of management have been and are studied by members of the academic community.'

--Merritt A. Williamson
Professor of Engineering Management
Vanderbilt University

**Insufficient Factual Knowledge**

Insufficient factual knowledge can cause the engineer-manager problems in situation assessment, self assessment, performance, and learning. Numerous observers have commented on these problems. Engineers and engineer-managers themselves have noted the necessity of sufficient factual knowledge of the managerial realm. Evidence indicates that insufficiencies of factual knowledge exist in the conscious as well as the intuitive domain.

Problems in situation assessment can result from the engineer-manager's ignorance of potential problems:
"Many engineers have little perception or understanding of the human and organizational problems involved in working and implementing changes in an ongoing company or agency. Thus, they tend to dismiss or grossly simplify what are often the most important considerations."

--Boyd C. Paulson
Professor of Civil Engineering
Stanford University

"The engineer's greatest weakness, as I see it, is that he has not acquired a workable appreciation of the human beings with whom he deals. In getting his facts, he often fails to realize that, for purposes of management, such things as attitudes, feelings, prejudices, states of health, philosophical and religious commitments, etc. are facts which must be taken into account. Those engineers make good managers who have acquired some feeling for the relevance and importance of these subjects."

--Merritt A. Williamson

Problems in self assessment can result from partial ignorance of the tools available or possessed. Richard Males has noted this problem in other graduates of the MITCED:

"And what of the recent products of MIT that I've hired or bumped into...They are unaware of what they don't know, of the places where tools are just inappropriate, where the process is more important than the objective, where deference to experience is not only polite but will get you to the solution faster than all the math models you could dream of."

Problems in performance can result from lack of functional knowledge. For example, lack of a "managerial vocabulary" can cause communication problems:
"It is absolutely essential that the engineer add to his technical vocabulary the concepts of working capital, interest rates, return on investment, etc."

--Carl Pacifico
Consultant
Management Supplements, Inc.

"The engineering background which we have is a conglomeration of educational and work experiences. Inherently during both of these periods of an engineer's life we tend to develop a language peculiar to our profession. Our technical jargon tends to befuddle non-engineers. By the same token, we don't understand the language of accountants, marketing people and others whom we as managers must communicate with. This language barrier can be a severe handicap and must be overcome to be effective in an administrative environment."

--Mark H. Sluis
Engineer-Manager
General Railway Signal Company

Additionally, lack of knowledge of business customs may cause problems in performance:

"As in society, observance of customs is subtle but important. Business, like every other sub-culture, has some customs that differ from those of engineers. There are differences in dress, in speech, and in manner."

--Carl Pacifico

Further, insufficient factual knowledge may prevent the transfer of skills between classes of problems. No evidence is readily available to indicate whether or not this actually is a problem for the engineer-manager. However, several authors have indicated the commonality that exists between skills that are important in certain technical work and those skills that
are important to managers. For example, David Heenan of the University of Hawaii College of Business Administration, has noted that various types of multivariate analytic techniques are useful in medicine and management as well as in the technical arena. George Boehm, "free-lance writer and consulting generalist", has written on various analytic techniques which are applicable to managerial decision-making. It is noted that particular techniques may be part of the repertoire of skills of an engineer:

- mathematical modeling and simulation
- linear and dynamic programming
- PERT and CPM
- queuing theory analysis
- decision analysis
- cost/effectiveness and cost/benefit analysis

Possession of a broad base of factual knowledge concerning these techniques and their applicability in areas other than engineering would facilitate generalization which might not otherwise occur.

Insufficient knowledge of "what can be known" may cause problems in learning as well as situation assessment and self assessment. As Douglas McGregor has noted, "Experience by itself does not necessarily teach anything". If an engineer-manager does not have a general idea of what can be known, he may never begin the search. Note particular examples of ignorance that may cause problems in learning:
"Engineers are deficient in their knowledge of the behavioral sciences. Many engineers also lack breadth in matters with society and social concerns."

--Merritt A. Williamson\textsuperscript{17}

"Engineers often lack knowledge of the behavioral sciences and frequently have a generally parochial view of the world."

--Edward D. Goldberg
Associate Dean
City University of New York\textsuperscript{18}

Knowledge and problems in the areas indicated may be avoided simply because an engineer-manager has no idea they exist.

Do engineers and engineer-managers note deficiencies in factual knowledge necessary to function in the managerial realm? Many surveys have addressed this question and the answer is normally affirmative. As one example, a 1975 survey by Marquette University of engineers enrolled in the Marquette MBA program noted that 75\% were pursuing the degree to "Broaden education, Add business knowledge, or Learn about management".\textsuperscript{19} Additionally, 95\% thought undergraduate engineering majors should take some business courses to broaden their knowledge of management. Further, 92\% of a group of practicing engineer-managers surveyed by Marquette concurred with the desirability of engineers acquiring managerial knowledge during the undergraduate years.
Summary

Technical knowledge possessed by engineers is valuable in the managerial realm when problems concern a technical organization or technical product or when communication is technical in nature. However, inappropriate factual knowledge possessed by engineers may cause problems when engineers function in the managerial realm:

- Inappropriate knowledge or understanding of the applicability of engineering techniques can result in ineffective and/or inefficient situation appraisal, self appraisal, or performance.

- Inappropriate knowledge concerning the possible means of attaining managerial knowledge and skills can mis-guide important learning activities.

Additionally, insufficient factual knowledge possessed by engineers may cause problems when engineers function in the managerial realm:

- Insufficient knowledge or understanding of potential managerial issues can result in inaccurate situation appraisal.

- Insufficient knowledge or understanding of the applicability of engineering techniques can result in improper self appraisal.

- Insufficient knowledge or understanding of managerial jargon or business customs can cause problems in performance.

- Insufficient knowledge of the generalizability of engineering techniques can result in suboptimal performance.
Insufficient knowledge of "what can be known" in the managerial realm can preclude necessary learning activities.

Factual knowledge is maintained in both the conscious and intuitive domains. Due to lack of understanding of the intuitive domain, educational experiences which avoid certain inappropriate intuitive knowledge or emphasize particular sufficiencies of intuitive knowledge may be difficult to construct.
Chapter 4: Endnotes


CHAPTER 5: INTELLECTUAL SKILLS

Intellectual skills provide the engineer-manager with capabilities "to do" particular activities. As opposed to the areas in which factual knowledge is important, intellectual skills are of primary importance in performance and learning. They are utilized to perform in situations involving

. human interactions
. oral and written communications
. technical and managerial decision-making

They are utilized to learn or to resolve ignorance by providing

. prerequisite skills on which learning of other capabilities is based
. necessary "acquisition" skills (e.g., techniques of introspection, reading, clerical skills)
. skills to select and employ problem-specific advice

Intellectual skills exist in both the conscious and intuitive domains. Certain intellectual skills of the engineer are often of value to the engineer-manager. It is possible, though, to identify particular areas of intellectual skills that may be troublesome for the engineer-manager. Problems result from insufficient or inappropriately applied intellectual skills.
Conscious versus Intuitive Intellectual Skills

Intellectual skills exist in both the conscious and intuitive domains. This is a particularly important distinction and one that is not consistently recognized in the literature of management, engineering, or engineers in management.

At least one observer is skeptical of the integrity of actions based on intuitive skills:

"Any intuitive alteration of a complex system will cause it to become worse off."

--Jay W. Forrester
Professor of Management
M.I.T.¹

A study of managerial decision-making by Henry Mintzberg noted that only in 18 of 83 instances did managers report employing explicit analysis.² If it is assumed that the results of these decisions were reasonably satisfactory and that the managers did not depend on blind luck, how were the decisions formulated? Mintzberg notes,

"In general the selection mode most commonly used was judgment. Typically, the options and all kinds of data associated with them were pumped into the mind of a manager, and somehow a choice later came out. How was never explained. How is never explained in any of the literature."³

Mintzberg suggests that this activity may be associated with the right hemisphere of the brain:
"A number of findings from my own research on policy-level processes suggest characteristics of right-hemispheric thinking. One fact recurs repeatedly in all of this research: the key managerial processes are enormously complex and mysterious (to me as a researcher, as well as to the managers who carry them out), drawing on the vaguest of information and using the least articulated of mental processes. These processes seem to be more relational and holistic than ordered and sequential, and more intuitive than intellectual; they seem to be most characteristic of right-hemispheric activity."  

Additionally, Mintzberg speculates about the general nature of the intuitive processes:

"In effect, managers (like everyone else) use their information to build mental 'models' of their world, which are implicit synthesized apprehensions of how their organizations and environments function. Then, whenever an action is contemplated, the manager can simulate the outcome using his implicit models."  

Historically, managers have learned the requirements of management through experience and repetition of experience. Gradually, through trial and error, what is relevant and important becomes clear. However, if experience were the only teacher, each generation could progress only by living longer than the previous generation. Experience is a costly and cantankerous medium for education. Bruce Henderson writes,

"Significant progress requires a more efficient teacher than experience. The foundation of efficient education is the formulation of concepts. This is the skeleton upon which the whole of our body of knowledge must be supported and coordinated. Therefore, in a very real sense our ability to become more effective businessmen depends upon our ability to acquire early the key concepts which
bring all our business information into focus. In the absence of concepts many of the business decision making skills have been intuitive."6

Developments in environmental engineering as well as such areas as market research, production scheduling, and financial analysis are illustrative of the development of efficient concepts. As in these examples, when intuitive skills can be articulated in the form of concepts, they can be discussed, improved, and taught efficiently.

There appear to be two types of concepts. First, there are those that fit into a logical, hierarchical framework (e.g. Newton's laws of motion and the large body of formulae derived therefrom). In view of their generalizability between individual problems, these concepts are often termed "fundamentals". They seem to be relatively easy for individuals to internalize as well as easy to teach. This may be due to the fact that they are clearly articulated and easily pondered by the conscious domain because of their linear, logical organization. Additionally, possible relationships among concepts become readily apparent (this is important for internalization in the intuitive domain).

