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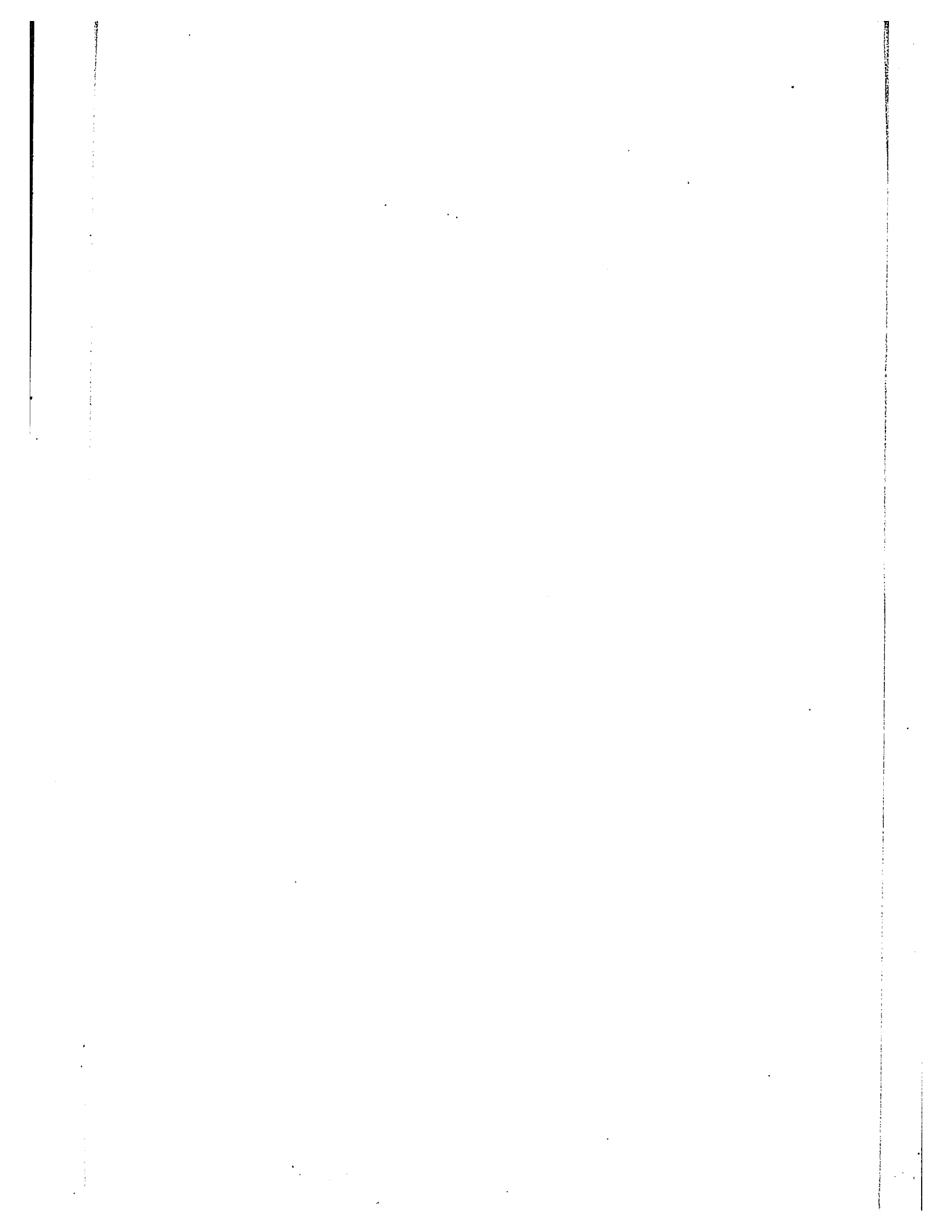
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Thinking Skill Development
in the Context of a
Mainstream Subject Area

by

K. Lynn Taylor

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Submitted in partial fulfillment of the requirements for the degree of
Master of Arts
at
Dalhousie University
Halifax, Nova Scotia
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Readers: 2
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AUTHOR K. Lynn Taylor

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ABSTRACT

University teaching and learning experiences which are characterized as unsatisfactory by many faculty and students can be more precisely defined as manifestations of poorly developed higher order thinking skills. Two hypotheses relevant to this problem are explored in this thesis. The first is that it is possible to use the characteristics of good and poor problem solvers documented in the literature as a productive way of recognizing and understanding the learning problems experienced by many university students. The second hypothesis is that the integration of the characteristics of effective problem solvers into a framework of general problem solving heuristics is a practical and effective strategy to move students along a continuum to better developed higher order thinking skills within the broader context of knowledge acquisition.

The teaching strategy developed from the literature and illustrated in a case study, is designed to capitalize on the scholarship of faculty often underutilized in their teaching, by encouraging faculty to be more self-conscious in making process skills explicit in a way that is meaningful to their students. As demonstrated in the case study, it is a strategy which utilizes teaching opportunities and data sources available in the classroom situation.

The results of the case study indicated that, in this case: (1) characteristics of good and poor problem solvers were observable in the classroom situation; (2) faculty could learn and use the strategy effectively in the context of discipline teaching; (3) the strategy did not seriously restrict the amount of content to be taught; (4) students did acquire skills specific to the strategy implemented; and (5) that particular areas of concern for further applications were encouraging students to actively engage in process tasks, to have more confidence in their use of reasoning as a tool and to place more emphasis on the cognitive skill of evaluation.

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CHAPTER ONE: DEFINING THE PROBLEM

I. INTRODUCTION

Most university faculty have, in one class or another, been discouraged by their students apparent inability to effectively comprehend and use the knowledge of a discipline. Typical among the complaints shared with colleagues are a reliance on rote memory rather than understanding, a failure to analyze or reason using the knowledge base or even to recognize situations in which the knowledge base is relevant or how it relates to new information. These characteristics of student learning represent a significant challenge to the effective transmission of the knowledge of a discipline. Effective transmission is an essential requirement for sustaining the integrity and development of the knowledge of a discipline so it is not unreasonable to suggest that as part of the commitment to scholarship faculty apply a scholarly disposition to the shortcomings recognized in the teaching and learning of a discipline. If a similar deficit were recognized in the research or thinking of a discipline it would provoke the scholarly action of defining the problem further, identifying and gathering relevant knowledge, developing a response and evaluating the outcome. In this thesis, the objective will be to define the problem with more precision and suggest a means by which it might be addressed at the classroom level.

Chapter one sets the context for the development of the thesis. Following chapters review the relevant literature, derive from the literature a strategy to recognize and develop general thinking skills with the context of knowledge acquisition and describe, analyze and evaluate a case study in which the strategy was applied.

II. DEFINING THE PROBLEM

Most faculty would acknowledge intermittent frustration with the performance of their students, particularly in their abilities to operate on the knowledge they acquire at levels beyond memorization. This gap between faculty expectations and student performance contributes to an erosion of faculty morale and increasing student dropout rates (Hutchinson, 1985). It is possible to move from general frustration to a better defined understanding of the problems through literature which documents student learning and thinking skills and, to a lesser extent, characterizes faculty teaching. A more precise definition of the problem provides a focus for seeking solutions.

A. Characterizing Student Learning and Thinking Abilities

There are actually relatively few studies of intellectual development in university and college students and particularly lacking are longitudinal studies. Most research on this group centers on the acquisition of substantive knowledge and on personality characteristics

which affect orientation to intellectual activities (Terenzini, Theophilides and Lorang, 1983). Among those studies concerned with intellectual development in these students, most conclude change but do not explore how the change occurs or why (McMillan, 1987).

1. Formal Versus Pre-Formal Reasoning Abilities

From the studies of learning and thinking skills available, results indicate that approximately 50 percent of a broad cross-section of university students fail or are incompletely successful in formal operations (Arons, 1984; Chiapetta, 1976; Juraschek, 1974; Kolodiy, 1975; McKinnon & Renner, 1971; Poduska and Phillips, 1986; Renner and Lawson, 1975). In performance terms, 50 percent of university students cannot reason abstractly. That is to say, they cannot generalize concepts or apply reasoning and problem solving skills to new situations (Nickerson, Perkins and Smith, 1985), deal effectively with hypothetical situations (Fuller, 1980) or see the interplay of ideas and actions (Duly, 1978). Pre-formal college students can deal effectively with concrete operations and concepts that can be represented in diagrams or with objects that can be manipulated but not with abstract ideas or verbal descriptions of such concepts or processes (Arons, 1976). The problem is not discipline specific and has been reported in varied domains (Glaser, 1984) including reading (e.g. Resnick, 1979), science (e.g. Champagne and Klopher, 1977), physics (e.g. Larkin, 1980), science teacher education (e.g. Arons, 1976, 1984) math (e.g. Schoenfeld, 1978)

and engineering (e.g. Woods, et al, 1975).

Although students report a perception of growth in thinking skills in each year of college study (Terenzini, Theophilides and Lorang, 1984), assessment shows that a traditional college experience does not substantially raise the cognitive skill level of students with regard to academic (Kolodiy, 1975; Larkin and Reif, 1976) or everyday issues (Perkins, 1985). Also reported are that the overall improvement in cognitive skills between the first and final years of study is due mainly to attrition of less skilled students (Kolodiy, 1975) and that verbal skills correlate more highly than cognitive skills with successful grades (Kolodiy, 1975).

In short, that intuitive feeling of faculty members that many of their students perform well on recall and simple application tasks, less well at analysis, and least well on tasks requiring synthesis of new ideas or evaluation has firm support in the research literature.

2. Thinking Skills and Bloom's Taxonomy

The categories of tasks identified above have been chosen carefully to coincide with categories of educational objectives described by Bloom (1956) in order that further research findings can be introduced. There is evidence that the cognitive skills required to successively pass through knowledge, comprehension, application,

analysis, synthesis and evaluation type tasks become increasingly complex (Rosen, 1984). Further, these cognitive skills appear to form a dichotomy: those skills which allow the first four types of tasks to be processed (which more students exhibit) and those skills required for synthesis and evaluation, (which fewer students exhibit) (Rosen, 1984). While this evidence helps to further define the problem, it also indicates that there are at least two classes of educational objectives which are not being adequately met and that they require specific cognitive skills.

3. A Summary

Can the problems with regard to student learning and thinking abilities now be defined more precisely? Firstly, the inability to reason abstractly affects approximately 50 percent of college and university students. Secondly, students are more likely to have acquired the necessary cognitive skills for and, hence be successful at, tasks requiring knowledge acquisition, comprehension, direct application of knowledge and analysis. Tasks requiring synthesis of new ideas and evaluation require higher order thinking skills which many students have not developed. Thirdly, the kinds of learning experiences these students receive will not, in most cases, help them develop the skills required to perform these tasks in academic or real-life situations.

B. Characterizing Faculty Teaching

The teaching practices of faculty can also be characterized in a more focused way to complete the scenario with which we begin.

1. Implicit Assumptions

Faculty have attained expert status in their discipline and, through their teaching, hope to have students develop some of that expertise. When faculty teaching is examined more closely however, it becomes evident that it makes implicit assumptions about the reasoning capacities of students (Arons, 1979; Hutchinson, 1985). Of particular importance is that most traditional courses require abstract reasoning skills (Prosser, 1979). Given what the research shows about student learning, inappropriate tacit assumptions create gaps between teaching and learning and can seriously interfere with the communication of the knowledge of a discipline. Arons (1979) outlines sixteen frequently made assumptions for which the teaching in varied disciplines can be examined. He includes assumptions concerning student skills in paraphrasing in ones own words, discriminating between observations and inferences, analyzing a line of reasoning, drawing inferences, evaluating outcomes and acquiring the skills of ones discipline.

2. Instructional Materials and Strategies

A second characteristic of faculty teaching is revealed by what kinds of knowledge faculty test for. Analyses of tests designed by faculty show

that test items requiring recall and application dominate the tasks required of students (Quellmaltz, 1984; Woods, 1987). The higher order skills essential to expertise and found wanting in at least one-half of university undergraduates are not assessed in testing. Testing reflects instructional materials and strategies which are largely intended to meet the requirement that a knowledge base in a discipline be established to build expertise. Students are not often asked to construct, to integrate, to argue, to appraise or to predict. The focus is on information and, even though the organization and processes of the discipline are implicit in its presentation, it is the information in isolation that the students perceive (Cyert, 1980; Norman, Gentner & Stevens, 1976; Mevarech and Werner, 1985). This characteristic is a hazard of expert knowledge and thinking: so much of expert knowledge becomes internalized, shifting from a basis of serial processing to pattern recognition and memory, that much of what makes an expert remains implicit in the teaching of others (Anderson, 1985). The implicit structure and process, however, is realized only by about 25 percent of students; the others remain uninformed (Arons 1979). The lack of explicit attention to the organization and processes of knowledge is further compounded by the failure of texts used in college courses to make the organization and process of the discipline obvious (e.g. Prosser, 1979).

3. A Summary

In summary, the more precisely defined problems faculty face as teachers are that there are tacit assumptions about student learning underlying teaching efforts that must be identified and examined for their validity and, secondly, that testing reflects that there is often no explicit recognition in the context of teaching of the kinds of knowledge that are required for expertise in a discipline.

Traditional university education has been found to have a less than impressive effect on the intellectual and social development of students (The Committee on the Student in Higher Education, 1968; Heath, 1968; Kolodiy, 1975; Perry, 1970). The characteristics of student learning and faculty teaching outlined here are a significant part of the problem. A review of the literature indicates that the skills which can be identified as being underdeveloped in many students are not addressed in university teaching. With these more refined definitions of what the problems are, it is possible to focus more clearly on whether they should be addressed and by what means.

III. DEFINING THINKING SKILLS

The failure to clearly define "general" or "higher order thinking skills" to this point has been quite a conscious one. A clear definition of what constitutes "higher order thinking skills" is essential to effective assessment of students, planning and implementation of instruction and evaluation of outcomes. However, such

a definition is not a simple task and will take some development so that, at least for the purposes of this thesis, its meaning is clear. As Sternberg (1987) puts it, there is no "periodic table of the mind", no consistent nomenclature or definitions of individual cognitive skills. Historically, thinking skill development has been of interest to and has been researched independently by philosophers, psychologists and educators and therein lies the source of confusion over a clear definition.

Traditionally, philosophers have emphasized those thinking skills necessary to justify an idea and its consequences (Dewey, 1933). This tradition is well represented in the delineation of "critical thinking skills" developed by Ennis (1962). Generally speaking, "critical thinking skills" include skills in focusing on a question, analyzing arguments, clarification of information, judging credibility of sources and information, induction, deduction, inference, making and assessing value judgements, definition and identifying assumptions and strategies for coordinating all skills in interaction with others (Ennis, 1985). The thinking skills defined by philosophers are those of effective reaction, although there is some recent movement to include those skills on the generative end of the spectrum (Ennis, 1985). The skills defined by psychologists include "critical thinking" skills but also the thinking skills necessary for dealing with novel information, situations or problems. Furthermore, psychologists concern themselves with the process underlying cognitive skills and their management (Newell and

Simon, 1972; Quellmaltz, 1985; Sternberg, 1983). Educators take all of these skills, identify the essential characteristics required for their development and map out strategies for their acquisition (Gagne, 1975; Klahr, 1976). It is quite possible to become mired in the lists of skills and different perspectives on what constitutes "higher order thinking skills". However, the insight of Edys Quellmaltz (1985; 1987) in finding common ground on the essential skills identified in all of these perspectives and across disciplines is most helpful in representing higher order thinking skills. She finds a relationship between those skills defined by philosophers and psychologists as thinking skills and synthesizes a single definition.

The definition suggested by Quellmaltz (1985; 1987) includes "purposeful, extended lines of thought in which they (students) identify and analyze a problem, identify and relate information necessary to address the task, and evaluate the adequacy of conclusions or solutions. Further, students should be critical of the strategies they use. The cognitive processes of analysis, comparison, inference and evaluation seem to be involved in various combinations in reasoning tasks as do the three metacognitive components--planning, monitoring and reviewing/revising" (Quellmaltz, 1985, p. 31). Her definition includes the strategies required, their underlying cognitive processes and their management.

The cognitive processes designated as a component of "higher order

thinking skills" by this definition represent a synthesis of the classification systems which have been used in higher education research. The placement of the line dividing "lower" and "higher" cognitive processes has varied across studies but designating analysis, comparison, inference and evaluation as higher order thinking skills is not inconsistent with existing literature (Bellack, Kliebard, Hyman and Smith, 1966; Guilford, 1956; Hegarty, 1979; Shymansky and Penick, 1979).

Table 1-1 Classification Systems for Cognitive Processes

Developer/ Process Categories	Bloom	Guilford	Bellack et al.	Quellmaltz
Lower Order Processes	Knowledge	Cognition	Defining	Recall
	Comprehension	Memory	Fact Stating Opining	
Higher Order Processes	Application	Divergent Production	Interpreting	Analysis
	Analysis	Convergent Production	Explaining	Comparison
	Synthesis	Evaluation	Justifying	Inference
	Evaluation			Evaluation

Stiggins, Rubel and Quellmaltz (1986) define the thinking skills which fall into each of the categories cited in the Quellmaltz definition. The specifications which emerge form a general framework for classifying thinking skills rather than a highly particularized

list. Such a general framework is required to resolve the debate over the choice of specific skills and the variation in skill application among perspectives and across disciplines. A more general framework provides a consistent basis for discussion and development of higher order thinking skills in all disciplines (see Table 1-2).

Table 1-2

**Defining Lower and Higher Order Cognitive Processes
(Stiggins, Rubel and Quellmaltz, 1986)**

Recall	Analysis	Comparison	Inference	Evaluation
<ul style="list-style-type: none"> ° recognize or remember key facts, principles, rules, etc. ° repeat or paraphrase 	<ul style="list-style-type: none"> ° divide a whole into component parts 	<ul style="list-style-type: none"> ° recognize or explain similarities or differences 	<ul style="list-style-type: none"> ° deductive & inductive reasoning ° hypothesizing predicting, concluding & synthesizing 	<ul style="list-style-type: none"> ° judge quality, credibility, worth or practicality ° explain the criteria used
Lower Order Thinking	Higher Order Thinking			

Earlier attempts to define thinking skills focused on identifying the individual cognitive skills which would constitute effective thinking. A review of the literature shows that more recent research (e.g., Nickerson, Perkins and Smith, 1980; Simon, 1980; Sternberg, 1983) and thinking in this area points to a need to expand the criteria characterizing "higher order thinking skills". As the definition cited earlier has indicated, these cognitive processes are not an end in themselves, but underlie effective, self-conscious management of

strategies to

1. identify and analyze a problem;
2. identify and relate relevant information; and
3. evaluate the outcome.

All three components--the underlying cognitive skills, the strategies for their use and management of the thinking process--are essential components of effective "higher order thinking". These criteria will receive broad support as the literature is reviewed.

IV. A RATIONALE

Having established an understanding of "higher order thinking skills", it is reasonable to consider why their development should command attention.

A. To Accommodate a Changing Knowledge Base

Although universities make it their business to study the world around them from every conceivable perspective, they have been noted to ignore growing pressures to cast that gaze inwards (Cyert, 1980). Gazing out, there is the widely recognized "information explosion" in all areas of study that makes learning all the information of a discipline a hopeless task and, even should it be possible, it would be

an accomplishment that would quickly become obsolete. The flood of information reaches far beyond any area of special knowledge and seeps into most decision making events. The same ever changing knowledge base fuels technological changes that find people in new careers, with new lifestyles and faced with new social problems.

These fast paced changes make it essential that people can think independently and solve novel problems (Simon, 1980).

In stark opposition to these well studied developments, individuals face this situation without having acquired the skills or motivation to elaborate on their acquired knowledge, to form networks of related knowledge, or bring knowledge to bear on problems or new situations, (National Assessment of Educational Progress, 1983) even though it is at these levels that people are most often called upon to use their knowledge (Broudy, 1969). In actual fact, assessments of the high order thinking skills show declining abilities (National Assessment of Educational Progress, 1983). Gender studies show a trend toward equalization of abilities between sexes, but only because these abilities are declining faster in males than females (Berger and Gold, 1979). If strategies for using intellectual abilities are not an invariant and can be developed through experience (Chipman, Segal and Glaser, 1985; Feuerstein and Jensen, 1980), then these findings indicate shortcomings in education outcomes.