Second, there are those concepts that as yet have not been incorporated in or subsumed by a conceptual framework. For example, articulated rules-of-thumb exist for handling particular aspects of human interactions (e.g., "Authority must be comensurate with responsibility"). Additionally,
concepts exist which are associated topically but not logically with a larger framework. These often are termed "tricks-of-the-trade" (e.g., empirical relationships utilized in structural design). The intuitive domain is necessary to link these "unconnected concepts" for productive action. The intuitive domain is also necessary for the development of these concepts from assimilated experience or by monitoring conscious thought. It is asserted that many "unconnected concepts" are used but never articulated.

In terms of the ideas presented, the debate of "theory versus practice: in engineering education appears polarized around "fundamental concepts versus unconnected concepts" and "abilities in the conscious domain versus abilities in the intuitive domain" (Exhibit 5-1). The "theory" side emphasizes fundamental concepts and development of the conscious domain. While they suggest that this type of education forms a solid base for further thinking and learning, they do not explicitly address the impact of education on the intuitive domain. Implicit in arguments of the "practice" side is the necessity of unconnected concepts and development of the intuitive domain. Since skills based on the full range of both dimensions are important, real trade-offs exist.

From this discussion and the discussion of cognitive processes, two relationships are inferred between the conscious and intuitive domains. First, learned attributes (including
### Exhibit 5-1

**Schematic Representation of Types of Concepts**

<table>
<thead>
<tr>
<th>conscious domain</th>
<th>intuitive domain</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>fundamental concepts</strong></td>
<td><strong>unconnected concepts</strong></td>
</tr>
</tbody>
</table>
The intellectual skills) are internalized in the intuitive domain in two modes:

. The intuitive domain may internalize learned attributes due to "monitoring" of activity in the conscious domain

. The intuitive domain may internalize learned attributes independently of the conscious domain

Second, learned attributes in the intuitive domain can be articulated in two ways:

. The conscious domain may articulate thoughts that surface from the intuitive domain

. The conscious domain can observe activities and infer that performance must be a result of learned attributes in the intuitive domain

Through the processes of articulation, conscious analysis, and internalization, the power of both the conscious and intuitive domains can be optimized.

In summary, the importance of skills in the two domains as well as the interaction that can occur between the domains require that neither conscious skills nor intuitive skills be overlooked.

The Value of the Engineer's Skills in the Managerial Realm

The intellectual skills that an engineer acquires are valuable to the engineer-manager in several areas. The particular skills are valuable in performance as well as for further learning.
The technical skills of an engineer facilitate decision-making in problems which involve engineering technology. A comparative study of engineers and managers notes the following:

"In high-technology areas, a major reason for the assignment of engineers to the management of major programs is that it is necessary to understand the technological requirements and ramifications of a program to administrate it." 7

Additionally, as was suggested in Chapter 4, the technical skills of an engineer may be transferable to particular types of managerial decision-making. John E. Burns observes the necessity of quantitative techniques:

"Recent developments have tended to quantify the manager's role. More and more numbers are creeping into his daily work. To handle effectively the volume and complexity of these numbers, the manager is forced to include the tools of operations research and mathematical techniques. Modern data processing methods are forcing the development of a mathematical language for business." 8

One researcher notes that the engineer is uniquely equipped to handle these quantitative tasks:

"Management finds that engineering graduates are generally familiar with scientific and technological developments; they are trained to deal with problems in quantitative terms; and they are skilled in the analytical, problem-solving approach to situations. In short, engineers have been subjected to a reasonably rigorous training which stresses the development of analytical and quantitative skills based on
Finally, some suggest that development of engineering skills in the intuitive domain may be transferable to performance in the managerial realm:

"Engineering and management are very analogous activities. Both involve systematic quantitative analysis combined with creativity and judgment. Thus, people who have the aptitude for, and have been trained in, engineering are likely to have the potential to be good managers."

--P. G. Forrester

The technical skills of an engineer are often prerequisites of quantitative managerial techniques:

"It is generally acknowledged that mathematical ability is important to engineering ability. This asset of the engineer stands him in good stead in statistics, linear programming, and other areas which are increasingly important in business."

--William B. Given

Thus, the engineer may be in a better position than other managerial candidates to pick up quantitative techniques not previously acquired. Additionally, in the area of ignorance resolution, the engineer-manager may be experienced in knowing how and where to obtain technical advice. This is of
obvious value in managerial situations involving technical issues.

**Insufficient Intellectual Skills**

Insufficient intellectual skills cause the engineer-manager problems principally in performance involving human interaction, communication, and decision-making. However, some problems may also occur due to deficiencies in particular skills required for learning or ignorance resolution. Problems with human interaction and communication appear to result from insufficient skills in both the conscious and intuitive domains. Nevertheless, the emphasis in the literature is frequently on problems associated with the conscious domain. Problems with decision-making seem to be related primarily to intuitive deficiencies.

Skills facilitating effective human interaction in various situations are vital to the engineer-manager. John Kemper notes in his book *The Engineer and His Profession*,

"During the office day, the executive is seldom alone. If he is not involved in a formal committee of some sort, he is informally engaged with one or more associates, because the executive is primarily concerned with people. The single most characteristic thing about the executive's job is that he must somehow be able to get numbers of people moving in the same direction; hopefully, he gets them to move on a willing basis."

Henry Boettinger asserts that skills in dealing with people are potentially more important than quantitative skills:
"There are many people, some in high positions, who are deficient in even an elementary understanding of human relations. And when ill-prepared persons have to deal with areas in which they are weak, for instance, accounting methods and sophisticated management information systems, their lack of human skills is even more crucial than their lack of quantitative ones."13

Unfortunately, the exact nature of human skills remains largely unarticulated, locked in the intuitive domain. Henry Mintzberg illustrates this observation by way of his appraisal of the current knowledge of "leadership" abilities:

"Leader describes how the manager deals with his own employees. It is ironic that despite an immense amount of research, managers and researchers still know virtually nothing about the essence of leadership, about why some people follow and others lead. Leadership remains a mysterious chemistry; catchall words such as charisma proclaim our ignorance."14

Relatively few concepts exist which are easily and effectively applied to human interactions (e.g., Maslow's Need Hierarchy, the principles of Dale Carnegie). Few, if any, concepts of human interaction enjoy the stature possessed by the laws of physical behavior. As a result, day-to-day human interactions are not assisted greatly by the conscious domain. Additionally, the body of unarticulated human skills are difficult to discuss, improve, or teach. The learning of human skills most often seems restricted to assimilation of experience by the intuitive domain. Note, however, that this does not exclude all impact of the conscious domain. As was inferred previously, when
skills can be articulated in conceptual form, the intuitive domain may internalize relationships as a result of monitoring of the conscious review of concepts.

Do engineers actually experience problems with human skills? A study performed by the National Society of Professional Engineers, *Career Satisfactions of Professional Engineers in Industry*, noted that approximately 70% of engineers sampled felt that their college education had been inadequate in terms of psychology and human relations training.¹⁵ A study executed by the American Society for Engineering Education found that approximately 60% of the 4000 engineers sampled felt that they were deficient in various aspects of "working with individuals, working with groups, and talking with people."¹⁶

In spite of difficulties experienced with insufficient human skills, engineers may be particularly resilient. An M.I.T. survey of engineering graduates 15 to 20 years out of school revealed that 55% had risen to significant managerial responsibility (president, general manager, or technical manager).¹⁷ On average, only 21% of this group reported negligible ability to "induce change in others and in organizations". On the other hand, 56% of those who had not attained significant managerial rank reported negligible possession of this trait. Two observations can be made in light of this data. First, it appears that leadership
abilities are especially important to the engineer-manager. Second, notwithstanding educational deficiencies, those engineers who must possess particular skills for human interactions seem potentially capable of acquiring such skills. However, this second observation in no way addresses the difficulty of acquisition. Additionally, "advancement" of those who remain engineers may be constrained permanently due to their lack of human skills (necessary for performance or as prerequisites of learning).

Skills necessary for written and oral communication are important to both engineers and managers. A 1979 survey of employers of civil engineers in the Kansas City area notes that 96% believe communication skills are of significant importance in civil engineering practice. 18

Unfortunately, 66% of the employers in the Kansas City area survey note that the writing and speaking ability of recent graduates (one to five years out of school) is inadequate. The severity of the problem may be subject to temporal and regional variance. Results of a survey of employers within the state of Tennessee indicates that only 19% of civil engineering graduates (five to 10 years out of school) are inadequate in written communication and 26% are inadequate in oral communication. 19 Results of a survey of employers within the New York-New Jersey area indicate, however, that 84% of "recent civil engineering graduates" are marginal or inadequate in
in written communication and 61% are marginal or inadequate in oral communication. Thus, if regional differences are discounted, engineers may possess a resiliency in communication skills similar to that displayed in skills necessary for human interaction.

It should be observed that certain aspects of written and oral communication skills can be clearly articulated (e.g., grammar and spelling rules). However, intuitive abilities are necessary for efficient execution (following the internalization of articulated communication skills) as well as for execution involving unarticulated communication skills.

Engineer-managers encounter deficiencies in two areas of managerial decision-making skills: those managerial decision-making skills involving "fundamental concepts" (e.g., accounting principles—although it can be argued whether or not these are truly "fundamental") and those involving "unconnected concepts" (i.e., rules-of-thumb and tricks-of-the-trade—both in the conscious and intuitive domains).

With regard to "fundamental concepts" of managerial decision-making, Jay Gould observed in his study "The Big Business Executive/1964",

"More than half of the technically trained executives wished that they had had more training in the business skills traditionally associated with the management function. In fact, 75 percent of the executives with technical training admitted that there were gaps in their non-technical education."
A study of engineer-managers by Marquette University revealed that 53% of those sampled believed engineering majors should pursue courses in accounting, finance, and marketing as a prelude to possible managerial decision-making. Deficiencies in this area of managerial decision-making seem adequately addressed through development in the conscious domain (although this does not prepare the engineer-manager for intricate applications of techniques).

Various "unconnected concepts" are required for decision-making that does not utilize fundamental techniques as well as for the application of fundamental techniques. M. K. Badawy, Professor of Business Administration, Cleveland State University, has noted,

"While the training of the engineer typically emphasizes the reduction of all problems to terms that can be dealt with by objective measurement and established formulas based on predictable regularities, success in management is entirely based on different criteria. The world of management is far less exact, less regular, fuzzier, and less predictable than the world of engineering. The present system erroneously over-develops their analytical skills (as model builders), while their managerial skills (as decision makers) remain highly underdeveloped."