B. To Meet Educational Objectives

That people should possess these higher order thinking skills is an important educational objective, not only in the academic literature but in the attitudes of governments, educators and the general public (Aikenhead, 1980; Hurd, 1975; Roberts, 1983; Science Council of Canada Report #36). The attainment of these skills appears as an explicitly stated objective throughout Canadian educational systems and abroad (Beyer 1984a; Science Council of Canada Report #36). When critical eye is turned inwards, universities should be asking why this objective is not more widely reflected in the outcomes of university education, especially since it has been shown that university-aged students should be most receptive to instruction to facilitate thinking skill development (Kuhn, Ho, and Adams, 1979; Lawson, 1982). It would appear that the answer lies in the observation that, while the goal of teaching thinking skills is explicit, the actual effort to develop them is most often implicit. There is an assumption underlying instruction that if students attend well to the acquisition of knowledge, the process of how that knowledge was generated and how it can be used are also acquired (Arons 1979). There is some question as to, firstly, whether process becomes obvious to students by inference from learned material (Perkins, 1985; Segal, 1985) and, secondly, whether knowing about these processes empowers the student with a capacity for using them (Bereiter, 1984; Polson and Jeffries, 1985; and others).

C. To Meet the Criteria for Effective Concept Teaching

Does it then follow that content oriented education is incompatible with the development of higher order thinking skills? Not at all. Good concept teaching, may in fact, contribute to the development of higher order thinking skills. There is research available which explains the how and why of good concept teaching (e.g. Tennyson and Cocchiarella, 1986). An examination of what constitutes good concept teaching reveals that, based on psychological theory and a theory of instructional design, the teaching strategy outlined below optimizes concept development.

Table 1-3

Concept Teaching Design

(Tennyson and Cocchiarella, 1986)

Steps in Concept Development	Implementation Strategies	Its Function
1. Define, Relate to Existing Knowledge	Make the meaning of the concept accessible: identify critical attributes and identify relevant prior learning. (Merrill and Tennyson, 1978).	Learners seldom learn well from definition alone, but definitions and labels delineate content and help establish links to existing knowledge.
2. Place in Context	Illustrate the context in which the to-be-learned concept is relevant.	Establishes the need-to-know motivation and facilitates effective storage and retrieval organization. (cont. next page)

Table 1-3 (cont.)

Steps in Concept Development	Implementation Strategies	Its Function
3. Best Examples	Illustrate one or more examples which represent the essential elements of the concept and which are rich in imagery. (Tennyson, 1978).	Makes the to-be-learned concept more meaningful and establishes further links to existing knowledge.
4. Expository Examples	Present other applications of the concept. Compare to best example.	Elaboration of the concept details & of the contexts in which it applies, facilitating storage and retrieval. Introduces the processes whereby the concept can be used.
5. Interrogatory Examples	Present example situations as problems to be solved with directions to compare to best example.	Develops skill in discrimination and generalizations. Practices process for using the concept.
6. Strategy Information	Present a strategy for using the new concept. Examples in which students practice any of the following are appropriate: a strategy to achieve better memory and retrieval; a strategy for identifying and acting on situations to which the concept applies. Assess for development of skills in using concepts as well as understanding. Allow sufficient exposure to optimize competency.	Makes students aware of the thinking skills required and strategies for their use. Students store the process knowledge. Students elaborate process knowledge and connect it to relevant conditions for using the concept. This adds dimensions to the concept and establishes more conditions to evoke retrieval.

(cont. next page)

Table 1-3 (cont.)

Steps in Concept Development	Implementation Strategies	Its Function
7. Attribute Elaboration	Ensure attention to how examples have elaborated on the original representation of the concept.	Generates elaboration and new links to existing knowledge.
8. Embedded Refreshment	Bring forward relevant prior-learning by requiring its application to a problem.	The learned concept is then available for association with to-be-learned concept, facilitating retrieval and use of prior-learning.

It is my belief, based on the literature on student learning and faculty teaching, that the gap between effective concept teaching in a discipline and its alternative lies most often in stages five and six.

V. THE ARGUMENT

The argument will be, that by self-consciously including these stages in concept development in ways prescribed by the research literature it is possible to achieve enhanced concept learning coupled with the development of higher order thinking skills. In so doing, we might integrate good concept teaching with concerns for education in the context of a changing knowledge base and for meeting unrealized educational objectives. The outcome would more closely resemble Richard Paul's description of education: "People become educated, as opposed to trained, in so far as they achieve a grasp of critical principles and an

ability and passion to choose, organize and shape their own ideas and beliefs." (Paul, 1987, p. 143)

The essential elements of the argument will be:

1. that thinking skills are an integral component of the knowledge of a discipline;
2. that these skills are learnable; and
3. that through the literature it is possible to develop practical ways to recognize and understand the learning problems associated with thinking skill development and to derive a solution strategy which is practical to apply in mainstream discipline teaching.

The argument will be supported by a description of a case study which was designed and implemented based on the principles derived from the literature.

CHAPTER TWO

I. INTRODUCTION

The context for the argument has been established but, to develop its thesis further, the thread of the argument must pass through the scholarly literature in several disciplines in order to draw together evidence for understanding and facilitating thinking skill development at the classroom level. The introduction has defined more precisely the gap between faculty expectations and student development, established a rationale for addressing that gap and identified the nature of the knowledge to be learned. The appropriate literature from which to address the problem in the classroom must next be identified. Particular attention will be given to the outcomes of research and the previous applications which directly influence the narrowing of the gap between student abilities and faculty expectations, educational objectives and outcomes.

The concern over meeting higher order education objectives or, in terms of outcomes, developing higher order thinking skills through learning experiences, is perhaps the least novel of educational issues. From ancient times to the present, there are documented efforts to "discipline the mind" and make thinking more effective. Aristotle and Sir Francis Bacon recommended mathematics as a developmental tool. In

the nineteenth century, the study of Latin was thought to develop generalizable effective thinking (Mann, 1979). In our own time, the study of computer programming was promoted as such a tool (Pea and Kurland, 1984). All suggestions were well intended but these strategies were not effective: efforts to shape thinking to conform to the organization and logical sequence of exemplary disciplines or examples clearly does not have the desired effect (Gick and Holyoak, 1980; Perfetto, Bransford and Franks, 1983; Simon and Hayes, 1976).

The optimism for a renewed effort is founded on the recent development of knowledge that underlies an alternative strategy to use what we know about effective thinking processes and their management to design the learning environment. With this new knowledge, it is possible to facilitate the development of learning and thinking skills rather than to impose an artificial framework from which to operate. This new information results from research in cognitive theory (which includes how knowledge is represented in the mind and how the mind functions), instructional design theory (which includes research in concept development and instructional methods and materials), problem solving theory (which includes the study of the thinking process, artificial intelligence and investigations into expert versus ineffective thinking. We have, and continue to accumulate, knowledge relevant to the problem, but it will only have an impact if it can be explicitly used to recognize student abilities and facilitate their further development. Fundamental principles of learning and problem

solving can be applied in teaching all disciplines if the literature on the underpinnings and their applications can be made accessible.

II. WHAT CONSTITUTES KNOWLEDGE OF A DISCIPLINE?

Perhaps the most fundamental requirement for the effective transmission of the knowledge of a discipline is a clear definition of what constitutes the knowledge of a discipline. Knowledge, in this context, demands a very broad interpretation best understood by asking, "What makes an expert in a discipline an expert?" If the characteristics of expert knowledge can be identified, then the reference points for educating the next generation of experts have been established. A careful consideration of what constitutes knowledge of a discipline in its broadest sense is essential to developing effective learning and teaching.

A. Content Knowledge

The most obvious constituent, of course, is content knowledge: the information accumulated within a discipline. It is the focus of learning at the university level and presently dominates teaching materials, methods and testing. Knowledge of content is essential to expertise, but it is not the only criterion that must be met. Studies of learning and expert thinking reveal other dimensions of knowledge.

B. Knowledge of the Structure and Organization of a Discipline

The second criterion for expert knowledge is a knowledge of the structure of the discipline: how content knowledge is organized to form concepts, the relationships among concepts and the conditions under which the concepts are relevant. This form of knowledge is important in accessing knowledge for use and in acquisition of new knowledge.

1. Accessing Existing Knowledge

First, consider the problem of access. Being able to retrieve relevant knowledge is an assumption underlying the learning effort, but in practice, learned knowledge often remains "inert": it cannot be retrieved when it is required for use (Whitehead, 1929; Bereiter and Scardamalia, 1985). Effective access is dependent on the organization of stored knowledge (Anderson, 1985) and when information is learned together with the conditions under which it is relevant, access is facilitated (Anderson, 1985; Glaser, 1984; Simon, 1980). This principle applies equally to strategies in learning and problem solving. Unless the learned information includes the circumstances under which the strategy is useful, the knowledge remains inert and cannot be accessed unless an explicit direction to do so is provided. (Brown, Bransford, Ferrara and Campione, 1983; Simon and Hayes, 1976).

2. Acquiring New Knowledge

Likewise, the acquisition of new knowledge is dependent on adequate organization of existing knowledge. Placing new learning in a meaningful context enhances memory as well as access (Anderson, 1985). When information is learned in the context of its significance within the discipline and its possible function, effective and independent learning is enhanced (Bransford, Sherwood, Vye and Rieser, 1986; Simon, 1980). Learners with such a structure (whether self induced or provided) are more likely to notice inconsistencies or gaps in given information (Markman, 1985 and others), judge difficulty appropriately (Bransford, Stern, Vye, Franks, Auble, Mezynski and Perfetto, 1982) and recognize mastery (Feuerstein, Rand, Hoffman and Miller, 1980). The researchers cited have contributed to an understanding of how people become effective learners and users of knowledge. Together they illustrate the importance of the organizational component of knowledge in a discipline.

C. Process Knowledge

A third characteristic of experts in a discipline is that they exhibit a knowledge of process: they have acquired process skills by which they use their knowledge to deal effectively with new information and novel situations. These skills include individual cognitive skills and the capacity for self-monitoring and management (Schoenfeld, 1979).

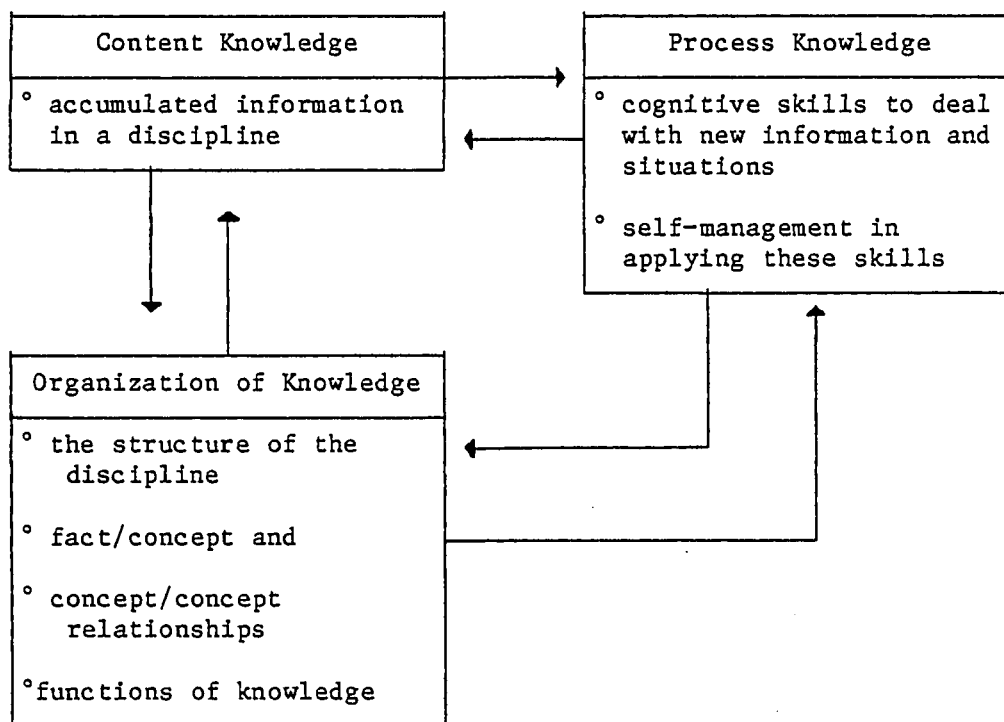
It is this component of expert knowledge which has the greatest potential for contributing to the development of higher order thinking skills (Perkins, 1986) but which is also most difficult to represent. The difficulty lies in that the thinking of novices is characterized by serial processing and step-by-step deduction, but as expertise develops, an accumulation of experience and knowledge allows experts to perceive patterns in problem situations and represent problems in terms of the principles involved (Anderson, 1985; Larkin, McDermott, Simon & Simon, 1980). This transformation makes process the most difficult component of expert knowledge to relate to novices because it requires an understanding of a process which has become automatic and condensed and is not easily articulated. Communicating this component of knowledge in a discipline requires thoughtful consideration.

D. The Interactive Relationship Among the Content, Organization and Process of Knowledge

These three components of expert knowledge are highly interactive (Figure 2-1). The acquisition of content builds on structure. Alterations in the knowledge structure contribute to content by generating inferences. Practicing process generates new content and elaborates on knowledge organization (Hayes, 1978). Applying knowledge improves memory and retrieval capacities for both content (Anderson, 1985; Mayer, 1983) and process knowledge (Glaser, 1984; Sternberg, 1981).

Figure 2-1

The Three Components of Expert Knowledge



Recent views on psychological development (Bransford, Sherwood, Vye and Rieser, 1986; Glaser, 1984) also indicate that the components of knowledge identified among experts and effective learners in a discipline are developed simultaneously and are interdependent. Although this relationship was pointed out by Bruner (1964), it is more recent research results which indicate that a growth in the ability to organize and process information proceeds as information is accumulated (Bransford, Sherwood, Vye and Rieser, 1986; Glaser, 1984), as opposed to the Piagetian view that the capacity for these capabilities is restricted not only by knowledge but by not having reached distinct

developmental stages. Lindberg (1980) showed that highly meaningful knowledge was processed at higher levels of thinking, connecting organization and process. Glaser (1984) makes a number of points consistent with this view, including: domain specific knowledge increases problem solving ability in the domain; and that in learning situations where content and concepts have certain purposes and goals (organization), thinking skills are encouraged. Sternberg (1985) represents knowledge acquisition and use as parts of a single system and further emphasizes (Sternberg, 1987) that process skills alone are not sufficient for thinking skill development and that knowledge, an appropriate organization of the knowledge, a means to select and coordinate the processes and the motivation to use them are also required. It would appear that what began as a common sense approach to what learners should know to become competent in a discipline is supported in the research literature: organizing knowledge increases the potential for memory and retrieval; using process knowledge elaborates on existing knowledge, enhances memory and retrieval, contributes to the organizational structure, and in turn, this structure facilitates new learning. If content, organization and process constitute expert knowledge and, furthermore, facilitate learning and thinking, then it makes good sense that they all should be explicitly taught.

This conceptualization of what constitutes knowledge in a discipline is compatible with the concept teaching design of Tennyson

and Cocchiarella cited earlier (Table 1-3) in that their design includes all forms of knowledge necessary for competency. (Table 2-1)

Table 2-1

Relationship of the Concept Teaching Design of Tennyson and Cocchiarella (1986) to the Kind of Knowledge Developed

Design Variable	Predominant Kind of Knowledge Developed
1. Define, Relate to Existing Knowledge	Content; Organization
2. Place in Context	Organization
3. Best Example	Organization
4. Expository Examples	Organization, Content
5. Interrogatory Examples	Process
6. Strategy Information Content	Process, Organization
7. Attribute Elaboration	Content, Organization
8. Embedded Refreshment	Organization

Through this framework, it is possible to redress the shortcomings identified in learning and thinking skills among university students and in the general educational outcome. By explicitly applying principles of cognitive psychology and problem solving theory, particularly with regard to interrogatory examples and strategy information, effective concept teaching can facilitate the development of higher order thinking skills.

III. THE ROLE OF INFORMATION PROCESSING THEORY

The position constructed throughout this thesis has been to establish the need for a greater emphasis on process in discipline teaching. Specifically, it is desirable to shift from content oriented teaching towards teaching process based on content. The ultimate goal is to empower students with skills to independently elaborate on and effectively use their knowledge. With attention focused on the acquisition of process, the most appropriate theoretical base is one which allows understanding and description of learning and thinking skills with enough precision to identify them for teaching and for measuring changes in these skills (Segal, 1985). Information processing theory seeks to represent mental processes in serially ordered sequences, analyzing the operations and products of knowledge acquisition and use in terms of process (Anderson, 1985). If it is the process variables in learning and thinking that can be identified as problematic, then information processing theory represents a source from which to directly understand and act on the problem. The information processing approach is also compatible with the characteristics of knowledge for competency presented. Information processing describes problem solving (in a very broad sense) as taking place in a problem space shaped by the individuals representation of the task at hand and which consists of the relevant knowledge, the operators with which to act and a strategy for solution (Newell and Simon, 1972). Selected

literature from information processing theory will serve to indicate a possible avenue to closing the gap between novice and expert.

A. The Human Information Processing System

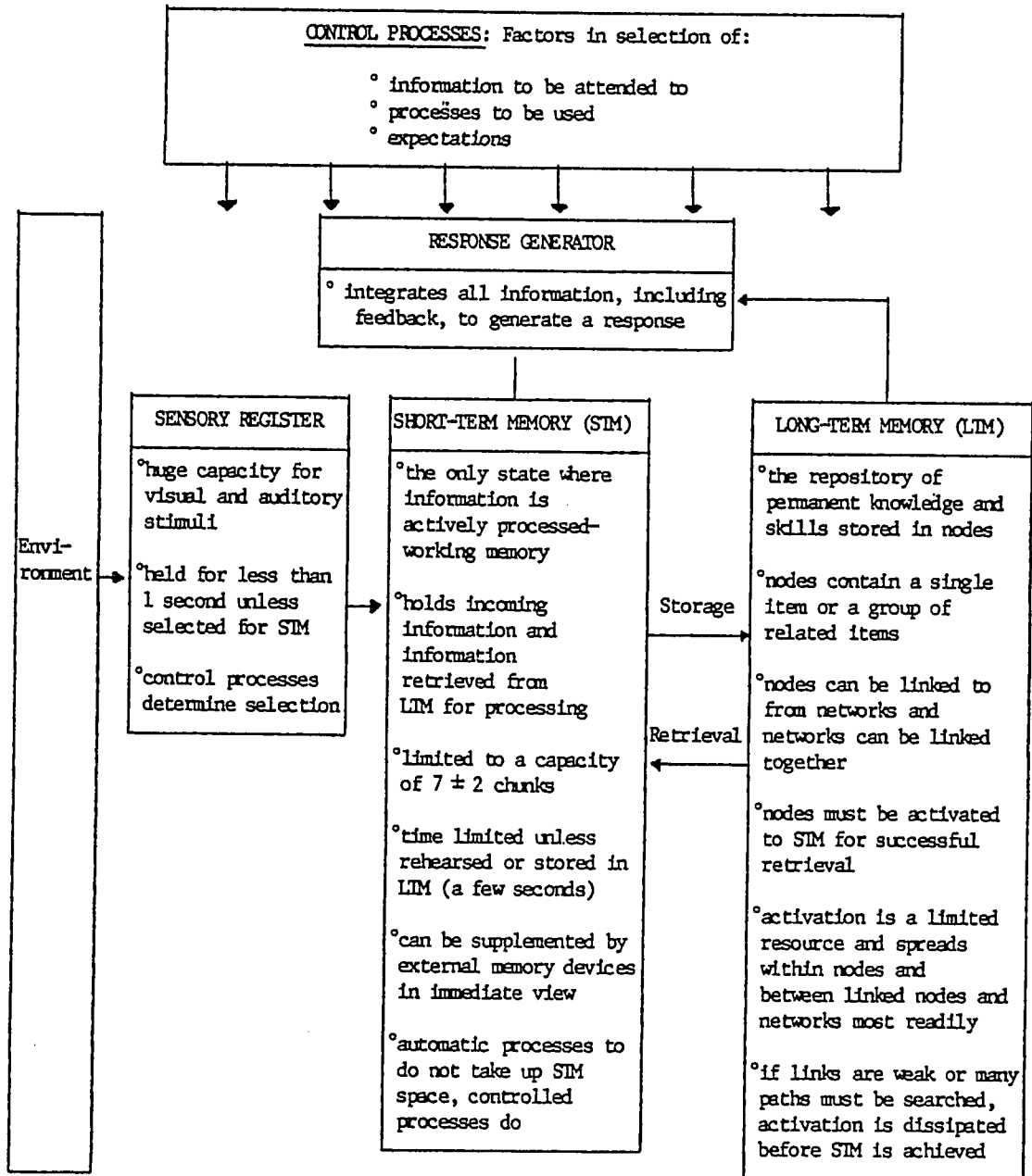
The principles underlying effective learning of the content, organization and processes of a discipline are those of how the human information processing system works. Memory, retrieval and manipulation of knowledge in this system is a function of its structure. The assumption in learning is that the information can be perceived, understood, learned and, under the appropriate conditions, can be retrieved. An awareness of the potential and restrictions of the system can make the teaching strategy more effective. The most essential details are show in Figure 2-2, which summarizes the characteristics of the system described by the authors cited.

B. Implications for Learning and Teaching

There are implications for teaching from even this sparse representation of the information processing model and related literature. They centre around (1) making efficient use of the small capacity in short-term memory (STM); and (2) establishing connections between facts, concepts and skills and the conditions for their use in long-term memory (LTM) that will facilitate retrieval in response to appropriate cues.

Figure 2-2

Essential Components of the Human Information Processing System
(Anderson, 1985; Frederiksen, 1986; Gagne, 1975; MacRobbie, 1983;
Newell and Simon, 1972)



Explicit organization of information helps to achieve both objectives. Organizing related facts into groups condenses them from requiring several chunks of the working memory to one (Battig and Bellizza, 1979). Developing a group of facts into a concept has a similar effect (Chi, Glaser and Rees, 1981), establishing both the structure of the knowledge and a means for coping with information load. With regard to LTM, the object is to facilitate activation of knowledge when it is required: to avoid "inert" knowledge. The theory indicates that activation of a node makes all of the information in that node accessible and facilitates activation of associated nodes to STM. It makes sense, then, that knowledge stored together with the conditions and constraints for its use is most accessible (Anderson, 1981; Glaser, 1984; Simon, 1980). In fact, experts and skilled individuals have been found to store knowledge in these problem type structures (Quellmaltz, 1985). When knowledge is stored in association with the conditions for its use, those conditions act as a cue to retrieve the appropriate knowledge (Simon, 1980). Students need to learn more about the conditions under which their formal knowledge applies (di Sessa, 1982), and to regard their knowledge as a tool (Bransford, Sherwood, Vye and Rieser, 1986).

The condition/content association contributes to the construction of an effective LTM but content/content' associations are also necessary. The identification of relevant prior learning when introducing new knowledge links the new knowledge to relevant networks.

Together, the associations form contribute to meaningful learning which enhances memory and retrieval (Anderson, 1985).

An instructional strategy based on the design of Tennyson and Cocchiarella can be effective in representing the significance and functions of information and in doing so, facilitate the development of accessible knowledge structures (Bransford, Sherwood, Vye and Rieser, 1986) but only if they are explicitly pursued.

Throughout, an essential characteristic of the recommended approach is "explicitness". Fundamental to the problems encountered in student learning is that traditionally it is only content which has been explicitly portrayed. That the structure (organization) of the knowledge and the processes whereby it can be used must be made explicit in teaching is the fundamental premise of the strategy presented here. A simple solution in words, but a loaded one in delivery, beginning with defining "explicit". A rule of thumb to remember throughout is that you are not explicit until the students recognize that explicitness: a significant factor of difficulty.

IV. THE ACQUISITION OF PROCESS KNOWLEDGE

A. Choosing the Approach

1. An Introduction

Throughout the research literature, the acquisition of the process skills necessary for effective thinking comes under the umbrella of "problem solving skills". This implies a very broad usage of this phrase and, for the purpose of accessing the relevant literature and understanding its use in this thesis, problem solving skills will be defined as those cognitive skills necessary to deal with new information and novel situations and will include self-management skills required for their use (Schoenfeld, 1979). This establishes the phrase in a very broad context, one which is consistent with its usage in the literature.

The task now becomes to determine how the research in the theory and practice of problem solving skill development can exercise some leverage on the documented lack of these skills among university students. This task represents an unfortunate juxtaposition of a serious problem and a theory which offers no certain answers. What is known with certainty is that the traditional strategy of presenting information and applications of the information is not effective (Cyert, 1980; Lawson, 1985; Mevarech and Werner, 1985; Norman, Gentner and Stevens, 1976; Schoenfeld, 1979). How to structure a remedial strategy

is not self-evident from the research literature because of the essential characteristic of the underlying problem: process.

Historically, educational research has focused on outcome, not process (Klahr, 1976; Larkin, 1980). The educational psychology that might have supported an effective teaching strategy does not do so because its emphasis is on description rather than prescription (Larkin, 1980; Teare, 1980). On the program end of the spectrum, there is literature describing programs designed to develop thinking skills, but these programs are often based on conjecture (Polson and Jeffries, 1985). Because existing programs are based on varying portions of immature theory and good intentions, a number of diverse strategies have emerged. They include programs designed to (1) teach individual cognitive skills assumed to be essential to effective thinking and problem solving such as analyzing, comparing or inferring (e.g., Feuerstein's Instrumental Enrichment Program); (2) teach explicit problem solving (thinking) strategies applicable to a variety of tasks such as identifying the problem or writing the problem in your own words (e.g., Rubinstein's Patterns of Problem Solving); (3) teach formal reasoning skills required for abstract thinking such as developing hypotheses or generalizing (e.g., Accent on the Development of Abstract Processes of Thought [ADAPT]); (4) develop thinking skills through developing skills in manipulating symbols in such tasks as writing, reading, speaking or computer programming (e.g., Confront, Construct, Complete); and (5) develop thinking skills by thinking about thinking

through such tasks as exploring cognitive capabilities and limitations or common reasoning problems. Thinking strategies can be included but with an emphasis on why they work (e.g., Philosophy for Children) (Nickerson, 1984; Nickerson, Perkins and Smith, 1985). Because of their origins, these programs must be evaluated carefully for their attributes, strengths, weaknesses and the validity of their claims. While these areas of the literature provide no direct solutions they do contribute to the solution building process.

There are other areas of research which more directly inform a solution. A body of literature described as instructional design theory seeks to link difficult to access cognitive theory and poorly informed teaching practices by forming theoretically well founded and practical strategies to facilitate the development of thinking skills. In addition, problem solving theory focuses on the process of problem solving. While there are no pat answers, knowledge gleaned from all of these sources contributes to the construction of a promising strategy for facilitating the development of problem solving skills.

The second dimension to the selection dilemma (at least in the literature) is whether thinking skill development is best delivered an independent course or in the context of acquiring other knowledge. Separate courses do have some advantages. Separate courses lend themselves to clearly defining the skills and to the evaluation of those skills (Sternberg, 1987). They are more simple to introduce as a block

than strategies for integrated skill development across curricula and they can effectively utilize real-life situations (Perkins, 1987). The development of this thesis, however, sets the case for integration. Apart from the criteria for expert knowledge and how it can be achieved presented earlier, and the concept teaching design employed as a framework, (both of which are premised on strong interactions between knowledge and process), there are specific characteristics of learning thinking skills that favour an integrated approach. Perkins (1987) argues for integration because teaching thinking out of the context in which it is required to be used, or conversely, teaching content without the means to make it meaningful is not productive. Sternberg (1987) adds that an integrated approach fits into institutional priorities. New courses and timetables do not have to be introduced and maintained. Independent courses (or even independent components within courses) can be viewed as enrichment and may not reach a broad cross section of students (Bereiter, 1984) or may be easily terminated under pressure (Swartz, 1986). The major theoretical problem with separate courses is that the skills do not transfer to new situations. Integration allows for longer term and varied opportunities for the practice essential for transfer (Gagne, 1980; Perkins, 1986; Belmont and Butterfield, 1977). If we value thinking skills as an educational outcome, we must act to ensure that the potential for their development exists and is maintained and that the transfer of learned skills is maximized.

The concensus that emerges from the literature is that any approach to making process explicit enhances the development of process skills and content learning (whereas drill and learning by inference does not) (Greenfield, 1987). This makes the choice of a strategy to develop thinking skills within the context of discipline teaching quite flexible. The strategy selected should fit the student needs and the knowledge base required to allow the hierarchy and functions of the knowledge to be explicitly presented; to explicitly teach the processes required with the conditions under which they apply and to explicitly develop a coordinated management of these skills (Frederiksen, 1984).

2. Why Choose Heuristics?

(a) Defining Heuristics

Given these criteria, one promising avenue to pursue is to introduce the teaching of heuristics to content oriented courses. In this context, a heuristic is synonymous with strategy (Nickerson, 1984). Schoenfeld (1979, p. 315) defines a heuristic as "a general suggestion or strategy, independent of subject matter, that helps problem solvers approach, understand, and/or efficiently marshal their resources in solving problems". Similarly, Perkins (1986, p.7) describes a thinking frame as "a representation intended to guide the process of thought, supporting, organizing and catalyzing that process". Both terms emphasize the general guide type function of the

strategy. Heuristics do not constitute rules for thinking (Greeno, 1980) but establish general frameworks for promoting effective processing of information (Mayer, 1983). General heuristics allow for differences in individual styles and content in that the specific heuristic employed in response to a general strategy can vary. For instance "define the problem" represents a general heuristic whereas drawing a diagram or writing the task in your own words are specific heuristics which can be selected from "to define the problem" to meet the requirement. (With regard to learning strategies, Snowman and McCown (1984) make a distinction between the overall "strategy" and specific "tactics" to meet that strategy. This distinction would also be useful here, with the overall strategy - define the problem - being the heuristic and drawing a diagram being the tactic.) The flexibility in the heuristic/tactic system allows a common framework for use on many different situations which facilitates generalized use of the skills (Derry and Murphy, 1986). This structure also allows ongoing development of the system through elaboration and maturation of tactics within the framework (Beyer, 1983).

(b) Characterizing Effective and Ineffective Problem Solvers

Problem solving strategies are highly variable from one person to the next and take years to develop (Schoenfeld, 1979; Greenfield, 1979). If there were commonalities between effective problem solvers on at least some strategies however, they may form an effective framework

from which to develop skills in ineffective problem solvers (Schoenfeld, 1979). One line of research in problem solving theory compares the processes of experts/effective problem solvers with those of novices/ineffective problem solvers (e.g., Bloom and Broder, 1950; Chi, Glaser and Rees, 1981; Derry, Hawkes and Tsai, 1987; Larkin, McDermott, Simon and Simon, 1980). An analysis of the results represented in Table 2-2 shows a distinct dichotomy on some characteristics, many of which will be frustratingly familiar. The overall conclusion which can be drawn is that experts differ from novices on the content, organization and process elements of their knowledge.

Table 2-2

**Characteristics of Expert/Effective Versus
Novice/Ineffective Problem Solvers**

EXPERT/EFFECTIVE PROBLEM SOLVERS	NOVICE/INEFFECTIVE PROBLEM SOLVERS
<ul style="list-style-type: none"> ° can identify a problem, define and redefine a problem, break problems into manageable sub-problems using special cases, working backwards, use memory images and mnemonics (Bransford, Sherwood and Sturdevant, 1987) ° take more time to assess the exact nature of the problem (Sternberg, 1971) and perceive more accurately what is required in the problem (Bloom and Broder, 1950) ° recognize and think using concepts in the problem 	<ul style="list-style-type: none"> ° do not intuitively use those tactics, as a rule. (Bransford, Sherwood and Sturdevant, 1987) ° fail to recognize and use all relevant facts ° do not approach problems in a systematic way - students jump to conclusions without checking results ° fail to construct an accurate representation of the problem (Whimby and Lochhead, 1980) ° think around literal objects in the problem and may not recognize (cont. next page)

Table 2-2 (cont.)

EXPERT/EFFECTIVE PROBLEM SOLVERS	NOVICE/INEFFECTIVE PROBLEM SOLVERS
<ul style="list-style-type: none"> ◦ show high effort, work at understanding meanings, creating hypotheses ◦ are able to follow through on a process or reasoning and recognize problems with in plan ◦ recognize and use relevant knowledge in contexts other than the learned context ◦ use reasoning as a tool on existing knowledge ◦ are confident in pursuing leads ◦ can state opinions and feelings but keep them separated from responses, maintaining an objective attitude ◦ have more confidence in their solutions ◦ display more subject matter knowledge 	<p>principles and applications, unless in the same context as knowledge was learned</p> <ul style="list-style-type: none"> ◦ show low effort, superficial thought, guess from previous problems ◦ do not plan, work with whole problem, unable to focus on parts of the problem ◦ might start with plan, but are easily distracted by details and do not complete a chain of reasoning ◦ have difficulty recognizing and using knowledge in new contexts ◦ are discouraged by lack of direct knowledge, show a know/don't know attitude ◦ guess, show less confidence in their strategy ◦ personal opinions and feelings colour responses and their willingness to pursue problems ◦ lack confidence in the outcomes of their efforts ◦ display less subject matter knowledge
<p>(Bloom and Broder, 1950; Greenfield, 1987)</p>	<p>(Bloom and Broder, 1950; Greenfield, 1987)</p> <p style="text-align: right;">(cont. next page)</p>

Table 2-2 (cont.)

EXPERT/EFFECTIVE PROBLEM SOLVERS	NOVICE/INEFFECTIVE PROBLEM SOLVERS
<ul style="list-style-type: none"> ◦ store knowledge to form a hierarchy, with conditions for applicability ◦ constantly monitor, assess and manage process ◦ implement strategy but are open to modifications 	<ul style="list-style-type: none"> ◦ do not organize their knowledge effectively for understanding or use ◦ do not monitor, assess or manage process ◦ quickly select a solution path with becomes fixed find it difficult to change hypothesis or plan
(Woods, 1985, 1987)	(Woods, 1985, 1987)
<ul style="list-style-type: none"> ◦ make efficient use of STM by using a pencil and paper generated external memory ◦ detect gaps in understanding and information, errors in strategy and recognize new concepts more often ◦ evaluate alternative strategies 	<ul style="list-style-type: none"> ◦ do not use an effective external memory, overloading the STM ◦ are less cognizant of information and process ◦ operate on whichever strategy occurs to them and do not consider alternatives use a low effort, trial and error strategy
(Derry, Hawkes and Tsai, 1987)	(Derry, Hawkes and Tsai, 1987)
<ul style="list-style-type: none"> ◦ restructure and reinterpret difficult problems to make them solvable ◦ show strong subgoal strategies, with well organized notes on paper 	<ul style="list-style-type: none"> ◦ read and reread difficult problems in their original form ◦ show weak subgoal strategies with spotty and disorganized notes on paper
(Derry and Kellis, 1987)	(Derry and Kellis, 1987)

(c) How can heuristics be learned?

If these observed differences are critical to good problem solving, then the characteristics of good problem solvers can be extracted, made explicit and practiced as problem solving heuristics (Simon, 1980). The acquisition of strategies for problem solving represents thinking skills which can be learned and has good potential for growth (Ross and Maynes, 1983). The requirements for effective learning of heuristics are (1) that the student understand the heuristic: what skills are involved, why they are useful and the conditions under which they apply, (Beyer, 1984; Schoenfeld, 1979; Sternberg, 1983); (2) that the student has and can identify the relevant knowledge to solve the problem (Larkin, 1980; Schoenfeld, 1979); (3) that the student develops a conscious management strategy for using heuristics (Perkins, 1987; Quellmaltz, 1987; Schoenfeld, 1979; Sternberg, 1987). Having the skill but not thinking to use it is a significant problem (McMillan, 1987). These requirements are supported by research in effective strategies for problem solving skill acquisition (Brown, Campione and Day, 1981) and also reflect the criteria set out earlier for knowledge acquisition in general.

To be learned effectively, the heuristic must be made learnable. General heuristics, such as trying to get a total picture of the problem before attempting to solve it (Rubinstein, 1975), do not convey the skills required or the tactics that would be useful. To be effectively learned, heuristics must first be described so that skills can be

recognized for teaching, learning and evaluation (Resnick, 1980). A more useful representation of the "get the total picture" heuristic would be to diagram the problem situation, verifying this representation with the original. Once a heuristic has been described in this way, it is possible for the student to acquire an understanding of what is required and apply it to simple examples. At this time, the process takes up much of the available space in the short-term memory and is awkward to use. With practice, the processes become chunked and, finally, automatic so that the short-term memory is freed to hold details of the problem allowing more complex examples to be processed. The final hurdle is transfer: using the heuristic first in similar contexts and eventually outside of the context in which it was acquired (Perkins, 1986, 1987).

Incorporating the explicit teaching of heuristics in expository and interrogatory examples in teaching reflects a commitment to developing the processes of independent learning and thinking, and not merely the appearances of knowledge. Many of the same tasks are appropriate, but there must be explicit attention to heuristics which make known and guide the processes involved. These tasks then take on the added dimension of skill improvement projects.

3. Which Heuristics Should be Chosen?

(a) Appropriate Frames of Reference

Which heuristics are most likely to assist in the development of the higher order thinking skills identified as lacking among many students? The workable definition of those skills adopted earlier includes the critical use of the cognitive skills of analyses, comparison, inference and evaluation; generating strategies to identify and analyze a situation, address the task and assess the outcome. Over all of these is exercised a conscious control in planning, monitoring and reviewing the process (Quellmaltz, 1985). This definition can help shape the selection process.

A second standard is set by existing programs designed to improve process skills through the use of heuristics. Throughout these programs there are heuristics which are consistently selected for use (Table 2-3).

Table 2-3
Heuristics Chosen for Inclusion in Selected Existing Programs

ORIGINATORS	HEURISTICS RECOMMENDED				
IDEAL Bransford and Stern (1984)	Identify the Problem	Define the Problem	Explore Possible Solutions	Act on the Problem	Look for Effects
Belmont, Butterfield & Ferrette (1982)	Decide on a Goal		Make a Plan	Did it work?	Did I follow the plan? What was wrong with the plan?
TAPS Derry and Hawkes (1985)	Clarify the Problem		Choose a Procedure	Carry it out	Check
Woods (1985)	Define	Explore the Problem	Plan a Solution	Do It	Look Back
Schoenfeld (1979)	Analyze the Problem	Explore the Problem Further if design diffi- culties arise	Design	Implemen- tation	Verifica- tion
Emerging Pattern	Represent the Problem		Plan a Strategy	Carry out the plan	Evaluate the outcome

The heuristics shown in Table 2-3 do incorporate the cognitive skills and strategies of Quellmaltz's definition, but it does not indicate the role of management skills included in some programs and necessary for effectiveness (Jones, 1983; Schoenfeld, 1979; Sternberg, 1983; 1987). There is a gap between learning process skills and knowing which skills to select in any particular situation (Quellmaltz, 1985). Therefore, developing a conscious monitoring and selection strategy must accompany skill acquisition (Jones, 1986; Sternberg, 1987).

(b) A Framework for Choosing Effective Heuristics

Out of these frames of reference for selecting heuristics, a hierarchy can be established and a framework for choosing appropriate heuristics can be constructed. (Table 2-4).

(c) The Effects of Applying Heuristics in the Classroom

Application of the heuristics help to isolate contributing components of general outcome problems. Few students, for instance, take time to think about what the problem/issue is (Sternberg, 1981). This strategy focuses the solution effort, determines strategy, primes retrieval of relevant information and establishes the basis for evaluation. If it is poorly implemented, the effects are diffuse. By approaching problem solving at the heuristics level, it is possible to be more exact in diagnosis and in prescribing a remedy.

The strategy applies equally to the learning process (Bransford, Sherwood, Vye and Rieser, 1986) when learning is seen as problem solving. Learners must identify the problem of incomplete or inconsistent knowledge (Markman, 1985) and the magnitude of the problem (Bransford et. al., 1982), they must plan a strategy to resolve the problem, apply learning strategies and evaluate the outcome. Ineffective learners do not use these strategies (Bransford, Sherwood, Vye and Rieser, 1986). The implication is that, if the general

Table 2-4

A Hierarchy From Which to Build an Instructional Strategy

CONTROL OF PROCESS	CONSCIOUS SELECTION, MONITORING AND EVALUATING THE PROBLEM SOLVING PROCESS			
GENERAL HEURISTICS (a widely applicable framework to guide process)	IDENTIFY AND DEFINE THE PROBLEM	PLAN A STRATEGY	CARRY OUT THE PLAN	EVALUATE THE OUTCOME
<u>EXAMPLES OF TACTICS</u> (selected to accommodate individual needs, styles and content areas)	<ul style="list-style-type: none"> °write the problem in your own words °draw a diagram to illustrate the problem °identify essential components of the problem °check your representation for clarity & completeness 	<ul style="list-style-type: none"> °don't commit yourself too early °think of similar problems that are solvable °break the problem into manageable parts °seek alternative plans °select relevant information a) is it complete? b) what further information is required? c) evaluate sources d) identify point of view °access strategies, choose most promising but be prepared to revise the plan °diagram the plan 	<ul style="list-style-type: none"> °stick to a plan °assess progress 	<ul style="list-style-type: none"> °Did I stick to a plan? °Is the outcome reasonable? °Was the problem addressed thoroughly? °What thinking processes were used?

heuristics strategy was extended from novel situations to new information, new learning as well as thinking skill development would be facilitated.