With regard to "tricks-of-the-trade", it seems that insufficiencies exist in both the conscious and intuitive domains. Richard Males has noted that an engineering education may not address this deficiency:
"So I went out into the real world, armed with tools, principles, and a way of thinking. And not surprisingly, some of the tools apply some of the time, as do some of the principles, and the trick is to know when they work and when they don't, and they never taught us that in school and I don't know how you would." 24

The unstructured nature of these concepts as well as their infrequent articulation in clear terms means that devising educational experiences to provide for attainment of the concepts may be difficult.

Intellectual skills may in some cases be insufficient to provide the prerequisites of further learning. However, evidence previously reviewed indicates that engineer-managers often may have sufficient prerequisites to learn skills necessary for human interactions or communication. Additionally, technical skills may serve as valuable prerequisites for learning of certain managerial skills (e.g., accounting and financial analysis).

Intellectual skills may be insufficient for the efficient acquisition of information needed to resolve ignorance. As Maurita Holland, Head Librarian, University of Michigan, has noted,

"Civil engineering departments have frequently overlooked an important aspect of their educational role -- that of developing the student's ability to use information resources, or put more directly, that of showing students how to find answers to new and immediate problems after they have left the classroom." 25
No evidence exists to indicate whether or not engineer-managers encounter problems in the selection and employment of expert advisors. Anthony Jay has noted, though, that for managers in general,

"Few ever ask themselves how well they use their advisors or consultants and those who do can easily come up with a satisfactory answer since there are few objective tests for this kind of performance. Nevertheless, the talent for making good use of professional advisors ranks as one of the most necessary skills for executives." 26

Inappropriately Applied Intellectual Skills

Inappropriate application of intellectual skills is a result of several possible factors:

- inappropriate knowledge
- insufficiencies in other intellectual skills
- inappropriate application of cognitive strategies
- inappropriate attitudes

Inappropriate application of intellectual skills causes the engineer-manager problems principally in human interactions and managerial decision-making. As a general observation, it appears that engineers tend to rely excessively on skills in the conscious domain. This tendency may continue as a problem for the engineer-manager.

It has been speculated in the literature that engineers tend to transfer analytic techniques to problems in human
interactions. A personality comparison of engineers, managers, and engineer-managers by the University of Utah seems to substantiate this assertion:

"Engineer-managers exhibit the same preference for leadership roles that managers do, but do not express the same qualities of poise and enjoyment of human interaction. The engineer-manager's style of management may be different than that of his non-engineering colleague. A plausible explanation is that engineer-managers base their leadership to a greater degree upon intellectual insight into the needs and motives of people and less on an enjoyment of interacting with them. It appears that engineer-managers use analytic skills on the human component of their tasks."

However, this reliance on skills in the conscious domain for situations involving human issues may cause problems:

"The ability to follow cause and effect relationships and to break down problems into their simpler and more manageable components is vitally important in engineering, as in many other fields. This quality is a very useful special ability for the executive, but it often leads engineers to overlook the human, illogical needs of followers and associates."

--William B. Given

"Managers must depend a great deal on their intuition when it comes to dealing with people or with situations for which there is no precedent. The obvious, but often ignored, fact is that the engineer or the scientist has been working for years with materials and objects that usually behave in a prescribed manner. As a manager, he is working with human beings, and human beings do not behave in a logical, predictable way. The technically trained manager who expects them to do so is in for many and perhaps costly problems."

--Richard A. Koplow
Harbridge House, Inc.
Note that this does not imply that all use of conscious skills in human interactions is bad. The point is simply that, due to the largely unarticulated nature of human skills, total reliance on conscious analysis may cause problems.

Frederick Taylor noted over fifty years ago the tendency of engineers to transfer technical skills to other types of decision-making and problem-solving:

"When men, whose education has given them the habit of generalizing and everywhere looking for laws, find themselves confronted with a multitude of problems, such as exist in every trade and which have a general similarity one to another, it is inevitable that they should try to gather these problems into certain logical groups, and then search for some general laws or rules to guide them in their solution." 30

As in human interactions, reliance on conscious analysis in all problems may be inappropriate:

"Many times problems arise in probing into the unknown when an imaginative approach becomes much more important than an analytical one. Guesses and hunches become necessary. Attempts to depend on charts and formulas rather than on intuition and judgment can often lead to a wrong answer."

--William B. Given31

Summary

Technical skills possessed by engineers are valuable in the managerial realm for performance and learning:
Technical skills may facilitate decision-making in problems involving engineering technology.

Technical skills may be transferable to particular types of managerial decision-making.

Engineering intellectual skills in the intuitive domain, if they exist, may be transferable to managerial situations which require intuitive abilities.

Technical skills may serve as prerequisites for learning quantitative managerial techniques.

However, insufficient intellectual skills may cause the engineer-manager problems:

- Engineers appear deficient in both conscious and intuitive intellectual skills necessary for human interactions (although they may be capable of acquiring these skills).

- Engineers appear deficient in both conscious and intuitive intellectual skills necessary for written and oral communication (although they may be capable of acquiring these skills).

- Engineers appear deficient in the "fundamental concepts" of managerial decision-making (although they may have the prerequisite skills for learning these fundamental techniques).

- Engineers appear particularly deficient in the intuitive "rules-of-thumb" necessary for managerial activities.

- Engineers may not possess particular abilities to gather information necessary for learning or to select and employ expert advice.

Additionally, the engineer-manager may encounter problems due to inappropriately applied intellectual skills:
Engineer-managers may rely excessively on conscious skills in human interactions.

Engineer-managers may rely on conscious skills in decision situations which require intuitive abilities.

Intellectual skills are maintained in both the conscious and intuitive domains. Additionally, underlying concepts are not always part of an orderly, articulated hierarchy. Thus, construction of educational experiences which optimally emphasize particular sufficiencies or avoid inappropriate application may be difficult.
Chapter 5: Endnotes


3. Ibid, p. 56.


5. Ibid, p. 54.


25. Maurita Peterson Holland, "Information Resources for Civil Engineers", Civil (1979), op. cit., p. 359.


27. Brown, op. cit., p. 132.

28. Given, op. cit., p. 50.


31. Given, *op. cit.*, p. 44.
Cognitive strategies provide the engineer-manager means to regulate the internal processes involved in thought and memory. In terms of the information processing model posited in Chapter 3, cognitive strategies comprise the engineer-manager's internal "operating system"—as contrasted with skills (i.e., problem-specific "programs") and knowledge (i.e., "data"). Cognitive strategies are utilized to assess situations by providing general abilities to

- find problems
- prioritize problems
- define problems

They are utilized to assess one's self by providing general abilities to

- appraise learned attributes possessed

They are utilized to perform, to learn, or to resolve ignorance by providing general abilities to

- recognize relevant and irrelevant data
- solve problems
- schedule the implementation of intellectual skills
- execute solutions
- evaluate feedback
- code and retrieve factual knowledge and intellectual skills

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As an important aside, mention of "learning" strategies often accompanies a discussion of "thinking" strategies. It is asserted that strategies of thinking, coding, and retrieval along with appropriate attitudes are the requisites of learning. Thus, the discussion herein subsumes a discussion of "learning" strategies—except in the respect that memory strategies are not explicitly addressed. Attitudes necessary for productive learning are discussed in Chapter 7.

Cognitive strategies appear to be resident in both the conscious and intuitive domains. Certain cognitive strategies of the engineer are often of value to the engineer-manager. Nevertheless, engineer-managers may encounter certain problems due to insufficient or inappropriately applied cognitive strategies.

Conscious versus Intuitive Cognitive Strategies

It is desirable to outline each of the cognitive strategies enumerated in the introduction to this chapter. It is desirable to suggest the forms that each cognitive strategy may assume in the two cognitive domains. Unfortunately, the current knowledge of cognitive strategies facilitates neither of these ends. The various cognitive strategies are not clearly defined or articulated. This probably is due, in part, to the residence of many important strategies in the intuitive domain. Additionally, cognitive strategies normally develop through experience. Thus, universal articulation of idiosyncratic
cognitive strategies is difficult.

Alternatively, three descriptions of decision-making (i.e., performance which utilizes cognitive strategies to explicitly as well as implicitly define problems, recognize relevant data, and solve problems) are presented herein. Decision-making can rest primarily on conscious strategies. On the other hand, decision-making can depend principally on intuitive strategies. The three descriptions consist of an example at each extreme as well as an illustration of a central position. The distinction between conscious and intuitive cognitive strategies is important. It is a possible key to eventual understanding of the cognitive strategies specified previously.

The three models of decision-making flow from the literature of political science and policy formulation. Charles Lindblom is responsible for the articulation of the two models that lie at each end of the conscious/intuitive spectrum.¹ The first model, the Rational-Comprehensive method, Lindblom likens to the scientific method and notes that it is the model of decision-making discussed most often in the literature. The Rational-Comprehensive method requires clear and complete articulation of the problem, the objectives, and the alternatives. It also requires comprehensive analysis of each alternative in terms of the degree to which each solves the problem and achieves the objectives. The Rational-Comprehensive method starts from fundamentals for each new problem and builds
on the past only as experience is captured in theory. The second model, the method of Successive Limited Comparisons, Lindblom likens to a process of "muddling through". The method of Successive Limited Comparisons usually does not involve clear articulation of the problem or the objectives. It normally focuses on a limited set of alternatives and relies on minimal analysis. It continually builds upon the current situation. Lindblom has summarized the characteristics of each model and these are displayed in Exhibit 6-1.

The Rational-Comprehensive method appears to depend critically on conscious analysis and hence conscious cognitive strategies (which may not always be explicitly articulated as such). In contrast, the method of Successive Limited Comparisons depends on a set of processes which are mysterious, largely unarticulated, and seemingly dependent on intuitive cognitive strategies for general guidance.