The intent is to provide very broad heuristics as a framework. These heuristics should be widely applicable - would they have been useful strategies on your last assignment or exam? While they can guide the thinking process in a general way, they may not be powerful strategies in specific situations or content areas. The more specific tactics which can be identified, made explicit and practiced give the system its power in individual circumstances. When choosing a set of tactics, bear in mind that they should not be too numerous, should be well organized, and should include both general and more specific strategies which will be effective in that discipline but will leave choice for the thinker. It is necessary to illustrate what, when and how to use the tactics and show how they fit into a self-monitoring and management plan (Perkins, 1987).

4. Implications for Teaching

(a) Effective Use of Expository and Interrogatory Examples and Strategy Information Variables

An effective use of expository and interrogatory examples and strategy information in concept teaching design can facilitate the

development of higher order thinking skills. Following an exploration of the research literature, it is possible to select a strategy which will meet the design requirements and enhance the acquisition, internalization and transfer of thinking strategies. To be effective, the following general strategy (heuristic) is recommended (Perkins, 1985, 1987):

Present explicit problem solving strategies in the context of problem situations. Be aware of the skills required by a problem, explicitly illustrate the skills, their organization and management and have students practice on progressively more difficult examples.

More specifically the literature suggests that, in order:

(a) to enhance acquisition of process skills: (1) carefully analyze the task for process and display the structure of the task in a learnable way; (2) make the problem solving processes, why they are useful and the conditions under which they apply, explicit; (3) practice skills on simple examples (with an external memory for procedure if necessary) (Simon, 1980); (4) wean the external memory as skill is acquired and increase the complexity of the problems; (5) provide prompt feedback to enhance skill development (Brown and Stanners, 1983); (6) have students verbalize the goals and strategies to enhance strategy invention, use of cues and knowledge scanning (Schadler and Pellegrino, 1974); (7) use real-life situations to prolong retention (Bransford,

Sherwood Vye and Rieser, 1986).

(b) to enhance internalization: (1) utilize real-life situations (Teare, 1980; Sternberg, 1983, 1985; McMillan, 1987); (2) utilize multiple media in instruction (Sternberg, 1987); and (3) have students check their efforts for process (Quellmaltz, 1985); and (4) explicitly use old strategies in new ways.

(c) to favour transfer: (1) a longer term of instruction with varied applications (Lawson, 1985); (2) varied contexts and types of problems in different disciplines (Sternberg, 1987); (3) having students check their efforts for process (Quellmaltz, 1985) and (4) explicitly using old strategies in new ways.

(d) and that, with regard to evaluation, it is necessary to test for both content and process (Glaser, 1985). The initial task analyses for expository and interrogatory examples can form the evaluation criteria.

(b) Implementation in the Context of Content Oriented Courses

How do these strategies for effectively implementing the design variables of expository and interrogatory examples and providing strategy information fit into a content oriented teaching effort? Throughout this thesis, the importance of fully implementing all components of effective concept teaching has been emphasized with regard

to efficient learning and effective use of a knowledge base. It requires careful thought on the part of individual faculty to integrate these research findings with the content requirements of educating students in a discipline.

One route to integrating these findings into courses where content requirements are high is suggested by Lawson and Renner (1975). They suggest that faculty examine their courses for what is being taught, why it is taught and how it is taught. Renner and Lawson (1975) suggest first asking if the course content reflects the structure of the discipline, if the content included is placed in the context of major concepts of the discipline. If it does not, then evidence in the literature suggests that the content should be organized in this way. Secondly, they suggest that course content be analyzed for its potential to illustrate and give students practice in thinking skills. Renner and Lawson put forth these two perspectives on content as primary criteria for content selection. When content is arranged to meet these criteria and is presented so as to maximize involvement of students with the content and the other people studying it, they anticipate effective development of the content, organization and process aspects of knowledge in a discipline.

These suggestions may have more impact on the "how" of content teaching than it will restrict the "what". If the knowledge of a discipline deserves transmission, then that knowledge should be

structured for effective transmission. Make the structure of the discipline and the processes of thinking and problem solving in the discipline explicit in teaching. It is most desirable that content be structured so that students derive structure and process for themselves. However, for the majority for whom this does not occur, the explicit teaching of structure and process is essential. For all students, the opportunity to practice process and employ structure is critical. Carefully planned exercises, assignment and exam questions facilitate this development.

More detailed assistance on developing instructional design strategies to meet the objective of thinking skill development are available in the literature. Ross and Maynes (1983) describe a strategy which can be applied here. Such a strategy would include:

1. selecting those tasks which you think are appropriate ways to operate on the content knowledge of your discipline;
2. constructing a hierarchy of what must be learned to achieve competency in that task (content, organization and process);
3. devising instructional strategies to acquire this learning; and
4. assembling appropriate learning materials.

This strategy places in reverse the sequence of instructional planning often employed at the university level: select the content, then find ways to use it. The modified sequence, such as that suggested

by Ross and Maynes (1983), reflects content as part of a bigger strategy for independent learning and thinking, both within the discipline and generally speaking. It represents an effort to move from having students accumulate the content of a discipline to educating students in a discipline.

The effective use of heuristics is one option that grows out of the research literature and provides an avenue to improve thinking skills among university undergraduates and its application is illustrated in the case study which follows. I see the strategy as a useful application of theory, given the constraints under which we must act. This choice, however, does not foreclose on other options which may be derived from this literature but stands as an example of how a strategy might be developed. The intended outcome is to close the gap between the level at which faculty operate on their knowledge and wish their students to attain, and the level at which student abilities are assessed.

CHAPTER THREE: THE DESIGN OF THE CASE STUDY

I. HYPOTHESIS

Two hypotheses which may be derived from the literature are that:

1. it is possible to use the characteristics of good and poor problem solvers as a productive way of defining the ineffective learning and thinking which has been shown to affect a large proportion of university students; and

2. the explicit application of heuristics based on these characteristics is a practical and effective strategy to move students along a continuum to better developed higher order thinking skills within the broader context of knowledge acquisition.

These hypotheses emerge from the integration of the characteristics of good and poor problem solvers compiled from the literature (Table 2-2) with the framework provided from a synthesis of programs designed to teach heuristics (Table 2-3). Together, they meet the requirements for effective "strategy information" outlined by Tennyson and Cocchiarella (1986). The strategy for the implementation of this consolidated framework will be based on principles of cognitive psychology and instructional design drawn from the literature review.

II. THE FRAME OF REFERENCE

The integration of the documented characteristics of good problem solvers within the organizational framework of general heuristics for effective problem solving is presented in Table 3-1*. This table is not a list of tactics to be pursued by every student in every class or in operating on every kind of context. It illustrates a consolidation of criteria on which effective problems solvers have been observed to differ from ineffective problem solvers. It is hypothesized that to explicitly move to facilitate the development of these traits in students who do not exhibit them in their efforts will result in enhancing the movement of these students along a continuum to more effective thinking skills. This representation serves as a consistent frame of reference for the development of the instructional design, the assessment of process skills displayed by the students, the explicit development of individual skills and the evaluation of the strategy.

* References for Heuristics: Bransford and Stein, 1984; Belmont, Butterfield and Ferrett, 1982, Derry and Hawkes, 1985; Schoenfeld, 1979; Woods, 1985.

References for Problem Solving Characteristics: Bloom and Broder, 1950; Derry and Kellis, 1986; Derry, Hawkes and Tsai, 1987; Sternberg, 1971; Whimby and Lochhead, 1980; Woods, 1985, 1987.

Table 3-1

Characteristics of Good Problem Solvers Relevant to the
Development of Heuristics for Effective Problem Solving

Represent the Problem	Plan a Strategy	Carry Out the Plan	Evaluate the Outcome
<p>Comprehension</p> <ul style="list-style-type: none"> ◦ take more time to assess the exact nature of the problem ◦ identify the essential components of the problem ◦ write the problem in your own words ◦ diagram the problem situation ◦ detect gaps in understanding and work understanding meanings ◦ restructure and reinterpret difficult problems to make them solvable ◦ identify and assemble the information given in the problem in an organized way on paper ◦ identify the larger concepts and principles involved 	<ul style="list-style-type: none"> ◦ do not jump to conclusions on a solution path ◦ use pencil and paper to outline ideas in an organized way ◦ complete chains of reasoning <p>Making the Problem Manageable</p> <ul style="list-style-type: none"> ◦ subgoal: break complex problems into parts which are manageable ◦ think of similar problems which were solvable ◦ create hypothesis regarding possible solutions <p>Selecting a Solution Process</p> <ul style="list-style-type: none"> ◦ follow through on a generalized version of the plan and assess for problems ◦ consider alternate plans 	<ul style="list-style-type: none"> ◦ stick to a plan and do not be distracted by details ◦ use all the relevant information ◦ complete chains of reasoning ◦ constantly monitor, assess and manage process 	<p>Determine Whether:</p> <ul style="list-style-type: none"> ◦ the plan was followed ◦ the outcome is reasonable ◦ the criteria for solution were met ◦ identify the thinking processes which were required.

(cont. next page)

Table 3-1 (Cont.)

Represent the Problem	Plan a Strategy	Carry Out the Plan	Evaluate the Outcome
<p>Attitudes</p> <ul style="list-style-type: none"> ◦ establish the criteria a solution must meet ◦ carefully assess your interpretation of the problem ◦ have confidence in meeting novel problem situations ◦ show care and system in analyzing the problems, do not jump to conclusions based on experiences with similar problems 	<p>Selecting Relevant Information</p> <ul style="list-style-type: none"> ◦ diagram the most promising plan, but be alert to shortcomings which may arise during the solution process ◦ gather and organize existing knowledge ◦ detect gaps in information ◦ use reasoning as a tool on existing knowledge ◦ search for relevant knowledge learned in other contexts ◦ be aware of personal feelings and biases toward the problem ◦ be critical of the sources of information and the context in which it is presented <p>Attitudes</p> <ul style="list-style-type: none"> ◦ have confidence in the in the value of reasoning, avoiding a know/don't know attitude ◦ have confidence in pursuing leads maintain open mindedness 		

III. THE DESIGN OF THE CASE STUDY

A case study was undertaken to illustrate how the strategies which had been derived from the literature could be applied in a university classroom. The study was designed to reflect the realities of faculty initiated innovation: restrictions set by time tabling, content requirements and availability of time on the part of faculty and students; the fact that the scholarship of faculty is discipline based and usually not strong in instructional design; and the degree to which it is possible to assess how students think in the course of discipline teaching.

The case study was evaluated throughout to determine:

1. whether problem solving characteristics formed a productive frame of reference to assess student learning and thinking;
2. the student's response to the implementation of the strategy; and
3. the response of faculty.

A. The Subjects

Seventeen students registered for the course and, with the exception of an accident victim, all remained with the course to its completion. All students were non-majors who chose the course as an elective. Their distribution by degree program, year, sex, age and status is represented in Table 3-2.

Table 3-2

Demographic Characteristics of the Class Studied

Degree Program	B.A.	12	B.Sc.N	1	No Degree	3
Year of Study	First	10	Second	4	Third	2
Fulltime/ Part-time	Fulltime	15	Parttime	1		
Sex	Female	14	Male	2		
Age	less than 20	9	20 to 25	6	more than 25	1

B. The Context in Which the Strategy is Implemented

The following description of the goals, strategies and outcomes of the course prior to the intervention implemented in this case study was provided by the professor who developed and teaches the course. It serves to establish the context in which the strategies for thinking skill development were designed and implemented.

The goal of the class is to develop interest, knowledge, ability and confidence sufficient for the students to actively participate in or to see that they can contribute to science-society issues.

The class size has varied from 15 to 30 over its four year existence and has attracted a mixture of 1st, 2nd and 3rd year students from a broad range of Arts departments. The whole class meets for one hour on Wednesday and Friday and, in tutorial, five to seven students on Thursday. Typically, this schedule is used to introduce topics on Wednesday. Small discussion groups on Thursday allow students to clear up confusion, explore ideas and discuss implications. The Friday meeting can be used to build on the base of understanding or bring together different perspectives raised by the tutorial groups.

As the goal is to involve students in science as citizens not as professional scientists class materials and resources include living organisms commonly seen on the seashore or on park walks, newstand science magazines and newspapers, television programs, public library books, hospital staff and public service scientists. The topics also reflect citizen interest and students select specific issues within the topics.

As the students have restricted science backgrounds and typically lack confidence with science, the topics are introduced in carefully graded steps with a minimum of "mystique", and technical jargon. For example, activities to develop the ability to observe nature and infer the relationship of natural structure to function begins with simple everyday structures like leaves and the hand and progresses to complex organisms such as crabs and starfish. To develop critical evaluation skills the students begin by explaining magazine articles, then evaluating articles and finally to writing a critical book review. Similarly, the citizen action concept develops from exercises developing informed personal opinions through considering the impact of genetic counselling on a family to developing a political action strategy on a society concern.

The achievement of the class goals has been mixed. The students have developed a high level of interest and motivation. They generally quickly grasp the required technical information and scientific explanations. They gradually acquire confidence in their ability to understand scientific ideas at a personally useful level. However, they frequently cannot build from this base of confidence, interest and information to a more profound understanding.

Their ability to interpret natural structure is limited by poor strategies of observation and a lack of appreciation of the requirements of inference. Observation strategies improved by comparison with other students but inferring function from structure was often unsatisfactory because no evidence was given for conclusions and no alternative conclusions were considered.

Similarly, in issues like genetic counselling many students were slow to appreciate the complexity of the social and ethical context of the technology. They were reluctant to consider alternate points of view and unable to objectively evaluate different interpretations.

These traits also limited their ability to critically evaluate information from "expert authorities" in magazines, books and television programs. While they could comprehend the information they could not systematically evaluate its credibility or consider alternative interpretations.

The goals of interest, motivation and confidence have been

satisfactorily achieved through a combination of topic selection, carefully graded introductions and a format allowing for frequent discussion in a non-critical environment. For the students to become effective contributors to science society issues will require the development of much better critical evaluation skills, a greater ability to see problems in the context of socio-economic and ethical factors and to consider and evaluate alternative points of view.

C. The General Strategy

The strategy for prescribing the modifications to the course which were designed to enhance the development of problem solving skills consisted of:

1. examining all of the major components of the course for process skills potential;
2. setting the process goals;
3. selecting tasks to facilitate the development of those process goals; and
4. choosing course materials.

There was no effort made to substantially change the intent or content areas of the course, which are well developed. The area in which students were having difficulty in meeting the course objectives

was in their capacity to think confidently and effectively about new information. The modifications are therefore focused on the integration of explicit thinking skill development with other course objectives, so that the difficulty will be addressed. A review of the literature indicated that the self-managed use of heuristics was a promising strategy to apply in discipline based teaching and the design of the course was adjusted to accommodate this approach. The instructional strategy, as prescribed by the literature review, was to:

1. have students become aware of the self-conscious management of the thinking process;
2. provide students with a generalizable heuristic framework to facilitate their problem solving efforts; and
3. develop specific skills within each area of the framework, based on the documented characteristics of effective problem solvers.

In terms of thinking skill development, the major components of the course were: (1) structure and function; (2) working with popular science in the media and (3) problem solving projects involving citizen action and decision making on issues having biological content. These choices were made based on the observations that each of these components offered long term development sequences, opportunities to practice the heuristics developed a number of times and opportunities to apply the heuristics in different contexts. These characteristics are essential respective to the acquisition, learning and transfer of

problem solving skills (Beyer, 1984; Perkins, 1986).

Essential to the successful implementation of this strategy is a clear understanding on the part of the instructor of the general heuristic framework and the characteristics of good problem solvers to be developed within the framework. Most critical, however, is the understanding that these skills must be made explicit to the students. To demonstrate good problem solving strategies is not enough (e.g., Arons, 1979; Perkins, 1985). The strategies must be described out right; the students must have opportunities to experience their positive outcome so that they become meaningful to them, they must actively think in terms of the process requirements of a problem. These guidelines help ensure that students are aware of the process skills to be learned.

D. Data Sources

The data sources were of two general types:

- (a) observation records; and
- (b) written assignments and exam questions.

(a) Observation Records

A transcript style record of discussion occurring in classroom periods, tutorial sessions and literature presentations was maintained

throughout the year. The major group project of the course was also documented in this way.

(b) Written Assignments and Exam Questions

A file of written responses to assignments and exam questions was maintained for each student. The file included structure and function exercises on the hand and an organism of their own choice from the sea water tanks; a report on a genetic disorder their own choice; a book report on an evolution related topic and responses to the mid-term and final exams.

E. The Approach to Gathering Observations Based Data

The system for observation used in this case study is best clarified by reference to a classification framework for recording and storing observations presented in a review by Evertson and Green (1986). In their broad classification system, descriptive systems are characterized by the following criteria:

1. The observation system is open, but may include preset categories. Events have boundries and behavior, events and processes which occur within those boundries are recorded and have content specific meaning.

2. The openness of the system is reflected in that it records a broad segment of any event and includes multiple aspects of behavior.
3. Observations are recorded orally or in written form and structured descriptive analysis systems are applied to this data.
4. The goals of users of this system include a detailed description of phenomena, explaining unfolding process, identifying the principles operating in a situation and generalizing within or comparing across cases.

These strategies were judged to be most appropriate to the goals and limitations of this case study. The study was undertaken to gain a depth of understanding into the nature of students' problem solving skills and how those skills might be enhanced. It was possible to establish a framework for observation by employing the characteristics of good and poor problem solving (Table 3-3) but, to achieve a depth of observation, it was also desirable to accommodate a wide variety of situations and behaviors as the source of those observations. All of the students responses, oral and written, were examined in terms of this observation framework.

Observations regarding the individual characteristics attributed to good and poor problem solvers do not occur in a vacuum. While these characteristics can be identified individually from the data sources

available, they are expressed differently in the performance of individual students and in different situations. Students respond as individuals to any teaching strategy and, to produce a comprehensive representation of those observations, it is useful to employ a multifaceted description of the students' responses. These descriptions may be presented within a structure which permits comparison between cases as well as understanding of individual cases. Both a wide spectrum of observations and a structured presentation are desirable in this study, which requires a description of students' problem solving skills and their subsequent development to determine if generalizations may be made in the context of the theory and research reviewed.

F. Data Analysis

The data compiled was analyzed from a number of different perspectives. All data sources were examined for evidence that:

- (a) the attributes of poor and good problem solvers described in the literature can be identified in students classroom performance;
- (b) these characteristics can be used as guidelines for selecting skills which, when learned, will enhance problem solving performance;
- (c) these skills can be learned in the context of knowledge acquisition; and
- (d) some of the requirements for effective teaching of these skills can be identified.

The analysis tool (Table 3-3) was derived from the characteristics of effective and ineffective problem solvers summarized in Table 2-2. The responses of all students were grouped by question or assignment specimens from each written data source were randomly selected and scored according to this list of criteria. The observation records were also interpreted using this framework, on a discussion by discussion basis. The results provide a common frame of reference from which to compare different students and to track the development of skills in individual students.

During an initial eight week assessment period this list of criteria formed a framework for observations undertaken in order to determine:

1. those traits which can be identified in classroom interactions and assignments; and
2. the relative prevalence of these traits among this group of students.

The criteria from each category which were clearly present in student performance and which reflected the characteristics of poor problem solvers were designated for further analysis in the case study and evidence of the remediation of these traits were tracked to the end of the study.

Table 3-3

Criteria For Assessing Student Problem Solving Skills

I. REPRESENT THE PROBLEM		
1. take time for careful assessment 2. write in your own words 3. diagram the situation 4. identify essential components 5. detect gaps in understanding 6. work on understanding meaning 7. identify information given 8. identify larger concepts and principles 9. establish solution criteria		1. assess quickly and superficially 2. read, reread as given 3. fail to diagram the situation 4. fail to identify essential components 5. fail to detect gaps in understanding 6. do not work on understanding meaning 7. fail to identify information given 8. think around literal objects involved 9. do not establish solution criteria
II. PLAN A STRATEGY		
A. Making the Problem Manageable		
1. subgoal 2. think of similar problems 3. create solution hypotheses		1. work with the whole problem 2. do not think of similar problems 3. do not create solution hypotheses
B. Selecting a Solution Process		
4. make a general plan before beginning 5. evaluate the plan 6. consider alternative plans 7. diagram plan		4. do not plan a solution 5. fail to recognize process inadequacies 6. solution path is fixed 7. has no plan on paper
C. Selecting Relevant Information		
8. make available information 9. organize available information 10. detect gaps in information 11. use reasoning as a tool 12. recognize knowledge learned in other contexts		8. do not note available information 9. do not organize information 10. fail to detect gaps in information 11. adopt a know/don't know position 12. fail to recognize knowledge learned in other contexts

Table 3-3 (cont.)