If the Rational-Comprehensive method does in fact depend on conscious cognitive strategies, these strategies should be possible to articulate. Such strategies are exemplified by the discussions of "rational decision-making" found in the literature. Richard de Neufville and Joseph H. Stafford note in their book Systems Analysis for Engineers and Managers (text for one of the core courses of the undergraduate curriculum of the MITCED) "five basic elements of a systematic analysis":

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### Exhibit 6-1

**Lindblom's Models of Decision-Making**

<table>
<thead>
<tr>
<th>Rational-Comprehensive</th>
<th>Successive Limited Comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1a.</strong> Clarification of values or objectives distinct from and usually prerequisite to empirical analysis of alternative decisions.</td>
<td><strong>1b.</strong> Selection of values, goals, and empirical analysis of the needed action are not distinct from one another but are closely intertwined.</td>
</tr>
<tr>
<td><strong>2a.</strong> Decision-formulation is therefore approached through means-end analysis: First the ends are isolated, then means are sought.</td>
<td><strong>2b.</strong> Since means and ends are not distinct, means-end analysis is often inappropriate or limited.</td>
</tr>
<tr>
<td><strong>3a.</strong> The test of a &quot;good&quot; decision is that it can be shown to be the most appropriate means to desired ends.</td>
<td><strong>3b.</strong> The test of a &quot;good&quot; decision is typically that various analysts find themselves directly agreeing on a decision (without their agreement that it is the most appropriate means to an agreed objective).</td>
</tr>
</tbody>
</table>
| **4a.** Analysis is comprehensive; every important relevant factor is taken into account. | **4b.** Analysis is drastically limited:  
   i) Important possible outcomes are neglected.  
   ii) Important alternative decisions are neglected.  
   iii) Important affected values are neglected. |
| **5a.** Theory is often heavily relied upon. | **5b.** A succession of comparisons greatly reduces or eliminates reliance on theory. |
1. Definition of objectives
2. Formulation of measures of effectiveness
3. Generation of alternatives
4. Evaluation of alternatives
5. Selection

Although forwarded with appropriate notes of caution, the authors' stated intent in enumerating these steps is to provide a framework for a set of techniques: "systems analysis". Indeed, the steps constitute a general framework to guide decision-making and as such qualify as a cognitive strategy.

Is there an alternative to the two models posited by Lindblom? Amitai Etzioni provides such an alternative through his formulation of the "mixed-scanning" method. In essence, mixed-scanning utilizes elements from each of Lindblom's models. In terms of ideas presented herein, intuition is used to select a conceptual framework capable of "broad scanning". When broad-scanning identifies areas of particular interest, detailed analysis is called into play. Thus, intuitive as well as conscious/analytic abilities (including cognitive strategies) are necessary. Etzioni observes (referencing Successive Limited Comparisons as "incrementalism"), 

"Each of the two elements in mixed-scanning helps to reduce the effects of the particular shortcomings of the other; incrementalism reduces the unrealistic aspects of rationalism by limiting the details required in fundamental decisions, and contextuating rationalism helps to overcome the conservative slant..."
of incrementalism by exploring longer-run alternatives."  

Simply, the value of Etzioni's model is to illustrate that a mode of decision-making may exist wherein both conscious and intuitive strategies may be profitably employed.

Evidence exists which indicates that some people may specialize in a thinking style which resembles the Rational-Comprehensive method. Additionally, some people may exhibit a cognitive style similar to the method of Successive Limited Comparisons. A study performed by the Harvard Graduate School of Business Administration provides such evidence. Out of a sample of 107 MBA students, 70% exhibited distinct differences in cognitive style. On the basis of these differences, subjects were grouped into two classes: "systematic thinkers" and "intuitive thinkers". It was noted that systematic thinkers tend to

- look for a method and make a plan for solving a problem
- be very conscious of their approach
- defend the quality of a solution largely in terms of the method
- define the specific constraints of the problem early in the process
- move through a process of increasing refinement of analysis
- conduct an ordered search for additional information
complete any discrete step in the analysis that they begin

- prefer program-type problems
- resemble the "thinking" stereotype of popular psychological tests

Additionally, intuitive thinkers were observed to tend to

- keep the overall problem continuously in mind
- redefine the problem frequently as they proceed
- defend a solution in terms of fit
- consider a number of alternatives and options simultaneously
- jump from one step in analysis or search to another and back again
- explore and abandon alternatives very quickly
- prefer open-ended problems
- resemble the "feeling" stereotype of psychological tests

If cognitive strategies are in fact general programs to regulate cognitive processes, they should be transferable among problems. In other words, people should utilize for all problems the particular set of cognitive strategies they possess. Indeed, the "extreme" subjects in the Harvard study revealed that

"The individual maps himself onto the problem, rather than matching his behavior to the constraints and demands of the particular task."
This does not imply that conscious and intuitive cognitive strategies are never used simultaneously. In fact, 30% of the sample exhibited characteristics reflective of both styles of thinking. In terms of the three models, this portion of subjects was illustrative of the "mixed-scanning" method.

What does this theory and empirical evidence mean for the engineer and, hence, the engineer-manager? Evidence indicates that engineers tend to be systematic thinkers. In other words, engineers tend to rely heavily on conscious abilities: conscious intellectual skills (as noted in Chapter 5) and conscious cognitive strategies. A study of "thinking types" by the University of Florida indicated that, of a "representative" sample of the general public, 63% exhibited a preference for intuitive processes over conscious thinking. Interestingly, 59% of a group of engineering students, faculty, and graduates of the University exhibited a significant tendency toward conscious thought and analysis. Results by engineering specialty are detailed in Exhibit 6-2. Additionally, qualitative evidence supports these observations:

"The engineer often prefers to have an algorithm for each problem he deals with."

--Edward D. Goldberg

"The engineer appears to be a better deductive than inductive reasoner."

--Donald E. Super
New England Consultants, Inc.
**Exhibit 6-2**

**Engineers’ Preference for Conscious Thought**

<table>
<thead>
<tr>
<th>Specialty</th>
<th>% Preference for Conscious Thought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>77</td>
</tr>
<tr>
<td>Aerospace</td>
<td>69</td>
</tr>
<tr>
<td>Agricultural</td>
<td>67</td>
</tr>
<tr>
<td>Electrical</td>
<td>60</td>
</tr>
<tr>
<td>Chemical</td>
<td>60</td>
</tr>
<tr>
<td>Civil</td>
<td>59</td>
</tr>
<tr>
<td>Total Sample</td>
<td>59</td>
</tr>
<tr>
<td>Mechanical</td>
<td>54</td>
</tr>
<tr>
<td>Industrial</td>
<td>50</td>
</tr>
</tbody>
</table>
"The real legacy of the MIT education, it now seems, is the way of thinking--and the essence of that thinking is, for me, to 'tear down the walls', to keep pushing at the boundaries, but avoid building 'interior walls'--that it, to keep coming back over the same ground, to see if there is anything new to be done, or, more importantly, to see if something has been overlooked."

--Richard M. Males12

Why do cognitive strategies develop which appear to depend particularly on one of the cognitive domains? Evidence indicates that cognitive activity emphasizing conscious skills and conscious thought will favor development of particular cognitive strategies. Alternatively, cognitive activity emphasizing intuitive skills and intuitive processes will also favor development of particular cognitive strategies. The Harvard study noted,

"There is a tendency, particularly in late high school and college, for a student to increasingly choose courses that build on his strengths. This reinforcing pattern further develops those strengths and perhaps atrophies the skills in which he is less confident. This suggests not only that tasks exist that are suited to particular cognitive styles, but also that the capable individual will search out those tasks that are compatible with his cognitive propensities. In addition, he will generally approach tasks and problems using his most comfortable mode of thinking."13

This suggests that education which develops skills of conscious analysis will tend to develop conscious thinking strategies more intensely than intuitive thinking strategies. This does not imply that such education totally fails to develop strat-
egies in the intuitive domain. As was asserted previously, the intuitive domain may monitor activity in the conscious domain and internalize certain relationships. Thus, the intuitive domain may internalize a set of relationships heavily colored by the scientific method.

Does education play a real role in the formation of cognitive strategies? Yes. A study which compared freshmen engineering students with senior engineering students and freshmen fine arts students with senior fine arts students observed the following:

"The senior engineers were much more analytic than their freshmen counterparts, but significantly less skillful on imaginative tests. The seniors in fine arts on the other hand, got higher scores on imaginative tests, while they fared worse than their freshmen counterparts on analytic tests." 14

Value of the Engineer's Strategies in the Managerial Realm

The conscious cognitive strategies (as well as strategies in the intuitive domain that have developed due to impact of conscious analysis) of the engineer can be of value in the managerial realm. William Given has noted,

"Engineers have definite assets for managerial work... Engineers are usually well trained in the orderly processes of thinking. They learn to accumulate facts, to arrange and analyze them logically, and to base conclusions and decisions on their findings. This approach becomes instinctive with them." 15

Several observers have noted that the qualities of a good
engineer--possession of well-developed abilities in both the conscious and intuitive domains--are valuable attributes that can be transferred to the managerial realm:

"In the conduct of modern industry, leadership has to be capable of making intelligent judgments on a near-infinite variety of complex problems. It is perfectly clear that a substantial proportion of this leadership will have to be made up of engineers."

--Ray E. Bittner
Assistant General Manager for Engineering
Esso Research

"The ability to separate the wheat from the chaff in the daily problems of engineering plays an important part in an engineer's progress...This quality may be very important to the manager."

--William B. Given

"First of all, we need the engineer's point of view, now more than ever, and in the future we will need it vastly more so than now. In the organization and direction of large scale enterprise, economic or social, we need the respect that the engineer has for basic facts. We need his analytical frame of mind. We need his imagination. We need his contact with the interpretation and control of physical forces."

--Alfred P. Sloan

**Insufficient Cognitive Strategies**

Bruce Henderson has noted that effective managers require both conscious and intuitive skills and strategies (i.e., a mixed-scanning approach):
"Business thinking starts with an intuitive choice of
assumptions. Its progress as analysis is inter-
twined with intuition. The final choice is always
intuitive...

"Intuition can be awesome in its value at times. It
is known as good judgment in everyday affairs. Intu-
tion is in fact the subconscious integration of all
the experiences, conditioning, and knowledge of a
lifetime, including the emotional and cultural biases
of that lifetime. But intuition alone is never
enough. Alone it can be disasterously wrong...

"Any complex problem has a near infinite combination
of facts and relationships. Business in particular
is affected by everything, including the past, the
nonlogical and the unknowable. This complexity is
compounded by multiple objectives to serve multiple
constituencies, many of whose objectives must be
traded off. Problem solving with such complexity
requires an orderly, systematic approach in order to
even hope to optimize the final decision...