<ul style="list-style-type: none"> 13. recognize personal beliefs/ biases, but maintain an objective attitude 14. be critical of information sources 15. be aware of the context 16. modify original ideas in the light of information 		<ul style="list-style-type: none"> 13. opinions and feelings determine responses 14. accept information passively 15. do not consider the context 16. find it difficult to modify ideas
III. CARRY OUT THE PLAN		
<ul style="list-style-type: none"> 1. stick to the plan 2. consider all relevant information 3. complete each chain of reasoning 4. avoid statements based on opinion 5. provide evidence for each point 6. constantly monitor the solution process 		<ul style="list-style-type: none"> 1. distracted from the strategy by details 2. overlook relevant information 3. fail to carry through ideas 4. use unsubstantiated opinion 5. neglect to provide evidence, as a rule 6. not conscious of the solution process
IV. EVALUATE THE OUTCOME		
<ul style="list-style-type: none"> 1. critically evaluate the outcome 2. relate the outcome to the problem posed 3. recognize inconsistencies 4. recognize gaps in information 5. recognize gaps in reasoning 		<ul style="list-style-type: none"> 1. does not evaluate the outcome 2. does not relate outcome to the problem posed 3. does not recognize inconsistencies 4. fail to recognize gaps in information 5. fail to recognize gaps in reasoning
V. ATTITUDES		
<ul style="list-style-type: none"> 1. confidence in novel situations 2. show care and system in thinking 3. confidence in the value of reasoning as a tool 4. confidence in pursuing leads 5. open-mindedness 6. high effort 		<ul style="list-style-type: none"> 1. lack confidence in novel situations 2. fail to show care and system in thinking 3. maintain a know/don't know attitude 4. lack confidence to pursue leads 5. confirmed opinions, narrow view 6. low effort

CHAPTER FOUR: PRESCRIBED MODIFICATIONS TO FACILITATE THE DEVELOPMENT OF PROBLEM SOLVING SKILLS

I. INTRODUCTION

The components of the course forming the framework for instructional modification have been identified as (1) structure and function; (2) working with popular science in the media and (3) citizen action and decision making. The development of each of these components of the course to allow for the integration of thinking skill development is outlined in the following sections which will include the general objectives and a sequence of suggested activities, prepared with the agreement of the professor who developed the course. This outline represents only those modifications focusing on the improvement of thinking skills within the context of other course and content objectives. These other objectives are compatible with and facilitate thinking skill development objectives but are not the direct object of this study.

In each activity area there is to be close attention to characteristics such as (1) explicit attention to developing heuristics (wherever possible by having the students come to realize them); (2) a highly interactive teaching style; (3) a progression in the complexity of content and its implications; (4) materials that relate to course

content and have high interest value; (5) student choice in the materials they select; (6) varied materials which offer opportunities for practice; (7) prompt feedback; and (8) an awareness of the process element of the task. The two exams administered should reflect a progression of process skills from recall of information to applying a given framework to independent use of the heuristics.

II. STRUCTURE AND FUNCTION

The structure and function component of the course was designed to facilitate the development of students' abilities to observe nature and infer from those observations an understanding. It consisted of a progressive series of tasks requiring students to create hypotheses linking structure to function in the context of major life functions and environment. Students were required to provide reasons, from a common sense perspective, for the associations they had made.

A. Objectives

- ° To reinforce confidence in the principle that biological concepts can be learned, understood and used in ways which do not require jargon or facility in Latin and which are interesting to non-scientists.
- ° To identify and introduce the use of problem solving heuristics to represent problems, plan solutions, carry out solutions and evaluate outcomes.

- ° To introduce students to specific tactics to follow these heuristics.
- ° To provide opportunities to practice the identification, selection and use of appropriate problem solving strategies.
- ° To establish that scientists use this approach to structure and function relationships in a very similar way.
- ° To have students gain confidence in their abilities to approach and interpret new information.

B. Instructional Plan

The instructional plan for thinking skill development within the structure and function component is organized according to the sequence of major activities assigned to the students. The plan is summarized in Figure 4-1 which places the plan on the actual time line for the course. The focus of the descriptions on the gradual introduction and explicit practice of process skills and not on the specific content (See Appendix A and D for specific examples).

Instructional Design for Structure and Function

Task #1

Introduction: Students are led through examples on familiar objects, one mechanical, one part of a living organism.

Figure 4-1 Strategy for Integrating Thinking Skill Development in the Structure and Function Component

- ° Introduce the importance of defining the problem effectively
 - ° Review the importance of:
 - Defining the problem
 - Identifying necessary skills
 - ° Review selected heuristics to facilitate these processes
 - ° From experiences, identify need to plan a strategy
- ° Identify major difficulties in performing the task effectively
 - ° Select 2-3 most useful heuristics to facilitate planning and apply them in the group effort
- ° Develop heuristics to facilitate the improvement of these skills
 - ° Compare individual and group products, identifying the impact of using heuristics

° Provide feedback on process content

Introduction
Students led through examples on familiar objects, one mechanical, one a part of a living organism

First Student Effort
- Students prepare a similar exercise on a part of an organism familiar to them, use it in a joint effort and then pass in their individual attempts

Tutorial Assignment-Assign strategy development (without knowing the organism) to be discussed before beginning the exercise - Provide an organism for study in a tutorial session - Groups report their results regarding strategy content

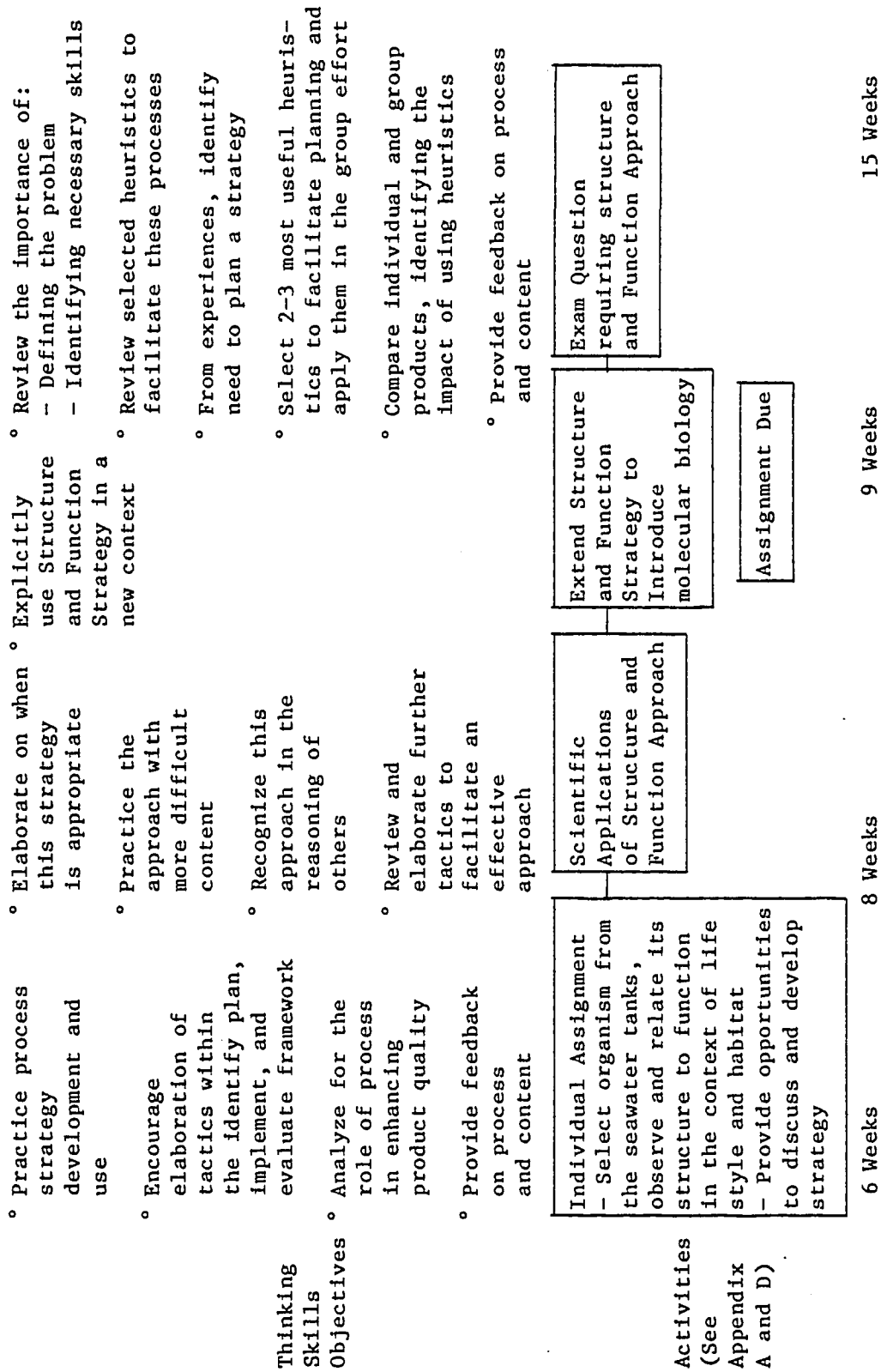
4 Weeks

5 Weeks

Time Line

cont. next page

Figure 4-1 (Cont.)



Instructional Strategies:

1. Make the students comfortable with the nature of the task: to observe an organism and, based on those observations, relate structure to possible functions. The first examples should be mechanical objects - clearly removed from the significant subject matter of the course - to encourage brainstorming and alternative hypothesis formation. Introductory examples of organisms should be familiar and simple, preferably a part of a familiar organism.
2. Introduce the importance of representing the problem accurately. Students should write in their own words what the task requires them to do and then, working together, build a comprehensive representation of what the problem requires. Discuss the importance of a clear representation of a task.
3. Identify difficulties in performing the task effectively; e.g., observation, reasoned inference.
4. Develop heuristics to facilitate the improvement of these skills; e.g., observation: ask students how to be more effective observers, based on their own experience with these examples. Suggestions might include: draw the organism; observe the organism in the context of its environment or in the context of its requirements to sustain life.

Leave open the choice of particular tactic, but build choosing a tactic for effective observation into subsequent examples; e.g., reasoned inference. For more general skills, like reasoned inference, suggestions made should be recognizable from Table 3-1: do not jump on the first idea that occurs to you; consider alternative hypotheses; and consider and evaluate evidence for each inference.

Task #2

First Student Effort: Students prepare a similar exercise on a part of an organism familiar to them. They use their results in a joint effort to build a comprehensive response. Individual efforts are assessed and feedback is provided.

Instructional Strategies:

1. Attend to the process elements of the introductory examples: representing the problem and identifying the skills required.
2. Review selected heuristics to facilitate these processes in the context of this new example.
3. From experience, identify the need to plan a strategy to deal with the task.

4. Select two or three heuristics from Table 3-1 which are likely to be most useful in facilitating planning. Likely examples include: diagramming the plan, make notes of all observations and ideas, and organize those notes.
5. Apply these heuristics - represent the problem and plan a strategy - and the specific tactics developed to the synthesis effort in this task.
6. Students should compare individual and group products with explicit attention to the role of attention to process in the outcome.
7. Provide feedback on the process and content of their individual efforts.

Task #3

Tutorial Group Assignment: Assign strategy development for a structure and function exercise (without making the organism known) to be developed by individuals ahead of time and discussed before beginning the exercise. Provide familiar organism for group study in the tutorial session. Groups are to report their results regarding strategy and content at the next class meeting.

Instructional Strategies:

1. This task allows individual students to practice explicit process planning on paper and to discuss and work with that strategy in a small group.
2. Introduce working with a plan while working on content. Identify the problems involved, which are likely to include keeping both process and content in mind and the necessity for frequent consultation with a representation of the plan on paper.
3. Introduce the importance of evaluating the outcome, particularly with regard to following a plan and following through chains of reasoning.
4. Review the problem solving strategy which has evolved:
Represent the Problem
Plan a strategy
Carry out the Plan
Evaluate the Outcome.
5. Solicit tactics which facilitate each of these strategies, supplementing as necessary.

6. Provide verbal feedback on content and process throughout the task.

Task #4

Individual Assignment: Select an organism from the sea water tanks, observe its structure and relate structure to function in the context of its life style and habitat.

Instructional Strategies:

1. This task is intended as an opportunity for individuals to practice process strategy development and use in a situation where consultation and feedback is available over the course of the task. Offer flexible observation opportunities including the regularly scheduled tutorial where consultation would be available.
2. Encourage the elaboration of tactics within the represent, plan, implement and evaluate framework.
3. Analyze efforts for the role of attention to process in enhancing the quality of the product.
4. Provide ongoing and summative feedback on process and content.

Task #5

Scientific Applications of the Structure and Function Approach: Examples of this strategy used by research biologists are presented for group analyses.

Instructional Strategies:

1. This task elaborates further the conditions under which these thinking strategies are appropriate and provides opportunities to practice the strategy with more difficult content.
2. Students are encouraged to recognize the process indicated by the reasoning of others.
3. Review and elaborate further tactics to facilitate an effective approach to problem solving while the individual assignment is in progress.

Task #6

Extend structure and function strategy to introduce molecular biology.

Instructional Strategies:

1. Explicitly use the structure and function strategy in a new context.

Task #7

Exam questions: After a 4 to 6 week period since the major assignment, students are provided with a situation where structure must be related to appropriate functions in the concept of an organisms habitat and lifestyle.

Instructional Strategies:

1. This task is an opportunity to assess the status of skill development and provide further feedback on process and content.
2. It is part of a larger plan to have students elicit and be cognizant of the heuristic framework in different contexts.

III. WORKING WITH POPULAR SCIENCE IN THE MEDIA

Non-scientists often feel excluded or unqualified to receive scientific content and form their own opinions. In this component of the course, students were exposed to scientific information typically available in magazines, books, newspapers, television, radio and from special interest groups. Students were encouraged to have interest and confidence in engaging the subject matter and in critically evaluating

the content and credibility from a citizen's perspective.

A. Objectives

To develop confidence in approaching scientific subject matter as non-threatening, informative and a component of significant social issues.

To challenge students to think about how ones point of view influences the topic chosen, the selection of relevant information, how it is used and evaluated.

To apply the heuristics framework of representing the problem, planning a strategy, carrying it through and evaluating the outcome to critically assess sources of scientific information encountered in the popular media.

To develop tactics within this framework to enhance the motivation and skills necessary to deal with new information in a complex social context.

To identify those strategies found to characterize effective articles and incorporate them in the heuristics framework for organizing information and developing lines of reasoning.

To explicitly develop student skills which influence how such issues are understood and judged such as separating fact from inference, identifying assumptions, determining source credibility, generating alternative ideas, detecting gaps in information and reasoning, recognizing the role of values in decision making.

B. Instructional Plan

The instructional plan for thinking skill development within the science in the popular media component (Figure 4-2) follow a similar organization to that of the structure and function component. The sequence of major instructional activities forms a framework for the description of the introduction and practice of process skills (See Appendices B and D for specific examples of content chosen).

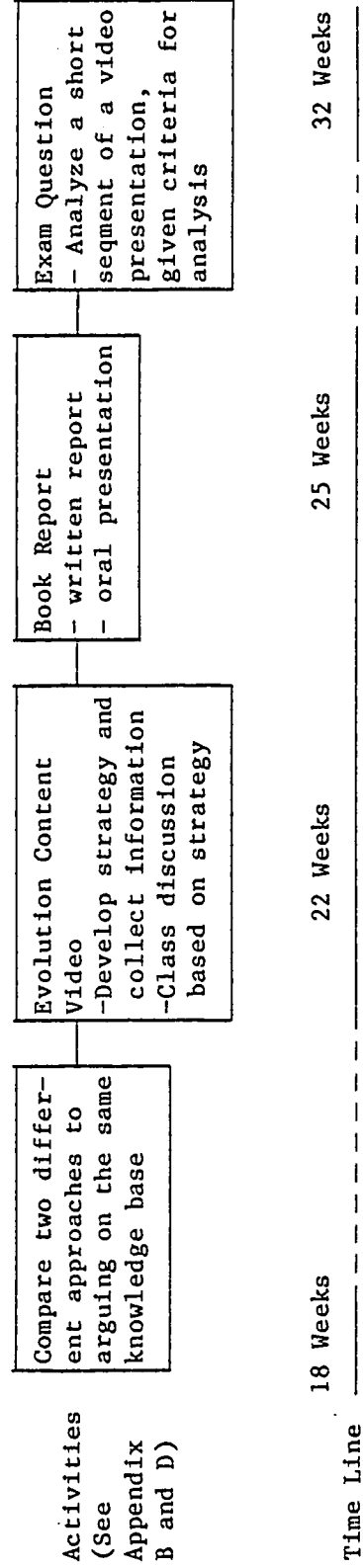
Task #1

Literature Presentation #1: Students are asked to choose a popular science magazine and select from it an article on which they will make a five minute presentation to their tutorial group. Students are encouraged to present not only the information in the article, but comment on why they found it interesting, whether it should be of general concern and its credibility.

Figure 4-2 (Cont.)

- ° Practice the recognition of strategy and the identification of point of view
- ° Compare strategies for the credibility of their outcomes
- ° Review the heuristics framework and specific tactics useful in analyzing the informational reasoning in the arguments of others/and in developing your own positions
- ° Apply the strategy to video presentation
- ° Use discussion to emphasize following through on a chain of reasoning
- ° Elaborate tactics, incorporating the best attributes of the articles examined
- ° Apply the strategy developed to more complex content
- ° Provide opportunities for discussion and consultation on the strategy and content of the report
- ° Provide indepth individual feedback on content and process
- ° Assess the independent effort of students to deal critically with new information

Thinking Skills Objectives



Instructional Strategies:

1. Make students comfortable with this type of task: to locate appropriate sources, select an article that is interesting to them and report on this article to their tutorial group in a five to ten minute presentation. Students are encouraged to communicate the information in the article but also to include why it was of interest to them and whether it makes good sense.
2. Encourage and ask questions in the group which explicitly promote clarity, a critical view of the information, an analysis of style and point of view and a consideration of consequences.
3. Provide feedback during the tutorial session emphasizing at this time, the positive points on their content and strategy.

Task #2

Literature Presentation #2
Students are asked to prepare a similar presentation but to integrate more of their own views on the interest value and credibility of the information. Their experiences with the first presentation will be used as a basis for developing a general strategy which can be applied to this second effort.

Instructional Strategies:

1. Introduce the requirement for an evaluation of the information and its use in the article.
2. Review the characteristics of the first round of presentations. Identify the positive elements of the presentations.
3. Consider how to expand the approach to information available through the media to include an evaluative element. Introduce the heuristics framework developed in structure and function as a guideline for analyzing information, representing the task as "evaluating the outcome" in terms of the remainder of the framework.
4. Illustrate how the framework can be flipped and used as a basis for analysis. For instance, "represent the problem" can be interpreted as "identify the issue"; "plan a strategy" as "what is the strategy?".
5. Ask students to apply these broad heuristics to the preparation of this round of presentations. Have students consider the role of these heuristics in their preparation as part of the tutorial discussion.
6. Provide feedback in the tutorial session on the content and strategy elements of their presentations, focusing once more on the positive points and identifying general areas for further development.

Task #3

Genetic Counselling Video: A video dealing with the theory, practice and implications of genetic screening will be viewed by the students in preparation for a class discussion on the issues it raises. The students will then be asked to examine their own discussion to develop tactics for effectively dealing with science in a social context.

Instructional Strategies:

1. Television is an important source of information and programming produced for television provides a rich and meaningful source of socially relevant science materials. Choose a content appropriate video.
2. Present the viewing as a source of information for an open discussion on the topic during the next meeting of the class.
3. Have the class examine their own discussion. Was it productive in developing the issues? If not, can they identify the problems? Was the discussion rational or irrational; reasoned or emotional, information or

feelings based, built on sound argument or opinions; characterized by respect for or dismissal of alternative views?

4. Identify the major components of science and society issues: information and the social content in which the consequences of the information are played out.

5. Identify using the class discussion as one example, the impediments to rational discussion (written or verbal) of these issues of values, emotions, point of view.