"The final choice in all business decisions is, of
course, intuitive. It must be. Otherwise it is not
a decision, just a conclusion, a printout."¹⁹

Henry Mintzberg has observed,

"Truly outstanding managers are no doubt the ones
who can couple effective right-hemispheric processes
(hunch, judgment, synthesis, and so on) with effective
processes of the left (articulateness, logic, analysis,
and so on)."²⁰

Are engineers, and hence engineer-managers, deficient in
productive cognitive strategies in the intuitive domain? The
evidence presented to this point seems to indicate that the
education of engineers stresses the development of strategies
in the conscious domain while failing to explicitly
develop strategies in the intuitive domain. Mark Sluis, an
engineer-manager, observes,

"Decision making is the most indisputable task a manager faces. He must make decisions more frequently than not on less than complete data. This problem is generally a real hang-up to an engineering-trained mind. We have been taught to do things logically, collect all the facts and then make a judgment...When facts are not known, unavailable, doubtful, etc. we lose confidence in making a subjective judgment. Unfortunately many make no decisions (which really is a type of decision alternative) or defer making one until timing catches up to us."\textsuperscript{21}

Additionally, Richard Males notes the stress the MITCED places on development in the conscious domain:

"We were given a vast assortment of 'tools' for problem definition and problem solving, and a philosophy and ethic--that of 'systems analysis', with the emphasis on analysis. We went about problem-solving by taking things apart, putting them into boxes, labeling the boxes. We had a box and a label for everything, and once a part of the problem was boxed and labelled, that was it. It was not possible for there to be two simultaneous and conflicting ways of looking at something. And most of all, there was no 'emotional' relationship to the problem--no idea of sniffing, smelling, puttering, no concept of an answer 'feeling right', no allowable 'fuzziness', no historical sense, in short, none of what I have come to call synthesis."\textsuperscript{22}

Finally, Peter Bulkeley, professor at Stanford University, writes,

"Too much of engineering education is centered about well-defined areas where students are expected to crawl into the shell of knowledge and learn all there is to know. Most real engineering problems are just the opposite--open-ended, interdisciplinary, unstructured, and have many multi-solutions. Students are
not subjected to the uncertainty they will encounter on their projects."\(^{23}\)

In sum, if the engineer-manager lacks cognitive strategies in the intuitive domain (or conscious strategies that utilize the skills and strategies of the intuitive domain), problems can occur. The primary problem is, of course, inaction.

**Inappropriately Applied Cognitive Strategies**

Inappropriate application of cognitive strategies is a result of several possible factors:

- inappropriate knowledge
- insufficient intellectual skills
- insufficient cognitive strategies
- inappropriate attitudes

Inappropriate application of cognitive strategies can cause the engineer-manager problems in many areas. In view of the current knowledge of cognitive strategies, the most identifiable problem area is that of decision-making. The Rational-Comprehensive method of decision-making is appropriate for well-structured problems and where ample time for analysis is available. The scientific method is time-consuming. Inappropriate application of cognitive strategies indicative of the Rational-Comprehensive method can cripple the engineer-manager.

**Summary**

Cognitive strategies guide the engineer-manager's internal
processes of thinking, coding, and retrieval. Unfortunately, due to the current state of knowledge of cognitive strategies, they cannot be extensively outlined and discussed.

Decision-making is an activity of significant importance for the engineer-manager. The cognitive strategies in the conscious domain of the engineer will likely be of value to the engineer-manager for managerial problems which require rigorous analysis.

Evidence indicates that engineering education develops cognitive strategies in the conscious domain while neglecting those in the intuitive domain. This can cause the engineer-manager problems:

- Insufficient intuitive cognitive strategies can result in inaction
- Inappropriate application of conscious cognitive strategies (often due to insufficient intuitive cognitive strategies) can cause fatal delays
Chapter 6: Endnotes


2. Ibid, p. 82.


7. Ibid, p. 84.


17. Given, op. cit., p. 50.


As noted previously, attitudes are "acquired internal states that influence choice of personal action". Attitudes serve several purposes for the engineer-manager. Attitudes guide assessment of situations by influencing

. which problems are seen as important
. which knowledge, skills, and strategies are deemed appropriate

Attitudes guide assessment of one's self (which is necessary for learning as well as performance) by influencing

. appraisal of the adequacy of learned attributes

Attitudes guide performance by influencing the particular approach taken for

. human interactions
. technical and managerial decision-making

Attitudes guide learning or ignorance resolution by influencing the perceived importance of

. continuous, independent learning
. acquisition of management technology
. problem-specific advice
. all forms of feedback

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Single attitudes appear to exist simultaneously in the conscious and intuitive domains. Attitudes characteristic of engineers are often of value to the engineer-manager. Unfortunately, certain attitudes developed by the engineer can cause problems for the engineer-manager. Problems result primarily from inappropriate attitudes.

**Conscious versus Intuitive Attitudes**

It is probably not appropriate to distinguish attitudes as either conscious or intuitive. Unitary attitudes often appear to have a component in each domain. Robert Gagné has noted,

"Attitudes have both cognitive and affective components. That is to say, they are internally mediated, in part, by propositions which incorporate the category of 'object' (events, persons, things) to which the attitude is directed. Usually, they appear also to be mediated, in part, by feelings which give them their 'affective' nature."

In view of the fact that attitudes cannot be completely articulated, educational programs stressing the development of attitudes may be difficult to detail in complete, explicit form.

As has been alluded previously, attitudes have intimate relationships with the other learned attributes. Particular factual knowledge influences the formation of attitudes and attitudes tend to perpetuate the acquisition of certain factual knowledge. Success with particular intellectual skills contributes to the formation of attitudes concerning use of those
skills and attitudes influence the selection of associated skills. Success with particular cognitive strategies produces similar results.

Value of the Engineer's Attitudes in the Managerial Realm

Basically, an attitude is valuable if it influences the development and use of the desirable learned attributes noted previously. A few additional examples can be explored.

If an engineer has confidence in the applicability of his learned attributes this can be of extreme value in the managerial realm. Richard Males suggests that, at least in the case of the MITCED, engineering education may encourage such an attitude:

"Probably one of the most significant things to come out of the undergraduate education was a sense of 'invincibility'...anything we didn't know, we could pick up along the way." 2

The engineer's tendency to quantify deserves mention. In certain circumstances this can be valuable to the engineer-manager. George Bugliarello writes,

"The particular strength of the engineer as a problem solver lies in his attitude and capacity toward quantification. In recent times, the problem solving orientation and the ability to quantify have led to the involvement of engineers in the solution of problems far removed from traditional engineering areas." 3

Healthy respect for the "skill" of introspection is of obvious value in continuous learning and self-development. A
psychological comparison of engineers, managers, and engineer-managers notes that engineers may be, surprisingly, introspective:

"Perhaps the most intriguing finding of this study is that engineer-managers were significantly higher on the trait of 'Psychological-mindedness' than managers. This is quite unexpected given that engineers are generally seen as non-introspective. The explanation may lie in the observation that engineering-trained persons are sought after for management because of their analytic skills. It seems reasonable that a man whose training includes specific problem-solving skills (i.e., how to organize a task, particularly by breaking it into its component parts) would transfer his training and observational skills to the area of human behavior when it becomes one of his task parameters."  

Inappropriate Attitudes

Presumably, engineering education attempts to avoid inappropriate attitudes. However, attitudes can be imparted indirectly or implicitly. Thus, certain inappropriate attitudes may be transmitted unintentionally. Additionally, certain attitudes which are appropriate for engineering work may betray the engineer-manager.

Particular attitudes encouraged in an engineering education may cause the engineer-manager to inaccurately assess a situation for relevant and important problems. It has been suggested by several observers that engineers may possess attitudes which cause them to focus principally on those problems which are quantitative or technical in nature:
"Certain characteristics which engineers tend to acquire result, first from their type of education, and second, from their work environment once they enter business. They are taught the practical approach to things—to keep their feet on the ground. Their concentration is with material things. As a result, even the experienced engineer sometimes doesn't look beyond technical aspects of his job."

--O. W. Tuthill

"Many engineers do not believe in the importance of things which cannot be measured—such things as attitudes, emotions, customs, traditions, prejudices. As a consequence they fail to deal with those things which cannot be solved by logic alone. Yet the non-logical (not illogical) is the crux of most business problems."

--William B. Given

Closely associated with attitudes that can obscure the importance of non-technical problems, engineers may possess attitudes which mediate against the recognition of "people problems". Several studies have noted the preference of engineers to deal with ideas or "things" rather than people. Specifically,

"There seems to be too little in the training of an engineer to make him realize that the world is full of people."

--William B. Given

"There are important consequences of the fact that thinking types are significantly more attracted to engineering: Any field heavily weighted with the same types can develop blind-spots of those types. One blind-spot of thinking types is a neglect of the human side of projects, because the technical aspects
are intrinsically more interesting."

--Mary H. McCaulley
Clinical Psychologist
University of Florida Health Center

Particular attitudes encouraged in an engineering education may cause the engineer-manager to inaccurately assess a situation for applicable learned attributes. This may lead to excessive dependence on quantitative factual knowledge and/or skills and strategies in the conscious domain:

"The weakness of technical education as a preparation for a business career...when it is not balanced by participation in liberal disciplines, is that it leaves in the mind of the student the impression that all problems are quantitative and that a solution will appear as soon as all the facts have been collected and the correct mathematical formula evolved."

--Clarence Randall
former Chairman
Inland Steel

Accurate self assessment is important for learning as well as performance. Education which stresses development in the conscious domain may cause the engineer, and hence the engineer-manager, to overestimate the power of skills and strategies in the conscious domain:

"The scientific method that engineers are exposed to in school presupposes a definite environment for the engineering problem so that solution is determined by a logical evaluation of existing constraints. All engineering problems are thus rationally solved and the student is set to face the next challenge. Thus, engineers tend to have the feeling that they
are equipped and ready to solve any and all problems."

--Michael N. Goodkind

"I believe that an engineering background will, at least in the operating end of management, yield better management people than a liberal arts background or lack of formal education beyond high school, if--and it is a big if--the engineer has inherently or can acquire the necessary amount of humility to do a good management job. Perhaps I overstate the importance of humility, but I believe that engineers in particular are apt by training to come out self-satisfied with the invincibility of the scientific method."

--William B. Given

Particular attitudes may cause the engineer-manager problems in performance involving human interaction. For example, an attitude which encourages the engineer-manager to work with things rather than people can be troublesome. A psychological profile of engineering students noted,

"[The student] has a history of painful and/or not completely successful personal-social contacts and of some adjustment problems. He has a history of liking to work with things and ideas as opposed to people."13

Such an attitude with regard to people may be manifested in a desire to work alone:

"Engineering training teaches a man to go at a problem from many approaches but usually on his own. There are probably more 'lone wolves' in engineering than in other departments. Often the brilliance and ambition of these men leads them into management. There they continue to build fences around themselves and around their field of work and eliminate
outside interests. They resent any intrusion on their time and thinking. The 'lone wolf' approach is, of course, disastrous in operating jobs."

--William B. Given

As a different example, an engineer-manager may have problems in accomplishing work through others:

"Unlike the average foreman, who is often restrained from participating in the work by union contract, the neophyte engineering-manager may find considerable difficulty disentangling himself from the engineering job, or in other words, 'meddling' instead of managing. While he may be able to achieve satisfactory results at the first level of management without making a clean break with the past, he will certainly not be able to do so at higher levels."

--Roland T. Eustace

Particular attitudes may cause the engineer-manager difficulty in performance involving managerial decision-making or technical decision-making related to managerial issues. Managers apparently require special information for the intuitive skills and strategies they often utilize:

"A great deal of the manager's inputs are soft and speculative--impressions and feelings about other people, heresay, gossip, and so on. Furthermore, the very analytical inputs--reports, documents, and hard data in general--seem to be relatively of little importance."

--Henry Mintzberg

Unfortunately, engineers may possess attitudes that mediate against use of intuitive abilities and "soft" information:
"Having a 'need for evidence' betrays many an engineer. He wants something that he can submit to fine analysis, something strong enough to underpin his ultimate decision. Much as his heart may yearn for this something, it is much more characteristic for a business manager to have to 'fly by the seat of his pants'...Often the desired information either is not available or is too costly to obtain. Time may be too short. Like it or not, intuition often must rule. Many engineers avoid intuitive responses per se, and even more of them never succeed in developing their intuition to the point where it yields good decisions more often than bad ones."

--Richard A. Koplow\textsuperscript{17}

"[As graduates of the MITCED] we had little appreciation of the need for and the appropriate time to use, quick and dirty solutions to small problems, or small parts of problems...[T]here was little if any 'reality testing'--we had to accept what our massive computer simulations told us, because we had no feel for the problem itself apart from the simulation...God forbid they should pull the plug on the computer. It would all be over."

--Richard M. Males\textsuperscript{18}

Additionally, engineering education may cause engineers to expect "one solution" to problems. This attitude can cause problems if carried into a managerial role:

"One of the more serious deficiencies in engineering education is the practice of teaching students that there is only one solution to every problem. A technical program should make the student realize that most engineering problems have more than one solution and contain 'tradeoffs'."

--Walter E. Thomas
Dean of Technology and
Applied Sciences
Western Carolina University\textsuperscript{19}
Attitudes which encourage continuous, independent learning are important to the engineer-manager (as well as to the engineer). George Houston in his book Manager Development: Principles and Perspectives notes,

"All development is self-development. Growth, development, and change can come only from within the individual and is determined by his ability, his willingness to apply himself, and the quality of his personal efforts." 20

An M.I.T. survey of engineering graduates 15 to 20 years out of school revealed that only 28% of those who were engineers and only 37% of engineers involved in management felt that they possessed the "ability to continue to learn" to any "great extent". 21 It is not possible to identify the exact role of attitudes in this assessment. However, it is evident that only a small portion of these graduates displayed an attitude of "I am very capable to continue to learn". Those who did not possess this attitude may feel "it is not important to continue to learn". Further work in this area would be valuable.

An attitude which acknowledges the importance of management technology is important to the engineer-manager:

"[A]n extremely important test of attitude comes when the manager...sizes up his familiarity with management technology and decides whether or not he needs to learn it as a separate discipline...Although some tools of engineering are valuable to the manager, the attempt to use only these tools for the job of management will prove as futile as the attempt of an artist to build a cathedral with his paint brush. Management has its
own technology."

--Richard A. Koplow

A survey of engineers and engineer-managers by Roland T. Eustace, however, revealed that while they were undergraduates, management courses ranked last in interest behind courses in engineering, science, mathematics, and humanities and social sciences. Nevertheless, it should be noted that this attitude may change as the engineer-manager progresses in his career.

**Insufficient Attitudes**

Insufficient attitudes would occur if the engineer-manager had insufficient conscious or intuitive knowledge to form an opinion. Areas in which inappropriate attitudes can cause problems are probably also subject to problems due to insufficient attitudes. However, no data are apparent which indicate engineer-managers encounter problems due to insufficient attitudes.

**Summary**

Attitudes possessed by the engineer are often valuable to the engineer-manager when such attitudes encourage the development and use of desirable learned attributes. However, inappropriate attitudes possessed by engineers may cause problems when engineers function in the managerial realm:
. Inappropriate attitudes regarding relevant problems (e.g., non-technical, non-quantifiable, and human problems) can result in inaccurate situation assessment

. Inappropriate attitudes regarding limitations of analytic procedures can result in inaccurate situation assessment for applicable methodology

. Inappropriate attitudes regarding limitations of analytic procedures can result in inaccurate assessment of the applicability of learned attributes possessed

. Inappropriate attitudes regarding people can result in problems in human interactions (e.g., working with things rather than people, working alone, failing to work through others)

. Inappropriate attitudes regarding applicability of analytic procedures, necessary data, and number of solutions seen as possible can result in problems in performance involving managerial decision-making or technical decision-making related to managerial issues

. Inappropriate attitudes regarding value of management technology may preclude important learning

No data is apparent which indicates engineer-managers encounter problems due to insufficient attitudes.
Chapter 7: Endnotes


8. Given, op. cit., p. 45.


CHAPTER 8: POSSIBLE EDUCATIONAL REMEDIES

Evidence indicates that at least 80% of all engineers eventually have some managerial responsibility. At least 50% eventually function principally in a managerial role. Most significantly, two out of three engineers have some managerial responsibility within five years after finishing undergraduate study.

The engineer possesses many learned attributes which are of particular value in the managerial realm. However, inappropriate or insufficient learned attributes (Exhibit 8-1) can cause the engineer-manager problems (as suggested previously, inappropriate application of learned attributes results largely from the possession of inappropriate or insufficient learned attributes). In view of these problem-producing attributes, what is an appropriate educational response at the undergraduate level? This question is actually comprised of two distinct, but easily obscured, component questions:

. What can be done?
. What should be done?

Currently, available data do not facilitates a definitive answer to the first question. However, a general outline of possible educational responses to insufficient or inappropriate learned attributes is assembled in this chapter. An accurate answer to the second question depends on several
### Exhibit 8-1

**Inappropriate or Insufficient Learned Attributes of the Engineer-Manager**

<table>
<thead>
<tr>
<th>Inappropriate Learned Attributes</th>
<th>Insufficient Learned Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factual Knowledge</strong></td>
<td></td>
</tr>
<tr>
<td>C/I . invincibility of analytic methods</td>
<td>C/I . limitations of analytic methods</td>
</tr>
<tr>
<td>C . transferability of engineering techniques</td>
<td>C . potential managerial issues</td>
</tr>
<tr>
<td>C/I . managerial jargon or customs</td>
<td>C . &quot;what can be known&quot; for management</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Intellectual Skills</strong></td>
<td></td>
</tr>
<tr>
<td>C/I . techniques of human interaction</td>
<td>C/I . techniques of communication</td>
</tr>
<tr>
<td>C . fundamental managerial techniques (e.g. accounting)</td>
<td>C/I . managerial &quot;rules-of-thumb&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cognitive Strategies</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>I . &quot;muddling&quot; component of &quot;mixed-scanning&quot; (i.e. intuitive cognitive strategies)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Attitudes</strong></td>
<td></td>
</tr>
<tr>
<td>. excessively emphasize invincibility of analytic methods</td>
<td></td>
</tr>
<tr>
<td>. excessively favor technical problems over non-quantifiable and human issues</td>
<td></td>
</tr>
<tr>
<td>. excessively favor hard data, analytic techniques, and &quot;one solution&quot;</td>
<td></td>
</tr>
<tr>
<td>. excessively favor work with things</td>
<td></td>
</tr>
<tr>
<td>. excessively favor independent work</td>
<td></td>
</tr>
<tr>
<td>. little respect for management technology</td>
<td></td>
</tr>
</tbody>
</table>

C=principally in conscious domain; I=principally in intuitive domain
factors for which data is largely subjective. Discussion is deferred to Chapter 9.

Development of Factual Knowledge, Intellectual Skills, and Cognitive Strategies

A review of instructional methods reveals that all "successful" methods provide for three distinct phases in the learning process:

- preparation (normally entails acquisition of basic information concerning what is to be learned; source can be human or inanimate)
- practice (normally focuses on the use of acquired knowledge or concepts in the solution of single-answer or open-ended problems)
- feedback (source can be human or inanimate)

Certain methods utilize single-answer or open-ended problems whereas other methods are best suited for practice that focuses on single-answer problems. Additionally, particular methods provide human feedback while others are restricted to inanimate feedback. For several examples, see Exhibit 8-2.

In view of

- the generally non-articulated nature of intuitive learned attributes, and
- the special capacity of the intuitive domain to assimilate unordered experience,

methods which emphasize solution of novel, open-ended problems are the best means of effectively developing learned attributes
### Exhibit 8-2

**Schematic Display of Instructional Methods**

<table>
<thead>
<tr>
<th>Type of Practice Possible</th>
<th>Single-Answer Problems</th>
<th>Open-Ended Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Feedback Possible</td>
<td>Human/Responsive</td>
<td>Inanimate/Inflexible</td>
</tr>
<tr>
<td>Case Method</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group Projects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lecture Method</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work Experience Programs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer Assisted Instruction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto-tutorial</td>
<td></td>
<td></td>
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<tr>
<td>Programmed Instruction</td>
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<td></td>
</tr>
</tbody>
</table>
in the intuitive domain. Additionally, methods which emphasize human feedback are necessary for optimal development of learned attributes in the intuitive domain:

"Coaching is not the same as lecturing. Feedback must be flexible. To develop an innovative worker, the teacher must coach him to develop his own creative, flexible approach to problem solving."