6. Based on this analysis, develop tactics for planning a strategy that takes the informational and emotional elements into account:

- Outline the scientific information
- Illustrate how it is to be applied
- Describe the social context
- Develop your own position.

7. Assess the credibility of an argument based on this framework.

8. Emphasize the importance of following through on each chain of reasoning.

Task #4

Literature Presentation #3 - Review the heuristics framework developed to this point for dealing critically with new scientific information. Apply the strategy when preparing the third literature presentation.

Instructional Strategies:

1. Review the heuristics framework and the tactics developed in the preceding assignments dealing with approaching new information:
 - Identify the issue

 - What is the strategy?
 - ° the scientific information included
 - ° the ways it is used
 - ° the social context in which it is used

 - Evaluate the conclusions in these terms.

2. Practice this heuristic framework in preparing the literature presentation.

3. Provide feedback on process and content.
4. Compare with earlier efforts.

Task #5

Compare two different approaches to arguing on the same knowledge base: Students will be assigned two articles which reflect two different approaches to using the same information. Students will be asked to identify the strategy used in each piece and evaluate the credibility of their outcomes.

Instructional Strategies:

1. Provide students with contrasting articles on a topic currently being developed and ask them to identify the point of view and the strategy used in both examples.
2. Compare the strategies for the credibility of their outcomes, identifying strong and weak strategies.
3. Identify the strategies which characterize effective articles and integrate or verify them in the heuristics framework for developing well reasoned positions. Likely examples include:
 - systematically providing evidence for each point made
 - organizing related points to reinforce each other

Task #6

Evolution Content Video: Students are asked to develop a strategy for critical viewing of a video-tape, to use the strategy to assess its content and to participate in a class discussion based on the ways the content was organized and developed.

Instructional Strategies:

1. Review the heuristic framework developed thus far with regard to assessing or developing positions based on scientific information.

Table 4-1

Application of General Heuristics to the Critical Analysis of Information

General Framework	Applications to Assessing or Developing Information
Represent the Problem	What is the issue?
Plan a Strategy	Assess/Plan the Strategy <ol style="list-style-type: none"> 1. the information component <ul style="list-style-type: none"> - gaps, sources, clarity 2. how it is used <ul style="list-style-type: none"> - organization, reasoning, development 3. style <ul style="list-style-type: none"> - vocabulary, intensity
Carry out the Plan	Fait Accompli/Carry out the Plan
Evaluate the Outcome	Examine the conclusion <ul style="list-style-type: none"> - what are they? - is there evidence for each one? - is it convincing?

2. Individual students should apply this strategy to the video presentation.
3. The strategy should be following in a discussion of the arguments presented.
4. Use the discussion to emphasize the importance of supporting ideas with evidence, developing opinions to reasoned positions.

Task #7

Book Report: Students are to choose a book on an evolution related topic, prepare a book report for submission and present a ten minute talk on the book to their tutorial group.

Instructional Strategies:

1. The students are advised to apply the heuristics developed to the development of their book report which involves more complex material than previously used.
2. Provide opportunities for discussion and consultation on the strategy and content of the reports.

3. Provide individual feedback on the content and strategy of the written and oral reports.

Task #8

Final Exam Question: Analyze a short segment of a video presentation for its effectiveness in presenting an argument.

Instructional Strategy:

1. Assess the independent effort of students to deal critically with new information.

IV. CITIZEN ACTION AND DECISION MAKING PROJECTS

In this component of the course students were presented with a series of social issues having a scientific knowledge component. They were encouraged to develop well reasoned, personal positions and/or plans for community action when faced with these multifaceted problems.

A. Objectives

- ° To develop a willingness to consider problems based on scientific content in the complex social context in which they occur.

- ° To develop an effective strategy for thinking about, discussing and taking positive action on these problems by extending the use of the heuristics framework.

- ° To apply the tactics for analyzing science issues in the media as criteria by which to organize and develop coherent positions from complex bodies of information.

- ° To explicitly encourage the development of students skills relevant to a responsible treatment of scientific issues in the community at large such as: identification and analysis of the available information, reasoned elaboration on information, careful consideration and building on the ideas of others, sustained lines of reasoning to develop ideas and synthesis of complex bodies of knowledge into a consistent whole.

B. Instructional Plan

The instructional plan for the citizen action and decision making component is an extension of the science in the popular media component and is similarly organized (Figure 4-3). The sequence of major instructional activities again forms the framework for a description of the strategies to develop process skills (See Appendices C and D for specific examples of content chosen).

Figure 4-3

Strategy for Thinking Skill Development Through Citizen Action and Decision Making Projects

- Introduce:
- ° the complexity of these issues
 - ° the need for accurate information
 - ° the social context in which the consequences of the information are played out
- Thinking Skills Objectives
- ° Apply the strategies used in other contents
 - carefully identify the nature of the task
 - plan a strategy
 - stick to the plan
 - evaluate the outcome
 - ° Emphasize
 - identification of relevant information
 - evaluation the sources and detecting the incomplete or biased information
 - following through on ideas
 - ° Provide individual feedback on content and process

Introduction
 Introduce the course by objectives and content and develop an example of a current controversial topic, illustrating the role of scientific information and societal considerations.

Genetic Disease Report:
 Students are to prepare a report on a genetic disorder of their own choice, including inheritance possible medical interventions, relevant social factors and their personal views

Christmas Exam Questions
 1. Identify the kinds of information relevant to a problem, given the framework.
 2. Working independently, develop an argument on a scientific-social issue.

1-3 Weeks

13 Weeks

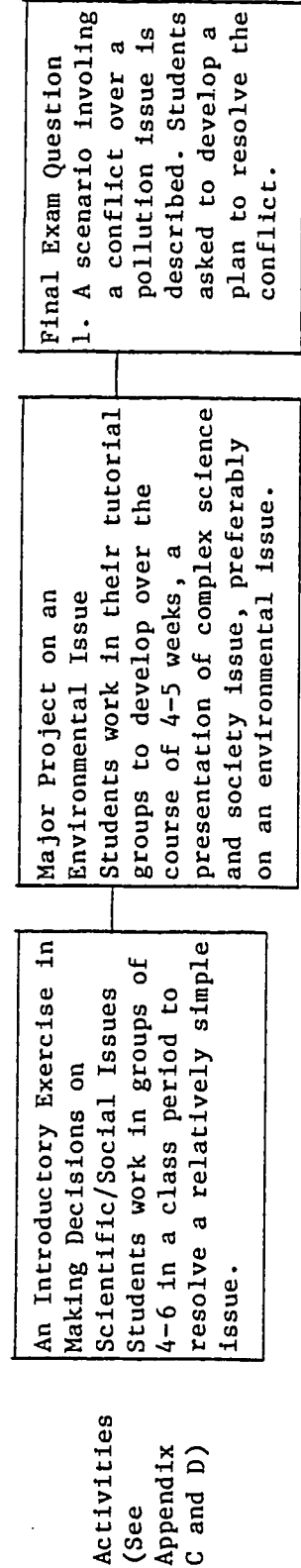
15 Weeks

Time Line

cont. next page

Figure 4-3 (Cont.)

- Thinking Skills Objectives
- ° Provide an example on which to model the major assignment
 - ° Practice the application of tactics within these heuristics
 - identify the problem
 - plan a solution
 - evaluate the outcome
 - ° Emphasis:
 - identifying relevant information
 - synthesizing the information from all sources to form a well reasoned position
 - ° Each tutorial group should explicitly plan a strategy
 - clearly represent the problem, redefine if necessary
 - identify relevant information areas and how to access the necessary information
 - how to organize and develop the information
 - what style of presentation will be effective
 - ° Work together to facilitate the implementation of the plan
 - ° Evaluate the outcome
 - ° Provide feedback on content and process
 - ° Provide feedback on content and process



Time Line ----- 27 Weeks ----- 31 Weeks ----- 32 Weeks

Task #1

Exemplify the content and approach to be taken: Students will be introduced to the scientific information underlying a current controversial topic and to the role of the larger social context in which it is used.

Instructional Strategies:

1. Introduce the students to the kind of subject matter, the level of participation required and the level at which the information should be operated on. Choose a topic which is currently controversial in order to motivate students to enter quickly into active participation.
2. Present the scientific information.
3. Introduce the complexity of these issues, the need for accurate information and a consideration of the social context in which the consequences of the information are played out.

Task #2

Genetic Disease Report: Students are to prepare a report on a genetic disorder of their own choice including the theory and pattern of inheritance, a description of the results of the disorder, possible medical interventions in reproduction and in treating the disorder, relevant social factors and their personal views on managing the inheritance of the disorders.

Instructional Strategies:

1. Review the strategies made explicit to date and, in particular, those developed from viewing the genetics videotape (Task #3, Media).
2. Assess whether this strategy would be useful and if it needs further elaboration.
3. Encourage students to use the strategy to prepare their own reports.
4. Provide individual feedback on the content and process of the reports.
5. Have students present a synopsis of their reports to their tutorial groups to elaborate the group's content and process knowledge.

Task #3

Christmas Exam Questions: The Christmas exam offers opportunities to assess individual performance. The first option selected was to determine if students could identify information which is relevant to science and society issues. Students were given a scenario, provided with a panel of experts and were asked to list the questions they would ask of each as a basis for resolving the situation. The second option taken was to ask students to develop a coherent argument for one side or the other in a course content related news item.

Instructional Strategies:

1. Assess students abilities to (1) identify relevant information, given a framework; and (2) identify the conditions under which the strategies apply and use them effectively.
2. Provide feedback on the content and process of the response.

Task #4

An Introduction to Decision Making on Science and Society Issues. Students work in groups of 4-6 to resolve a relatively simple issue in a class period.

Instructional Strategies:

1. Provide an example on which to model the upcoming project.
2. When students have worked through the example, have them describe their process.
3. Emphasize: identifying relevant information and tactics for synthesizing the information from all sources to form a well reasoned position.

4. Indicate the relevance of the strategy to more complex issues.

Task #5

Major Project on an Environmental Issue:
Students work in their tutorial groups to develop, over the course of 4-5 weeks, a presentation of complex science and society issue, preferably on an environmental issue.

Instructional Strategies:

1. Each tutorial group should meet and decide on a topic which is significant to them and appropriate to the task.
2. Each group should explicitly plan a strategy:
 - clearly represent the problem, redefine, if necessary
 - identify relevant information areas and how to access the necessary information
 - what style of presentation will be effective.
3. Work together to facilitate the implementation of the plan.
4. Evaluate the outcome by the planning criteria.
5. Students should be provided with feedback on their content and process.

Task #6

Final Exam Question: A scenario involving a conflict over a pollution issue is described. Students are asked to develop a plan to resolve the conflict.

Instructional Strategies:

1. To determine if students can independently devise an effective plan for action on issues relevant to responsible citizenship.

V. THE THREE COMPONENTS AS AN INTEGRATED WHOLE

The instructional plan describes three different but not independent components through which it is intended that thinking skills will be explicitly developed. Contrary to their separate descriptions, the components are designed to form an integrated whole when viewed from the perspectives of time, their common heuristics framework and their interaction.

If the time lines for each of the components described are overlapped, it becomes obvious that elements of all three components are interspersed through the first term and that the latter two components continue to be interspersed throughout the second term (See Appendix E). The distribution of elements of the three components' is not

random. A careful analysis of each activity in a consecutive time sequence will show that elements of all three components act interchangeably to lay the foundation for skill development, to offer opportunities to elaborate and practice skills and to assess skill acquisition. The objectives and strategies of each component overlap extensively to build continuity between elements and to reinforce the common goals of the components.

The common thread which binds together all of the elements described is their common heuristics structure. All three components share the same explicitly articulated strategy for approaching and dealing with new information and novel situations. It is this strategy which is the focus of the instructional plan and not specific sequences of activities or the content on which they are based.

CHAPTER FIVE: CHARACTERIZING STUDENTS' PROBLEM SOLVING SKILLS

I. INTRODUCTION

The first hypothesis underlying this study is that it is possible to use the characteristics of good and poor problem solvers as a productive way of defining the ineffective learning and thinking shown to affect a large proportion of university students. In this chapter data and analysis relevant to this hypothesis are presented. The assumptions underlying this hypothesis in the context of this case study and in other classroom situations to which the strategy outlined may be generalizable are:

1. that characteristics of good and poor problem solvers are recognizable in classroom performance; and
2. that they are evidenced with sufficient consistency across groups of students to form a basis for the development and evaluation of classroom based remediation strategies.

The analysis of this initial period of observation was undertaken, therefore, to determine whether problem solving characteristics can be identified in classroom performance and the relative frequency with which they are evidenced in this group of students. This preliminary

period of study is essential as a test that these traits are both recognizable and broadly based in order to be useful as a practical perspective from which to approach the development of thinking skills in the classroom.

II. THE DATA

The data were collected using the observation framework outlined in the description of the case study (Page 65) over the first eight weeks of the course. Transcript style observation records were kept for the interactive segments of all scheduled class sessions and tutorials. During this period, the subject matter varied widely and included discussions on the biology, epidemiology and social context of A.I.D.S.; two literature presentations, spaced four weeks apart; group efforts on structure and function exercises involving a leaf, the hand and a mouse, and observation and consultation in preparation for the major structure and function assignment. In addition, the students prepared a written assignment on structure and function of the hand and a marine organism of their choice.

The structured analysis system illustrated in Table 3-3 was applied to all data sources and the number of different characteristics recognized in early efforts is represented in Table 5-1. The numbers in the central columns represent the number of students in whom the behaviors were actually observed, and will not always be consistent or total sixteen.

Table 5-1

The Number of Different Students Exhibiting Specified Problem Solving Characteristics During the Assessment Period

I. REPRESENT THE PROBLEM			
1. take time for careful assessment	N/O	16	1. assess quickly and superficially
2. write in your own words	1	9	2. read, reread as given
3. diagram the situation	N/O	N/O	3. fail to diagram the situation
4. identify essential components	1	11	4. fail to identify essential components
5. detect gaps in understanding	N/O	N/O	5. fail to detect gaps in understanding
6. work on understanding meaning	N/O	N/O	6. do not work on understanding meaning
7. identify information given	N/O	N/O	7. fail to identify information given
8. identify larger concepts and principles	N/O	N/O	8. think around literal objects involved
9. establish solution criteria	N/O	N/O	9. do not establish solution criteria
II. PLAN A STRATEGY			
A. Making the Problem Manageable			
1. subgoal			1. work with the whole problem
2. think of similar problems	N/O	N/O	2. do not think of similar problems
3. create solution hypotheses	N/O	N/O	3. do not create solution by hypotheses
B. Selecting a Solution Process			
4. make a general plan before beginning	1	11	4. do not plan a solution
5. evaluate the plan	N/O	N/O	5. fail to recognize process inadequacies
6. consider alternative plans	N/O	N/O	6. solution path is fixed
7. diagram plan	N/O	12	7. has no plan on paper
C. Selecting Relevant Information			
8. note available information	2	7	8. do not note available information
9. organize available information	2	6	9. do not organize information
10. detect gaps in information	2	8	10. fail to detect gaps in information
11. use reasoning as a tool	2	10	11. adopt a know/don't know position
12. recognize knowledge learned in other contexts	2	9	12. fail to recognize knowledge learned in other contexts
13. recognize personal beliefs/biases, but maintain an objective attitude	N/O	6	13. opinions and feelings determine responses

(cont. next page)

Table 5-1 (cont.)

14. be critical of information sources	1	8	14. accept information passively
15. be aware of the context	N/O	N/O	15. do not consider the context
16. modify original ideas in the light of information	N/O	4	16. find it difficult to modify ideas
III. CARRY OUT THE PLAN			
1. stick to the plan	N/O	12	1. distracted frm the strategy by detail
2. consider all relevant information	N/O	8	2. overlook relevant information
3. complete each chain of reasoning	N/O	14	3. fail to carry through ideas
4. avoid statements based on opinion	N/O	6	4. use unsubstantiated opinion
5. provide evidence for each point	N/O	11	5. neglect to provide evidence, as a rule
6. constantly monitor the solution process	N/O	N/O	6. not conscious of the solution process
IV. EVALUATE THE OUTCOME			
1. critically evaluate the outcome	N/O	N/O	1. does not evaluate the outcome
2. relate the outcome to the problem posed	N/O	N/O	2. does not relate outcome to the problem posed
3. recognize inconsistencies	N/O	9	3. does not recognize inconsistencies
4. recognize gaps in information	N/O	6	4. fail to recognize gaps in information
5. recognize gaps in reasoning	N/O	9	5. fail to recognize gaps in reasoning
V. ATTITUDES			
1. confidence in novel situations	3	8	1. lack confidence in novel situations
2. show care and system in thinking	N/O	7	2. fail to show care and system in thinking
3. confidence in the value of reasoning as a tool	N/O	7	3. maintain a know/don't know attitude
4. confidence in pursuing leads	1	4	4. lack confidence to pursue leads
5. open-mindedness	2	6	5. confirmed opinions, narrow view
6. high effort	5*	9	6. low effort

= Not Observed

* One unconditional, four conditional on interest or knowledge

III. DATA ANALYSIS

A. Traits Not Observed During the Assessment Period

The summary of problem solving characteristics observed during the assessment period shown in Table 5-1 indicates that not all documented characteristics of good and poor problem solvers are recognizable in students' classroom performance. Those traits which were not recognized included:

1. with regard to representing the problem:
 - (a) whether students diagram the problem situation
 - (b) whether students detect gaps in their understanding of the problem
 - (c) whether students work at understanding meanings
 - (d) whether students identify and assemble the information given
 - (e) whether students establish solution criteria

2. with regard to planning a strategy:
 - (a) whether students think of similar problems they have solved
 - (b) whether students create solution hypotheses
 - (c) whether students critically assess their planned approach for problems
 - (d) whether students consider alternative strategies
 - (e) whether students are aware of the context of information

3. with regard to carrying out the plan:
 - (a) whether students consistently monitor process

4. with regard to evaluating the outcome:
 - (a) whether students check outcomes for preset criteria for solution
 - (b) whether students relate outcome to the problems posed.

The fact that some traits documented in the literature are not readily identifiable in the course of classroom practice is not surprising. Many of the characteristics listed in Table 5-1 were identified in intensive think aloud protocols which made the thinking process known under artificial circumstances. Under normal classroom circumstances, these processes remain covert and are not available for observation. This interpretation is further reinforced by the observation that many of the problem solving characteristics for which there were no evidence during the observation period are those which are primarily carried out at a mental level and often produce no tangible evidence: representing the problem and planning a solution.

This study is concerned with those traits which present themselves clearly in the classroom and consequently can form the basis for assesment and development of thinking skills. This initial observation period was intended to identify appropriate traits and the analysis will continue with this focus. This is not to say that the

traits which were not observed could not be made explicit if they proved to be an important part of a strategy, but that there are other characteristics which may be more practical to apply.

B. Traits Observed During the Assessment Period

Characteristics from each of the four categories in the heuristics framework were observed during the assessment period. The characteristics which were recognized included:

1. with regard to representing the problems:
 - (a) whether students take time to assess the problem carefully
 - (b) whether students interpret the problem in their own words or work with the problem as given
 - (c) whether students identify the essential components of the problem

2. with regard to planning a strategy:
 - (a) whether students subgoal or work with the whole problem
 - (b) whether students make a general plan
 - (c) whether students diagram their plan
 - (d) whether students take note of available information
 - (e) whether students effectively organize information
 - (f) whether students detect gaps in information

- (g) whether students use reasoning as a tool or have know/don'tknow attitude
 - (h) whether students recognize knowledge learned in other contexts
 - (i) whether students can recognize their personal feelings and emotions and still maintain objectivity towards information or whether their opinions and feelings determine their responses
 - (j) whether students are critical of information sources or accept information uncritically
 - (k) whether students change their positions when they conflict with available knowledge
3. with regard to carrying out the plan:
- (a) whether students stick to a plan or are distracted by details
 - (b) whether students consider all relevant information
 - (c) whether students carry through chains of reasoning
 - (d) whether students provide evidence for each point or use unsubstantiated opinion
 - (e) whether students show a low or high effort when confronted with new information or novel situations
4. with regard to evaluating the outcome:
- (a) whether students recognize gaps in information
 - (b) whether students recognize gaps in reasoning

5. with regard to attitudes:
- (a) whether students show confidence in new situations
 - (b) whether students have confidence in the value of reasoning
 - (c) whether students have confidence in pursuing leads
 - (d) whether students show openmindedness
 - (e) whether students show high or low effort
 - (f) whether students show care and system in thinking.

It is through this collection of traits that the students in this case study manifested their problem solving skills and/or difficulties in approaching new information or situations. Some of the ways in which these characteristics became evident are next described.