--Myron Tribus
Director
Center for Advanced Engineering Study
M.I.T.

In view of these observations and the severe time constraint imposed on student-faculty interaction, two implications are apparent:

. to the extent that time is desired for development of learned attributes in the intuitive domain, development of learned attributes in the conscious domain should be restricted to methods which effectively guide learning through inanimate feedback (e.g. programmed instruction, computer assisted instruction)

. development of learned attributes in the intuitive domain should emphasize methods which effectively guide learning through novel, open-ended problems and responsive human feedback (e.g. case method, group projects, lecture method with flexible teacher-student interactions, work experience with professorial guidance)—in essence, "acceleration" of raw experience

Development of Attitudes

Gagné notes three primary means of attitude change:
. Classical Conditioning (the perception of success in some activity leads to the establishment of a positive attitude toward that activity or toward objects and capabilities associated with the activity)

. Human Modeling (a person who is admired, respected, or perceived as having "credibility" is observed to exhibit certain behavior which is accompanied by an impression of "good" or "bad")

. Message Content (actually content has little impact but perception of the "communicator" does have impact—thus, this is equivalent to human modeling)

Thus, in reference to the work of Gagné, certain attitudes noted in Exhibit 8-1 may be ameliorated through use of classical conditioning:

. providing opportunities for failure in the use of analytic techniques accompanied by success in the use of intuitive abilities will develop respect for the limitations of analytic methods

. providing opportunities for success in the solution of open-ended problems where non-technical issues are important will develop a positive attitude toward such issues

. providing opportunities for success in activities such as group problem-solving will develop positive attitudes toward human issues, the frequent necessity of working with people, the frequent necessity of directing the work of others (rather than working independently)

. providing opportunities for success in the solution of open-ended problems entailing quantifiable as well as non-quantifiable issues will develop a positive attitude toward "soft data", intuitive abilities, and multiple solutions

Human modeling can also be used in the development exhibited in the preceding examples. Additionally, human modeling is par-
particularly important in the development of a positive attitude toward management technology.

Educational Trade-offs

Various trade-offs exist within the time constraint imposed by a four year undergraduate program:

. focus of content
  --engineering versus management

. focus of educational effectiveness
  --effective current performers versus effective future learners and leaders

. focus of development of learned attributes
  --conscious domain versus intuitive domain
  --factual knowledge versus intellectual skills versus cognitive strategies versus attitudes

Synergism probably exists between trade-offs. In other words, intense focus on one variable continues to yield development along other dimensions. For example, writing and speaking skills are important in both engineering and management activities.

These trade-offs must be made in light of educational objectives of individual educational institutions (see Chapter 9). Nevertheless, it is interesting to speculate on the educational decisions made in the trade-off of "effective current performers versus effective future leaders". Referring to Exhibit 8-1, development of effective current performers may emphasize development of the following (attitudinal development in either case should remedy the problems noted):
. factual knowledge of
  --limitations of analytic methods (conscious)
  --transferability of engineering techniques (conscious)
  --potential managerial issues (conscious)
  --managerial jargon or customs (conscious)

. intellectual skills encompassing
  --techniques of human interaction (conscious)
  --techniques of communication (conscious)
  --fundamental managerial techniques (conscious)

On the other hand, development of effective future learners and leaders may emphasize development of

. factual knowledge of
  --limitations of analytic methods (conscious and intuitive)
  --transferability of engineering techniques (conscious)
  --potential managerial issues (conscious)
  --"what can be know" for management (conscious)

. cognitive strategies
  --in the intuitive domain and which utilize intuitive abilities

As a final note, an important administrative trade-off exists in the development of learned attributes required by the engineer-manager: should this development be relegated to one or more courses created specifically for such learning activities or should development pervade many courses in the undergraduate curricula? Research of educational psychologist D. Krathwohl suggests the latter tack:
"Only small gains are attained when merely a single course in a college program aims to develop a particular type of competence. On the other hand, when the entire curriculum is devoted to this same purpose (i.e., when these objectives become the theme that plays through a large number of courses) the student's gain in competence becomes very large. In effect, the entire educational environment must be turned toward the achievement of complex objectives if they are to be attained in any significant way." 4

Note that such an approach pertains particularly to complex objectives (e.g. the development of cognitive strategies). Learning which involves practice of single-answer problems can probably be adequately handled in a single course.
Chapter 8: Endnotes


CHAPTER 9: NORMATIVE DETERMINANTS OF FEASIBLE EDUCATIONAL REMEDIES

In view of the problems of engineer-managers and the possible educational remedies at the undergraduate level, what should be done? This is largely determined by the objectives and constraints of undergraduate engineering education. Objectives are both explicit and implicit and are determined in part by existing constraints:

- faculty constraints (e.g., time spent on research versus time spent on teaching, faculty interests, etc.)
- student tastes
- requirements of employers

Judicious distillation and review of the objectives of engineering education could easily fuel a significant and separate study. The intent of this chapter is somewhat less ambitious:

- Construct a framework to conveniently and productively array objectives and attendant issues
- Speculate on how appropriate preparation for managerial activities varies as a function of objectives

Objectives and Issues

Debate over the objectives of undergraduate engineering education is conducted by both individuals and institutions (e.g., universities as well as professional societies such as ASEE, ASCE, IEEE, ASME). Concern extends to programs of par-
ticular educational institutions as well as programs across all engineering educational institutions. A review of the literature reveals objectives and issues which fall into five key areas:

. **appropriate role of undergraduate engineering education as preparation for engineering practice or other careers**

. **types of problems recognized as within the realm of engineering practice**

. **types of practitioners recognized as needed by the engineering profession**
   --leaders versus executors
   --generalists versus specialists
   --career transitions

. **types of learned attributes recognized as appropriate to transmit at the undergraduate level for engineering practice or other careers**

. **types of programs necessary to produce desired learned attributes**
   --content
   --length and efficiency
   --instructional methods

Discussions rarely respect the integrity of each category. For example, the debate over practice-oriented curricula frequently addresses in the same breadth desired types of practitioners and programs necessary for their education. Simultaneously, required learned attributes remain largely unarticulated.

**Appropriate Role of Undergraduate Engineering Education**

Should undergraduate engineering education prepare students principally for engineering practice or should it also serve as a foundation for other careers? Is it suitable as
stand-alone preparation for professional practice? In essence, four views exist as to the proper role of undergraduate engineering education (Exhibit 9-1).

Certain individuals and institutions explicitly accept engineering education as valid preparation for careers other than engineering practice. For example, consider the following:

"The injection in the engineering curriculum of subjects in the physical sciences, humanities, and social sciences gives the engineer the opportunity to communicate, or at least to not be totally unfamiliar with a broad segment of the disciplines in the university...However imperfectly educated, the engineering student is potentially more able to comprehend the position of man in the modern world than the student of the humanities or of the arts, who has looked at only one segment of that world."

--George Bugliarello

"The undergraduate degree program in engineering is traditionally, rightfully, and increasingly an excellent background for those going on to other professions and other activities. In our technologically based civilization, a sound engineering education is a true liberal education and a fine preparation for life in the world of tomorrow."

--Daniel C. Drucker
Dean, College of Engineering
University of Illinois at Urbana-Champaign

"Appropriate endeavors for modern engineering graduates would also be found in non-engineering fields in which methods of thought and analysis associated with engineering could be usefully applied. The obvious ones would be business administration, in which the methods of analysis in use have become increasingly more quantitative and decision methods more objec-
Exhibit 9-1

Schematic Representation of the Possible Roles of Undergraduate Engineering Education

<table>
<thead>
<tr>
<th>position in formal learning process</th>
<th>graduate study</th>
</tr>
</thead>
<tbody>
<tr>
<td>stand-alone</td>
<td>follows</td>
</tr>
</tbody>
</table>

Legend:
- Ostensible preparatory purpose
- Engineering practice
- Other careers
tive and complex; medicine...; and law..."

--Andrew Schultz, Jr.
Professor of Engineering
Cornell University

This role is also acknowledged by various civil engineering educational institutions including the MITCED. The 1971-1972 Annual Report of the MITCED noted "the breadth and largely pre-professional character of our undergraduate programs" and observed that "increasing numbers of our students intend to go on to work in law, management, public administration, etc."4

Additionally, some emphasize the necessary role of undergraduate engineering education as the primary instrument of preparation for professional practice:

"The 4 year undergraduate program is the key to educating engineers for effective practice in our world of perpetual crisis...It occupies the crucial central position in engineering education not only for those students who terminate their formal engineering education at the Bachelor's level but also for those who go on to graduate study."

--Daniel C. Drucker5

The NSPE Ad Hoc Committee on Professional Schools of Engineering concurs with the idea of education for practice and emphasizes that

"The education of individuals to practice the profession of engineering and to serve the public will necessarily have to involve education beyond the traditional baccalaureate degree."6
With regard to the MITCED, graduate education is often recommended. As one recent graduate noted, "four years was insufficient--a graduate education was a necessity, and that graduate education should be at MIT."  

Types of Problems

Which problems are relevant to engineering practice? Basically, debate contrasts problems along two dimensions:

- current problems versus potential future problems
- technical problems and problems in engineering economics versus societal, environmental, and managerial problems

Alfred Keil, Dean of Engineering at M.I.T., has stressed the importance of keeping an eye on the future:

"Schools of engineering must make sure that engineering education is not controlled by professional requirements directed merely at past or current needs, but by the challenges which engineers will have to face in the years to come."  