C. Representing the Problem

The data collected indicated that the students had no habit of thinking carefully about what it was that the problem/question was asking. Typically there was only a superficial consideration of the task to be undertaken.

The situation is best illustrated by the students' responses to a structure and function exercise involving the hand, assigned following an example in which the nature of the task was illustrated.

Carefully observe the structure of your own hand. Relate its structure to the functions it performs.

The individual written responses to this assignment indicate clearly that only one of the students (D.D.) appears to have identified the essential components of the problem: observe structure, consider function and relate one to the other. One student (K.A.) contributed a description of the skeletal structure of the hand, clearly missing the intent of the problem presented. Other students showed various combinations of observations, consideration of function and relating one to the other, as indicated in Table 5-2. In an open effort to develop the task, students identified function as the key component of the problem, but did not identify observation as an essential component except in the context of establishing function and generally missed altogether the requirement for making well reasoned connections.

Table 5-2 indicates that while all students participating (12) recognized the requirement for observation, only four recorded more than general observations (e.g., that there were four digits and an opposable thumb versus elaborating on this observation with the number of joints, direction of flexibility or range of flexibility).

Fewer students (2) represented function adequately with most students considering only touch and grasp. Some students (4) missed the requirements to relate structure and function completely and others stated the relationship as a matter of fact with no evidence to support the connection, a requirement emphasized in the introductory examples, but which these students failed to apply. These observations indicate that the students had not considered the essential components of the problem, what each component involved or the degree to which it should be pursued.

Table 5-2

Characteristics of Written Hand Assignments (N=12)

	Good Depth of Observation	Superficial Observation
adequate function/did not relate		
adequate function/related as a matter of fact	C.H.	J.E.
inadequate function/did not relate	K.E., A.N.	K.A., D.H.
inadequate function/related as a matter fact	D.D.	J.K., T.A., L.Y., D.F., H.E.

Implicit in these results and explicit in the discussion on the structure and function of the hand is the observation that these students failed to take time to assess the problem carefully. During the class effort on the hand, students were quite candid in admitting

that they read the problem and jump right in to produce a solution. They acknowledge that it makes good sense to carefully consider the problem before launching a solution, but it is a new strategy to them.

Following a discussion of the results of the hand exercise which focused on both content and process, the students were asked to develop a strategy for their next attempt, to be assigned in a tutorial period. One of the directives included in the assignment was "to consider how to make sure you know what the task entails". Even following their experiences with the hand, these students were reluctant to enter into an examination of the problem itself. Only one student (H.E.) was able to articulate the requirements of the task: examine and note structures, use observations to generate hypotheses regarding function, build evidence for the hypothesized relationships considering the environment, and evaluate evidence to decide on the most likely relationship. Other students found it difficult to free themselves from working with the task as given. When pressed in a class session to put the task in their own words and given some time to do so, responded:

T.I. : " observe study body relate to function"

J.K. : ". . . . relate to function is the tricky part - think of why it [structure] is best suited to function" (student's emphasis)

D.D. : ". . . . we can deduce function if we consider the natural environment of the organism"

H.E. : "if you look at it this way, you don't have to know anything about the organism before you start".

The reticence of the class in this activity and their difficulty in discussing what the problem was, indicate that they work with the problem as given without seeking their own understanding of the task.

D. Planning a Strategy

The observations regarding how students represent the task to be performed are closely linked to those which focus on planning a solution strategy. Just as these students did not consciously pursue their own understanding of what the task was to be, neither did they make a significant conscious effort to plan a pathway through the task.

At the most general level, there is the question of whether these students think about how they will solve the problem before they begin: whether they tentatively plan the solution approach. A direct question to the students regarding their hand assignments indicated that, for most, there was no particular strategy in mind as the task was being carried out, that, for the most part, one idea followed another as the response progressed. The written products were the only pencil and

paper efforts on the exercise. When the first structured opportunity to practice developing a plan was offered, some students (D.D., C.H., D.F., J.K. and J.E.) had difficulty even in becoming focused on that task and insisted on moving into producing their response immediately. A corollary of this observation is that the students did not diagram their solution strategies.

It was interesting to find that D.D., who, together with her tutorial group, showed little interest in planning a solution strategy, acquired and used the structure, function and relating structure and function criteria in a superficial way in her hand report. It would seem that she recognized these criteria as professor expectations for successful task performance rather than a useful strategy at this point. More specific indications of individual aspects of planning a solution are described in turn.

Essential to effective problem solving are the identification and organization of relevant information. The first level of concern is whether students comprehend information and are able to report that information to others. The students in this sample, for the most part, were quite competent in dealing with information as an end in itself. Even in the early A.I.D.S. discussion C.H., A.N., D.D., K.E. and T.A. contributed readily with direct information from the assigned literature. Similarly, in the first literature presentation (N=9), six students showed excellent command of the content and two chose

technically difficult topics but were able to deal with the important concepts. Only one student, who chose an article on the basis that "nothing else (in the magazine) interested me", made an inadequate presentation with regard to content she reflected in her presentation but was able to improve the content level of her presentation upon questioning. Six additional students joined the next round of literature presentations and all presentations were characterized by an adequate grasp and direct communication of the informational content. Despite anxiety regarding the presentation of information, each student in these examples had confidence in the information they reported directly from the article and used the organization of the article to organize their presentations. They accepted uncritically the information and the purposes to which it was used. This confidence in sources of information, without considering the credibility of the source or the argument being made, applied not only to media products but to less likely sources as well: assertively stated but erroneous statements on electron distribution by a fellow student were taken as truth. Inferences made about an animal skull identity went unchallenged (even though there were alternative possibilities) because the speaker asserted her expertise in making the point: (after some general examination and comments by the class)

C.H.: (examining the skull) "it's a goat"

Professor: "How do you know?"

C.H.: "because I have kept goats and I know they tear off grass with their teeth and this is the way the teeth are placed" (demonstrating)

J.E.: "I heard goats have a space in the front of their head so they can butt without getting hurt. Is that true?" (examines the skull, class looks on quietly, no visible evidence)

C.H.: "it's a goat"

This terminates the discussion.

The degree to which students accepted information uncritically varied inversely with their confidence in their own knowledge on a topic. For example, in the first literature presentation, J.K. was quite confident in elaborating on and evaluating an article on twins in the course of her presentation because she is one of a twin and related well to the content. Students who did not include elaboration and evaluation in their presentations did not necessarily lack the individual skills required, but did not think to apply them. Even in the early literature presentations, some students (T.A., D.F., D.D., K.I., A.N., C.H., H.E.) could be easily encouraged to make such assessments but did not do so independently.

When students moved away from tasks where there was an information base in a written form and which was organized in a certain way, they

had much more difficulty in recognizing and organizing relevant knowledge. Throughout the structure and function exercises, it proved a challenge to have students record, during the observation periods, their observations, possible functions and ideas as to how the two are linked or to show any system in doing this. The results were that students jumped between organisms and between parts of the same organism and had no written records available for later organization, either. One tutorial session on the mouse produced the following sequence of structures observed:

- teeth (structure)
- paws (structure)
- ears (structure)
- tail (structure and function)
- whiskers (function)
- expression of exasperation with the lack of organization
- suggestion to start with head
- suggestion to notice at random, organize later
- legs
- teeth
- exasperated student drops out and proceeds independently,
making notes without communicating content
- fur (function)
- legs (structure)
- tail (function)
- ears (structure and function)

This lack of system in gathering and organizing information was reflected in the preparation of the major structure and function assignment with few students pursuing the detail of structure, recording their observations or making drawings for later use. With this superficial approach to attending to the information available, it was difficult for students to notice gaps in their information.

Much of the superficiality in dealing with new information or novel situations appears to stem from the know/don't know attitude which prevailed and the failure of students to use reasoning as a tool on existing knowledge. The reluctance to use reasoning as a tool appears throughout the students activities. One manifestation is in their dependence on direct sources of information. On the hand exercise, J.E. quotes "they said" with regard to information she offered; K.A. is restricted to a text book description of the skeletal structure. In studying organisms from the seawater tanks there was a general apprehension about studying "an unknown", they picked the brains of majors working at the tanks, sought direct information from instructors since "that's what [they] are paid for" and asked for advice on reference books. All of these tactics are legitimate, but the information gained is not an end in itself. The requirement to use this information to develop ideas was an essential component of the task but students stated relationships as fact without reasoned evidence and, in some cases (e.g., T.I.), included irrelevant information because it was included in the encyclopedia. Three students (L.Y., J.E. and T.I.)

persisted in presenting a reference book based report on their organism, rather than a report based on observation supplemented by information and a common sense based interpretation.

Not all students found it impossible to break out of the know/don't know situation. A.N., who was very apprehensive about a major project on what, for him, were unknown creatures, adapted quickly to "figuring things out" and his insight transferred well to the scientific examples of structure, function, molecular biology and beyond. D.D. began as a "formula for success" user but showed more insight into the process. After a slow start on her structure and function assignment in which she could not become focused on the task, she found the suggested strategy to be productive and became an enthusiastic participant.

One step away from having or wishing to find direct answers is recognizing relevant knowledge learned in other contexts. This kind of flexibility also requires breaking out of the know/don't know track. In the A.I.D.S. discussion students reported the information in the articles provided and showed an understanding of its meaning but did not use the information in subsequent discussions. While this shift would indicate a change in the level at which information was used, it is hardly a change in context, and yet the information does not become available at that moment. For those students who recognized relevant knowledge learned in other contexts, there were two major effects: students recognize concepts and principles which can be generalized to

explain a new situation and students recognize specific instances of a principle which limit the interpretation of the new situation. For instance, A.N. recognized and applied the concept of surface area to volume ratio with positive results in several structure and function exercises. On the other hand C.H., who had a wealth of specific knowledge, was limited, rather than primed by that knowledge. In the early weeks of the course she took the position that because she new A to be true, she could not consider B. In the skull example used earlier, any appropriately sized grazing animal would be acceptable, not only a goat.

When bringing together information from which to synthesize a response to any problem or issue it is important to recognize the personal feelings and emotions around the task, to take them into account, but to keep them separate from factual information. This element of problem solving affects the students' attitude towards approaching the problem and how they perceive, choose and use relevant information. D.E. and C.H. both had problems in approaching the mouse task. D.E. experienced the mouse as a household pest and could not move beyond that context; C.H. felt she already knew quite a bit about mice and did not really engage on the task.

With regard to the perception, choice and use of information, the A.I.D.S. discussion provides several illustrations. Even though students have a good command of the relevant information they

acknowledge that their views are determined, in the case of A.N. by his opinions on homosexuality, in the case of D.E. by a desire to avoid a threat to her children and in the case of T.A. because A.I.D.S. is personally threatening. It was these feelings which characterized the discussion. In a classic moment, J.E. expressed the epitome of the problem: ". . . facts don't explain anything to me - it's the way I feel about something".

The students discussions and interactions in general were marked by the difficulty they had in modifying their hypotheses or what they believed to be true when faced with new information.

For instance, in the class effort in developing the structure and function of the hand, the following exchange took place regarding the function of the loose skin found between the digits.

K.E.: ". . . it looks like webbing . . . for swimming"

A.N.: "I don't think so . . . if that were true, there would be more webbing, like ducks' feet"

K.E.: "(demonstrates open fingered stroking motion). The webbing creates a greater resistance."

A.N.: "But to swim most efficiently you have to keep the fingers closed side by side (demonstrates). How many people here swim? (seeks agreement)."

There is a growing consensus that the loose skin between the fingers does not function in the same way as webbing in ducks.

J.E.: "what about flexibility" (demonstrates that the loose skin allows sideways extention)

After a short discussion on choosing the more plausible option, there is general agreement that the second hypothesis is more plausible but K.E. is very reluctant to give up the first idea as the better option.

Similarly, on the A.I.D.S. discussion, the idea that this disorder was a concern only for certain minorities persisted and surfaced even at the end of the development of this topic. Even though students had been exposed to information about the nature of the disease, how it is spread and the pattern in which it spread through populations already studied, which contradicted their initial position, they persisted in not seeing A.I.D.S. as a threat to the community at large.

It appears that there is a commitment to the first idea, even if it is not well developed or is in conflict with new information, which interferes with generating, considering or accepting alternative ideas.

E. Carry Out the Plan

The most visible part of the problem solving process is in the actual production of the response. It is this product that most often indicates the students' understanding of the problem and the care they have taken in planning a strategy. The observations made in this class allow for an assessment of written work, oral presentations and discussions which also reflects difficulties encountered when actually carrying out the solution.

Not the least of these difficulties is the ability to stick to the strategy developed for solving the problem. The mouse tutorial sessions provide the clearest illustration that self-monitoring of this state of the problem solving process is also required. In preparation for the tutorial session, students were asked to plan how they can effectively approach the task. As described earlier (page 116) students showed difficulty in representing the problem in their own words and similarly, they had difficulty in making the plan and articulating it clearly, but in each tutorial a plan was derived before observation of the mouse began.

Although some students reluctantly participated in the task, each group had alternative strategies, any of which would have made an adequate framework. Once the task had begun the students, without exception, became completely absorbed in the details of the mouse and abandoned any strategy for producing a response. Even H.E., who outlined an excellent strategy in an independent effort, did not follow her own strategy once the task was in progress.

Even though students were not observed to follow a strategy derived in advance when they worked their way through questions and problems, responses did, nevertheless, get generated. When the products of these efforts are examined in terms of the characteristics attributed to good and poor problem solvers, a number of observations emerge.

Perhaps because there was not a conscious search for an organization of relevant knowledge before launching a response, students were observed to overlook relevant information in generating responses. During the development of the A.I.D.S. issue, students were given discussion topics to prepare for class discussion on two occasions. On both occasions, students could directly report information from the assigned materials but failed to apply that information in discussion questions raised. When pushed to find relevant information the students could use the same information appropriately. There had not been a lack of information, but a failure to recognize and use that information.

The characteristic which surfaced most frequently and in all kinds of tasks was that these students did not often complete chains of reasoning. There was no shortage of ideas, but they were not carried through or developed adequately. In the example of the progression of topics in a tutorial observation session on the mouse (page 121), one can see the students jumping from one aspect of the mouse to the other. That example did not show the superficial consideration afforded each structure. To illustrate further, a more detailed account of a segment of that interaction follows.

After settling on a strategy based on main life processes, observation begins with a random inventory. One student asks for more organization and a slightly more detailed sequence follows:

legs: J.E.: "back legs are strong to run and jump"

J.K.: "strong for standing on only two legs and balancing . . ."

teeth: confirmed continuous growth

fur: J.E.: "grows in only one direction"

J.K.: "the water would run off so the mouse wouldn't get
wet protects the skin"

legs: D.D.: "the front legs are shorter than the back" (make general comparisons)

tail: J.E.: "it's so long" (mouse curls up)

: "it's very flexible"

J.K.: "there is no fur (gross!) so it's not for warmth. It's probably sensitive"

One could argue that it may be more difficult to maintain a chain of reasoning in a group effort but the trend continues in individual efforts. In the marine organism exercise quite valid ideas were raised but were not pursued. For example,

T.A. indicated that suckers along the length of a sea cucumber were present to grip the bottom but not why this was a likely explanation.

K.A. acknowledged that sea anemones are stuck in one place but didn't consider what constraints this imposed.

In their oral presentations and discussions, students were somewhat more likely to follow through on ideas. In the literature presentations, interaction between participants and with faculty helped students develop ideas put forth by the articles. In tallies of ideas introduced versus ideas carried through in these sessions, most students

could carry through at least one-half of the ideas introduced. In their written presentations, they were much less likely to carry through ideas raised. Other related characteristics can be identified in these observations. Examples used throughout this analysis provide evidence for two characteristics, the assessment period students have been observed to have difficulty in avoiding statements based on opinion and emotion and consequently, do not systematically provide evidence for each point.

F. Evaluating the Outcome

Working with the students written assignments as the primary data source, there is consistent evidence that the students did not evaluate their products in terms of the problem posed or their own stated strategy for approaching the task. On the structure and function assignment, a number of students (3) explicitly stated what their strategy would be, but did not fulfill those requirements in their product.

C.A.: ". . . . examining an organism and noting their most apparent structures develop hypotheses about its structure and function and relate these ideas to its environment."

The main body of the assignment, however, indicated a superficial effort to infer function from observations. There were very few reasons

why structure was linked to a particular function or how function was related to the environment, as laid out in the strategy statement.

More commonly, students (6) performed the task adequately for a couple of major structures but not for others. One student (L.Y.) provided a detailed description, considered only two major functions and adequately related structure and function on only one structure. Students showing this pattern clearly had understood the nature of the task but had not assessed their responses for the appropriate content.

A third characteristic of their work is that these students do not recognize the gaps in reasoning in their responses. This observation runs much deeper into the problem solving process and stems from the students attention to providing evidence and developing ideas in generating a response. The component of this assignment with which the most students (9) had difficulty was in providing reasoned evidence for structure-function relationships. The difficulty stems from a lack of attention to providing evidence and, secondarily, a failure to detect this shortcoming in their product.

G. Attitudes

The attitudes which students bring to the problem solving process are reflected in their performance and were judged to represent a significant factor in ineffective problem solving over the course of

this case study. There were times when students had both the information and skills necessary to generate a response in a novel situation, but any effort was pre-empted by attitudes which denied them the confidence to proceed.

At the most general level, this lack of confidence in novel situations is evidenced in students reaction when the new situation is posed. Some students consistently withdrew and took no overt interest in the problem (D.F., K.A., J.E., D.E., C.A. AND D.A.). The typical response of other students was to avoid eye contact by consulting their notes, in one case (T.I.) by superficially gazing over poor notes in no specific content area, in another (D.H.) by a more focused search through better notes. In neither case did contributions result. A third group of students would consistently work together to contribute comments, not necessarily directly towards a response, but pieces of information related to the topic which they drew directly from their existing knowledge. They seemed to show little confidence in the value of reasoning from existing knowledge and instead were trying to score hits with bits of information directly available. For instance, in the introduction to molecular biology, a table of characteristics of polar and non-polar molecules was constructed on a common sense basis. When asked to apply these principles, J.K. reverted to searching her knowledge of chemistry for direct answers rather than reasoning from the table provided. A.N. recognized the problem with this strategy and successfully used the table rather than a direct knowledge of chemistry

in predicting a molecule's orientation in aqueous solution.

In their assignments, there were numerous examples of failure to use reasoning as a tool (e.g., page 122). The pattern of being able to use information directly, but not being able to build it into an advanced idea, elaborate or reason from it, is common throughout these early activities. Is the origin of this pattern in that these students lack the necessary thinking skills required or that their attitudes towards using those skills limits their performance? It seems, at least for some students, that confidence in being able to figure out things not directly known is the missing element. An excellent opportunity to see this distinction was during the observation periods at the sea water tanks. All of the students expressed apprehension at the outset of the task and were open to consultation to help get the task started. Students who perceived themselves as not able to make informed observations or draw inferences responded well to questions which led them to see more detail or develop an idea more fully. Most had no difficulty in responding but would not have developed that line of investigation independently. For instance, K.I. was reinforced by the discovery that asking how or why is a useful strategy for generating information from structural observations; A.N. found that considering structure in the context of niche was useful and worked independently after this. A specific illustration comes from an exchange with D.E. who was quite tentative in her observations and frustrated with her lack of knowledge about sea anemones.

Professor: "What important features can you see?"

D.E.: "It's stuck on."

Professor: "Does this give you a place to start thinking about how this organism maintains basic life functions?"

D.E.: "Perhaps" (pause)

Professor: "Try one."

D.E.: "Eating the fluffy structures have a big surface area for collecting food that passes by they could even attract food"

Professor: "Exactly - can you keep going?"

D.E.: "O.K."

Other interactions with these students illustrate that it is not a lack of ideas, but confidence in pursuing those ideas which impedes the development of their responses. At the sea water tanks J.K. carefully observed a sea cucumber produce a current of water at regular intervals. She hypothesized that this could be important for obtaining food or for excretion. With some prodding, respiration was also

identified as a possible function. Even though she had noted observations which would favour one option over another, she found herself in a dilemma, unable to choose the most likely one. She quickly concluded that she could take the process no further without consulting a text. K.A. undertook a similar observation task and, when faced with determining an organisms animal or plant nature was admittedly uncomfortable without a text to consult. She did decide in favour of animal, but clearly was not confident since the confusion continued to resurface throughout the observation period.