Traditionally, engineers have been concerned principally with technical factors and immediate cost implications for construction or manufacturing. The scope of problems relevant to engineering practice has been expanding and this may continue. Lawrence Grayson, head of the Program on Telecommunications Applications for the National Institute of Education, has outlined the details of this trend:
"The engineer must become conscious of the social consequences of his work, and that he must at times work in concert with sociologists, economists, industrialists, psychologists, politicians, and even theologians... Programs are being developed at numerous universities to acquaint the student with political and social processes and values, the structure of public systems, economics, social sciences, law, public health, rural, urban and international development, civil welfare, business administration, environmental design, and public policy. All are attempting to make the student more conscious of the obligations the engineer has to society and to enlarge his outlook to include the human aspect of his future work."\textsuperscript{9}

Upon review of the literature, it is apparent that schools vary widely according to which problems they consider relevant to practice. The MITCED displays a broad definition of relevant problems. This definition is evidenced by the departmental description of the civil engineering profession in the 1976-1977 M.I.T. Bulletin:

"The essence of the profession, as we view it, is to bring about a symbiosis of the constructed facility with the natural environment on the one hand, and with the social environment on the other. Creating this accommodation between man and his environment requires recognition and formulation of very complex problems when the objectives are multiple; when human and institutional, as well as technical, constraints are operative; and when both our understanding and the available information are imperfect."\textsuperscript{10}

**Types of Practitioners**

Apparent agreement exists on the need for many types of practitioners to fill the various roles of engineering practice.\textsuperscript{11} Further, an engineer is often expected to pass through several phases in the span of a career.\textsuperscript{12} These ideas
are summarized in Exhibit 9-2. Several observations can be made:

. Engineering generalists, specialists, and scientists are normally referred to collectively as engineers.

. The various types of engineers can have identical undergraduate educational backgrounds; technologists and technicians normally do not share the undergraduate background of engineers.

. Engineering "leadership" may or may not be defined so as to include management.

. In a broad sense, engineers can "lead" through technical creativity or management; technologists and technicians normally lead only through management.

. It is possible to function in technical and managerial roles concurrently.

. The apprenticeship of technologists and technicians is usually short due to educational design; as will be discussed, an education appropriate for short apprenticeship of engineers is not necessarily optimal for a career of leadership.

The MITCED recognizes the need to educate both generalists and specialists:

"The broad scope of civil engineering activities, embracing planning, analysis, design, construction, and management, requires an equally diverse set of practitioners--those with the breadth of perspective to assess needs and to evaluate impacts, and the specialists within the disciplines who design and make it work."13

Additionally, the MITCED emphasizes preparation for leadership:
Exhibit 9-2
Types of Engineering Practitioners and Their Career Phases

<table>
<thead>
<tr>
<th>career phases</th>
<th>expected to lead</th>
<th>expected to execute</th>
<th>expected to learn</th>
</tr>
</thead>
<tbody>
<tr>
<td>accepted roles</td>
<td>leaders</td>
<td>effective executors</td>
<td>apprentices</td>
</tr>
<tr>
<td>engineering generalist</td>
<td>e.g. planner</td>
<td>work</td>
<td>graduate school</td>
</tr>
<tr>
<td>engineering specialist</td>
<td>e.g. experienced engineer</td>
<td>work</td>
<td></td>
</tr>
<tr>
<td>engineering scientist</td>
<td>e.g. professor</td>
<td>research</td>
<td>research ass't</td>
</tr>
<tr>
<td>manager/administrator</td>
<td>work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>technologist</td>
<td>work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>technician</td>
<td>work</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
"Our objective should be to educate men who are capable of independent thinking, problem-solving, and leadership...Leadership recognizes: innovation, initiative and decision-making ability." 14

Learned Attributes and Necessary Educational Programs

What particular factual knowledge, skills, thinking strategies, and attitudes are necessary equipment for an engineering career? Appropriate learned attributes are debated in two principal arenas. First, views vary as to the necessary generality or specificity of an undergraduate program. Second, effective current practice as well as future leadership are both accepted goals of undergraduate engineering education--however, there may be a conflict involved in simultaneously achieving these ends. This debate between preparation for current practice and preparation for future leadership deserves discussion.

Summary comments of the 1974 ASCE Conference Civil Engineering Education suggest the desirability of education for both effective current practice and future leadership:

"The challenge to civil engineering education is to prepare graduates well-qualified to enter the profession effectively and to practice competently throughout their careers...We should educate engineers as leaders, but their training should be practice oriented." 15

Drucker notes, however, that finding the optimal educational program is a real problem:
"The major problem of the schools is to balance the need to prepare graduates flexibly for the professional practice of the future with the need to provide a sufficient knowledge of current practice for acceptability to employers."  

Relevant problems and applicable technology change not only for the profession but for the practitioner over his career. Thus, it is desirable for education to be transferable across varying problems as well as transferable to further learning. Drucker adds, "Curricula aimed at today's needs obviously should not be taught because they would guarantee obsolescence on graduation."  

The usual distinction in possible educational program content is drawn between theory and application--theoretical skills versus the skills associated with the application of the theory:  

"What is important is the balance between current practice and theory within each course, especially the design courses."

--Robert M. Sykes  
Assistant Professor of Civil Engineering  
Ohio State University  

"Clearly, there is room for both the science-based curriculum and the traditional curriculum. One should not supplant the other."

--Richard M. Males

"As the 20th century approached, a new era was dawning as the discoveries of scientists evolved new theories that led to numerous advances in engineering. The
engineer was called upon to use his skills and innovations to exploit new scientific theories. The teaching technique shifted from one of application to a combination of application and theory."

--Paul Reed
W. F. Jones Consulting Engineers

An education optimized for effective and efficient current practice must focus on the prevailing application of engineering techniques.

An education that prepares the learner for future leadership must provide for attainment of learned attributes including but not restricted to pure theory:

1. broad factual knowledge of the problems and technology of engineering practice to aid in the transfer of education to varying problems and for transfer in future learning

2. certain skills transferable to current performance as well as future learning

3. cognitive strategies for creative problem-solving and self-education

4. attitudes which respect changing problems and encourage self-education in necessary areas of skills and factual knowledge

Preparation for Managerial Activities

Given the preceding review of objectives of undergraduate engineering education, it is possible to speculate on feasible forms of preparation for managerial activities:

1. Avoid transmission of learned attributes inappropriate for management in all those institutions acknowledging the extensive phenomenon of engineers functioning in the managerial realm
Provide explicit consideration of certain learned attributes necessary to function in the managerial realm wherever such learned attributes can be transmitted without detracting from other educational objectives.

Additionally, provide explicit preparation for managerial activities to the degree that an undergraduate educational institution:

--recognizes that graduates may move rapidly into the managerial realm whether through engineering practice or other careers

--assigns little likelihood of graduate education in managerial learned attributes

--accepts a broad definition of engineering practice (including managerial problems)

--accepts a broad definition of practitioners required by the engineering profession (including managers)

--emphasizes a career for leadership in either creative problem-solving or management

Objectives of the MITCED have been distilled from the M.I.T. Bulletin and the MITCED publication Civil Engineering at M.I.T.: The Undergraduate Curricula Effective September 1978 (Exhibit 9-3). It should be noted that such a compilation is necessarily subjective and may not reflect truly the objectives of the MITCED. The following assertions concerning possible preparation for managerial activities on the undergraduate level in the MITCED are based on the preceding guidelines and the objectives in Exhibit 9-3:
Exhibit 9-3

Hierarchy of Objectives for MITCED Undergraduate Educational Programs

Provide educational programs which meet the needs and backgrounds of MITCED students while meeting the objectives of the Department

Educate Civil Engineers who will function as generalists as well as those who will function as specialists

Educate Civil Engineers primarily as future leaders (innovators, initiators, and coordinators) and secondarily as efficient current practitioners

Provide for attainment of certain attitudes and basic knowledge of Civil Engineering problems

. Awareness of the broad spectrum of problems that may be encountered

. Awareness of the multiple issues, constraints, and objectives that should be considered: technical, economic, environmental, institutional, human

. Awareness of the pragmatic engineering constraints of time and cost

. Awareness of the skills required to achieve and implement solutions

. Confidence in ability to solve complex problems (gained through actual competence in problem formulation and solution)

Provide for attainment of the latest fundamental technical skills as well as the fundamental "economic, political, and social science skills which permit assessment of need, and evaluation of both social and environmental impacts, as well as methods for managing the engineering enterprise"
- Avoid transmission of learned attributes inappropriate for management

- Provide explicit preparation for managerial activities through development of

  -- broad factual knowledge of the problems and technology of managerial activities in engineering practice; knowledge of the limitations of analytic techniques; knowledge to facilitate the transfer of engineering techniques to managerial activities

  -- cognitive strategies for creative problem-solving and self-education (i.e., an increased emphasis on cognitive strategies in the intuitive domain and cognitive strategies which utilize intuitive abilities)

  -- attitudes which respect managerial issues as real problems of practice, respect the knowledge and skills necessary to function in the managerial realm, respect the limitations of conscious analysis, and encourage self-education as needed in managerial knowledge and skills

Additionally, in view of the objective including "methods for managing the engineering enterprise" (Exhibit 9-3), an argument can be made for explicit consideration of certain fundamental managerial skills. This point, however, is probably a candidate for serious debate.
Chapter 9: Endnotes


12. Ibid.


16. Drucker, op. cit., p. 5

17. Ibid, p. 4.


CHAPTER 10: FUTURE STUDY

There are several areas where further study would be of value. These involve refinement of the arguments explored as well as extension to other professions of the concepts presented. Wherever possible, collection of quantitative data would be valuable.

For engineers in general, data on the problems engineers encounter as managers need to be refined. Problems need to be more fully detailed and substantiated. The extent to which engineer-managers successfully respond to such problems should be examined.

Before implementation of educational change at a particular institution, institution-specific data should be assembled. Institution-specific data should be gathered on the movement of the particular institution's engineers into management, the problems they encounter, and the degree to which they successfully respond to such problems.

Two additional questions should be explored before implementation of educational change:

1. Are educational institutions uniquely suited to the development of particular learned attributes (e.g., learned attributes in the conscious domain)?

2. Should educational institutions make an explicit attempt to develop learned attributes in the intuitive domain?
The concepts presented may be extended profitably to other professions and the functioning of professionals as managers. For example, the involvement of lawyers in linearly structured legal arguments may emphasize left-hemispheric development at the expense of right-hemispheric development. Does this impair the lawyer's ability to perform certain managerial activities?