Besides confidence in approaching new information, in the value of reasoning and in pursuing leads, openmindedness emerges as a significant characteristic in the ability of students to think effectively. In the A.I.D.S. discussion in particular, students tend to take a narrow view of the problem, one which corresponded to their own life style. Two students who were also parents held strong views supporting reduced civil rights for HIV positive individuals. A.N. held a fairly liberal position until confronted with "What if you were a parent?" and admitted not considering all the angles. He was, however, willing to reconsider. The students who viewed the problem from a parent's perspective were not willing to consider new information or different perspectives on this issue - a lesson in the important role of perspective.

The earlier observation that students had difficulty in modifying what they believed to be true (page 125) reflects a kind of closed mindedness. The case of C.H. is a good example of entrenchment in a way of seeing that precludes attending to or considering alternatives. This student was very firm in her own personal knowledge and did not really consider alternative ideas. Furthermore, she cut off alternative suggestions on a number of occasions. The goat episode was one example, and this sequence from the class session is another.

K.I.: "There are nerve endings."

Professor: "How do you know."

K.I.: "You can sense things like heat or pain"

A.N.: "cold"

J.K.: "feel texture"

C.H.: "Pain is different from those other things they are things you feel from the outside pain comes from the inside."

A.N.: "No, they are all sensed when nerve endings are stimulated."
(several students express agreement).

C.H. has some difficulty articulating her point and switches to another trait. In about five minutes, she returns to the point.

C.H.: "I am not saying this well, but I am a nurse and I know that feeling pain is different than feeling heat or cold."

Even though she could think of no reasons why, she remained quite assertive.

When the examples illustrated in this chapter are taken together, the accumulated evidence indicates that most of these students are not aware of any system in their thinking and do not consciously monitor their thinking processes. They acknowledge readily that employing a framework of representing the problem, planning a strategy, carrying out the strategy and evaluating the outcome makes good sense, but admit that their general reaction to tasks does not include these components. Their efforts are focused on the actual production of a response, after only a superficial consideration of the task. In fact, when required to represent the task more carefully or to systematically gather relevant information, organize it and plan how it can be used, they admit the task is unusual and have some difficulty in their initial attempts. Furthermore, keeping the essential components of the task or the planned strategy in mind while a response is being generated, proved to be a challenge.

A final attitudinal consideration is whether students are consistently willing to give problems a high or low level of effort. This characteristic is difficult to judge fairly early in the course when students may be tentative about contributing, but a number of observations apply: A.N. makes an unconditional high effort in actively engaging materials as presented, and there are a number of students who are prepared to let him do this on their behalf; other students (D.D. and K.E.) participated actively when the topics interested them; a third observation was that some students (C.H. and J.K.) contributed actively when they felt confident in the knowledge base underlying the topic. Most students; however, were more passive. They responded briefly if called upon, but appeared to make a generally low effort on written and oral tasks.

IV. THE IMPLICATIONS OF THE DATA ANALYSIS

The introduction to this chapter set the task for the analysis of the initial period of observation to be:

1. to determine whether documented problem solving characteristics present themselves in students' classroom performance; and
2. to determine the relative frequency with which the traits observed occur in this group of students.

The data presented in this chapter provides evidence that many of the traits which are attributed to effective and ineffective problem solvers primarily as a result of intensive examinations of thinking protocols, also manifest themselves in classroom performance. In all categories of the heuristics framework derived using these traits, there are characteristics which were clearly recognizable in the students' performance in the classroom situation. Furthermore, most of those traits, were those associated with ineffective problem solving, and were quite consistently expressed by students in the case study group.

The strategies for thinking skill development outlined in chapter four are derived from the literature but are also well placed in terms of the early performance of this group of students. The plan includes the self-conscious management of strategies for using individual problem solving skills in the context of knowledge acquisition. The students in this group highlight the need for all three components of this approach. They admitted quite candidly that they do not "think about their thinking". They acknowledge that a conscious management of the thinking process would be useful, but it is not a habit they have acquired. The general strategy provided by the heuristics framework also appears to meet these students needs head on, drawing their attention to important phases of the problem solving process which most of them overlook: to consider more carefully the nature of the problem, to plan more carefully their solution strategies and to evaluate more carefully their outcomes.

Some of the individual skills included in the instructional strategy which have special relevance for this group are:

1. with regard to representing the problem,
 - (a) take time for careful assessment of the problem
 - (b) identify the essential components of the problem
 - (c) write the task in your own words

2. with regard to planning a strategy,
 - (a) make a general plan before you begin the task
 - (b) diagram the plan
 - (c) gather and organize on paper information relevant to the task
 - (d) recognize personal beliefs and feelings, but deal with information objectively
 - (e) recognize knowledge learned in other contexts
 - (f) recognize gaps in the information gathered
 - (g) be critical of information sources

3. with regard to carrying out the plan,
 - (a) stick to the plan
 - (b) consider all relevant information
 - (c) complete chains of reasoning
 - (d) avoid statements based on opinion
 - (e) provide evidence for each point

4. with regard to evaluating the outcome,
 - (a) take time to critically evaluate the outcome
 - (b) check for inconsistencies
 - (c) recognize gaps in information
 - (d) recognize gaps in reasoning

5. with regard to attitudes,
 - (a) show care and system in thinking
 - (b) have confidence in approaching new information and new situations
 - (c) have confidence in using reasoning as a tool and in pursuing ideas
 - (d) engage tasks actively and actively seek solutions.

By interpreting student behaviours in terms of the heuristics framework instead of expressing a general dissatisfaction with students' thinking skills, it is possible to use observations as a point from which to begin to systematically understand these more specifically defined problems. In the language of the heuristics framework, it is now possible to "subgoal in order to make the problem solvable": to systematically develop and coordinate individual skills which will contribute to the larger goal of more effective problem solving.

CHAPTER SIX: OBSERVATIONS OVER THE REMEDIATION PERIOD

I. INTRODUCTION

The second clause of the hypothesis explored in this thesis is that the explicit application of heuristics based on the characteristics of effective problem solvers is an effective strategy to enhance students' higher order thinking skills. In this chapter, some of the observations made in the course of this case study regarding this hypothesis are described. The instructional strategy derived from the literature (Chapter 4) addresses directly the remediation of problem solving skills based on the documented characteristics of problem solvers. This strategy would have faculty recognize, in terms of these characteristics, where the starting points are and then to establish as explicit goals the variation of these characteristics associated with effective problem solving. Evidence presented in Chapter 5 indicates that many characteristics of problem solvers can be recognized in the classroom situation. Furthermore, assessment of the skills of students in this group indicates a need for remediation on a number of characteristics conducive to more effective problem solving. The emphasis in this chapter is on the development of characteristics of effective problem solvers as the course progressed and observations with regard to the implementation of the strategy. The focus of the observations presented in this chapter is the remediation (as it is evidenced by the students performance on major tasks) of a number of

characteristics identified during the assessment period as typical of poor problem solvers. The first level of analysis is to determine if the general heuristics framework is reflected in their responses: have the students accurately represented the problem, used a strategy for developing a response and taken care to evaluate that response?

A more specific level of analysis examines the students' responses in terms of some of the characteristics evaluated using Table 5-1. Individual characteristics within the general framework were selected and their development was tracked throughout the course. These traits were selected on the basis that:

1. together they represent all components of the general heuristics framework;
2. they are typical of the documented strategies of poor problem solvers; and
3. they are recognizable in the classroom performance of more than half of the students.

The traits selected using these criteria are presented in Table 6-1. The tracking of the modification of these traits in the performance of individual students on the main tasks in the course becomes the framework for presenting the observations made with regard to the explicit application of heuristics as a teaching strategy.

Table 6-1

Selected Characteristics On Which Remediation Was Tracked

The General Heuristics Framework	Specific Traits Selected for Tracking Throughout the Course
Represent the Problem	<ul style="list-style-type: none"> ° Assess the problem superficially
Plan a Strategy	<ul style="list-style-type: none"> ° Do not make a plan for solution. ° Adopt a know/don't know position, do not use reasoning as a tool. ° Accept information passively.
Carry out the Plan	<ul style="list-style-type: none"> ° Distracted from solution plan by details. ° Overlook relevant information. ° Fail to carry through ideas, incomplete chains of reasoning. ° Neglect to provide evidence, use unsubstantiated opinion. ° Low, passive effort.
Evaluate the Outcome	<ul style="list-style-type: none"> ° Do not examine outcome for gaps in strategy. ° Do not examine outcome for gaps in information ° Do not examine outcome for gaps in reasoning.

II. IMPLEMENTATION OF THE INSTRUCTIONAL STRATEGY

A primary concern in the development and implementation of any instructional strategy is whether the strategy was actually implemented as planned. In this case study, implementation was monitored constantly and consultation with the professor delivering the instruction was maintained throughout the course. Although the principles underlying the strategy and the type of task to be undertaken were developed prior to the delivery of the strategy, the specific content, the rate of increasing complexity and the number of practice opportunities remained quite flexible and were selected as the course progressed and the students needs and interests became clear. The result was that the actual instructional strategy reflected very closely the plan outlined in Chapter 4. The time line outlining the progression of the course is represented in Appendix E.

III. CASE HISTORIES

Nine case histories have been developed based on an analysis of each student's written efforts supplemented with observation records of class and tutorial interactions. The traits presented in Table 6-1 constitute the framework for the development of these profiles.

A case history for each student has not been included. The cases which were selected were chosen to reflect a comprehensive representa-

tion of the variations observed in the class: in initial levels of ability, readiness to engage in the strategy, response to the strategy and the kinds of outcomes achieved. Some cases not presented here simply lack data from which reliable profiles could be assembled. Most, however, represent replications of trends and reactions already explored in the cases outlined and would not be productive to pursue in terms of developing the total picture.

The selected case histories are presented within a structure intended to facilitate the development of a comprehensible description of the range of learning and teaching experiences encountered in the implementation of this teaching strategy. They are presented in an order which first depicts the circumstances underwhich positive outcomes were achieved and continues with cases illustrating the implementation difficulties experienced. The case studies will be bridged by short comments placing them in the context of one or more of the variations identified earlier: initial levels of ability, readiness to engage in the strategy, response to the strategy and the kinds of outcomes achieved. These comments are intended to focus the readers attention on specific aspects of the students' performance contained in a complex data base, rather than to restrict thinking on the multiple facets presented.

Case History # 1 (A.N.)

Most simply put, A.N.'s profile represents that of a good student who became more effective in terms of manifesting higher order thinking skills over the course of the case study. He entered the course able to use individual cognitive skills and his broad knowledge base, but only when cued to do so and usually within a narrow perspective on a problem. He lacked self-management of his skills and knowledge early in the course, but actively participated in the development and use of heuristics, achieving effective, independent use of process strategies.

Assessment Period Summary

Primary among the characteristics of this student is that he consistently expends a high effort, engaging actively on any content and attempting any level requested. He exhibited a wide knowledge base and dealt effectively with new information at a memory and recall level. He did not independently see when this knowledge was relevant or use it effectively in new situations but could apply it effectively when encouraged by appropriate questioning. In the A.I.D.S. discussion A.N. was observed to recognize information which was relevant to his own position, but not other sources. In a small group discussion he admits not carefully considering what the problem or issue is or planning a solution strategy, but reacting with an immediate response. During the structure and function exercises he was able to generate more than one

idea and gained confidence in reasoning his way to a choice. A.N. arrived with motivation and many individual skills but with no conscious self-management strategy - he manifested his knowledge and skills when appropriately cued, but required development in this management.

Development Profile

Following the genetics video, A.N. backed off the highly emotional discussion but contributed to building the strategy for handling such topics in future. In his term assignment he defined the problem well, used the strategy developed and rationalized an individual decision. Significant in these developments is the attention to strategy and an expanded perspective on the problem.

On his mid-term exam (Appendix D), A.N. followed a life function strategy on the structure and function question. Although not all points were covered, he did provide reasoned links to function for the structures discussed, illustrating some points with diagrams. His response followed suggestions made after the term assignment. On the genetic theory question he presented comprehensive and well organized information. On the question which evaluated ability to identify, within a framework, information relevant to a problem, he covered major areas in his outline but did not pursue lines of questioning in the areas identified. He did not show evidence of reasoning through the information which would be useful in each area. On the social issues

problem he met all of the required criteria: identify the issue, cite scientific information and its consequences, integrate it in the social context and provide a reasoned position.

His literature reviews also reflect a growing awareness of strategy and application of feedback information. His first effort was characterized by an inappropriate degree of difficulty (meeting A.N.'s notion of what constituted "scientific") and he could provide only some description of its information. The second choice was more appropriate and his presentation reflected a good command of information with some non-text elaboration. His next topic was more complex but he related information well to class discussions. He was thinking about the content but not evaluating it critically at this point. His final effort reflected some evaluation of organization and conclusions in addition to comprehension of information.

During the tasks on evolution content, A.N. showed good insight into content, identifying the essence of the arguments. He considered not only the organization of the opinion based paper, but the consequences of accepting this style without question. He contributed extra sources on creationism and had given careful thought to the issue, having engaged a creationist roommate in discussion. His book report on this content illustrated the strategy developed in class and A.N. met all of the criteria adequately: identify the issue, evaluate the information, organization and style of the argument and identify and

evaluate the conclusions.

In his group's science and society project, A.N. assumed the much needed role of co-ordinator. He engineered not only much of the information gathering but made explicit efforts to keep strategy on track. In his own efforts he used varied sources and integrated them to form his own position. Of his group, he was the only student to venture into the "I think" mode as opposed to quoting expert information. A.N. was able to break out of a reliance on direct sources of information and develop a well reasoned presentation.

On his final exam (Appendix D), A.N.'s best effort was in comparing his own knowledge of Darwinian theory with a quoted explanation of the evolution of the A.I.D.S. virus. He recognized the inconsistencies and used his own knowledge to develop evidence for the points he made. On the video exerpt, he identified the issue clearly and was able to develop a conclusion supported by evidence. He evaluated the argument in terms of content, much less so in terms of style and did not evaluate its organization. The socio-scientific problem illustrated a clear definition of the problem and adequate identification of relevant scientific information. The consideration of social context and following through to a solution was; however, weakly pursued. Despite a willingness to engage actively the content and process components of all tasks assigned over the course of the case study, A.N. tends to retreat somewhat to the security of information

from external sources, rather than having confidence in his own reasoning from that information when placed in an examination situation.

Some observations on his examination responses excepted, A.N. has been observed to show significant progress in his mindfulness of the thinking process. In tasks like his book report and the science and society project he indicated that he could independently recognize conditions under which a strategy was useful and co-ordinate his skills using that strategy to effect a solution.

Case History # 2 (H.E.)

Like A.N., H.E. entered the course with good individual cognitive skills but lacked an awareness of the thinking process and self-management of those skills. Unlike A.N., however, she did not have a strong knowledge base. Despite a high effort on the process components of most tasks, H.E. was slow to gain confidence in her reasoning. The impact of this lack of confidence is illustrated in her reluctance to depend on the reasoning skills she exhibited in class sessions when marks were at stake.

Assessment Period Summary

During the assessment period H.E. showed characteristics identifying her potential. When provided with a framework she clearly

articulated a structure and function strategy in her own words. She carefully gathered and recorded her observations at the sea water tanks. During the observation period she became stuck in her first track of thinking (feeding) and even with encouraging questioning she had great difficulty in breaking into alternative hypotheses. H.E. had assessed the nature of the structure and function task accurately ("the encyclopedia wasn't helpful") but underestimated her abilities to think and make inferences, failing to develop reasons for structure and function relationships even though she articulated this criterion in defining the task. H.E. had individual skills but she was not conscious of them, or their management.

Development Profile

In response to the genetic screening video, H.E. enters the discussion by clarifying the issue and interjecting points missed, but backs out of the discussion as it becomes less rational. She did not actively contribute to building a strategy for dealing rationally with such issues in future but quietly led her group in the first application of the strategy. In her genetics assignment she chose a novel and controversial topic, used the strategy effectively and produced a credible result.

On her mid-term exam, her structure and function response indicates that she followed the strategy developed in class and outlined

her information and ideas before launching a response. She began well but tapered off quickly on providing reasons why and overlooked points gathered in the planning process. This reflects a loss of attention to process over the course of the response. Her response to the genetics theory question answered the question posed and provided the required information. H.E. had a unique and telling approach to gathering relevant information in preparing the response to the third question, which called on students to identify relevant information. She systematically developed lines of questioning showing a chain of reasoning and interaction of information and then assigned the questions to likely sources in her formal response. In her social issue response her use of the strategy developed in class was clear but she lacked accuracy in some scientific information and left her reasons for her position somewhat underdeveloped. H.E. has clearly understood the focus on strategy and has attempted to employ it in her exam. Her attention to process sometimes wanes over the course of the response, reflecting the need for further practice and evaluation in terms of strategy. She has, however, gained confidence in strategy and is more conscious of managing her skills.

Her literature presentations began with a coherent description of the content of the article and, when encouraged, some elaboration. In her first effort only one idea was well developed. In a second attempt she volunteered information with some elaboration and when encouraged, offered comments on the validity of the article. H.E. provided one of

the stronger final efforts in identifying the issue, analyzing the argument and the conclusions of her article.

During the development of the evaluation H.E. showed good analytical skills. In the comparing the contrasting papers, she identified the issue, saw gaps in both information and reasoning and could find the essence of the argument. On the discussion of the video H.E. shows several skills, identifying: claims without evidence, assumptions made in making generalizations and information that could serve as evidence.

She continues to build strategy and, in this task, acknowledged the strength of meeting objections head on with counterevidence. She continued to show a reticence to give her own reasoned position at this stage, often claiming a need for further information. In her book report she followed the strategy developed and met all criteria adequately with the exception of evaluating style.

On her science and society project, H.E. reported expert thinking and opinions as evidence, apparently on a one source at a time basis for a result that did not seem well integrated. She provided evidence but did not use the evidence to generate a solution.

Her final exam responses reflect a good command of relevant information in each question. On the analysis of the video excerpt she

identifies major points on the development of the argument but does not give evidence for the points she raised. Her response to the socio-scientific problem was dominated by technical information but that information was not fully integrated into a strategy for solution.

H.E. clearly understood the strategy being pursued. She commented "I wish more people in the education system placed emphasis where you do [on process]". She benefitted from being exposed to the strategy in that she gained in her awareness of the thinking process and acquired a system to "think about the thinking" underlying the products of others. Although she appears to be more confident in process in class discussions, her exams and the science and society project reflect a reluctance to depend on those skills when grades are at stake.

Case History # 3 (C.H.)

The profile of C.H. illustrates the difficulties that a student with a strong knowledge base can experience in developing process skills. C.H. showed a great deal of confidence in her strong knowledge base and engaged actively on content. Although she steadfastly resisted attention to process throughout most of the first term the strategy did eventually become meaningful to her and she acquired it quickly and used it well.

Assessment Period Summary

From the beginning, C.H. was a frequent contributor. She had a strong and varied knowledge base and strongly held views, but she typically cited pieces of information or referred to her experience for credibility, rather than providing reasoned explanations. All of her early activities were strong on information, but in a way distinctly different than other students illustrating this characteristic. The strength of her confidence in her own knowledge actually hampered her efforts to consider alternative ideas or suggestions made by other students and to see new things in structure and function. By her own admission, she did not consider the criteria to be met in a response, solution strategy or the reasonableness of the outcome. She relied on authority, not reasoning, for her confidence and was openly uncomfortable with the reasoning strategy being pursued. She showed good fluency of ideas but, as a rule, did not develop, test or justify those ideas.

Development Profile

In the discussion of the genetic screening video, C.H. contributed points mainly in the moral and ethical context and the heated tone of the discussion did not deter her participation. She did not contribute actively to developing a strategy for dealing with such issues, expressing frustration at not knowing what the requirements for

that kind of task were. In the first opportunity to apply the strategy in a group of five, C.H. forms a closed group with another student who had available information and ignored the others. She had not seen the point of strategy and still only valued the information component of the task. After several rounds of practice and feedback; however, her term assignment showed a shift from her original position: she explicitly followed the strategy, touching on all criteria and developing reasoned evidence on one issue in particular.

Despite some degree of heuristics use on her genetics assignment, her mid-term exam responses were clearly information oriented. On structure and function, the significance of major structures was noted, but not elaborated, placed in context or supported by evidence. The genetics theory question contained facts but did not really describe the event as requested. In working with a framework to identify relevant information, C.H. could identify appropriate kinds of knowledge and her outline reflects a chain of reasoning, one question leading to another. In the social issue problem she did not utilize the strategy developed and used in her genetics assignment and focused primarily on scientific information. She had not been convinced of the value of either the thinking strategy or reasoning and remained secure in information.

C.H. attended two literature presentations. In the first she showed some elaboration and was able to detect ambiguity. In her second presentation (the last) she was functioning well on the analysis

framework: identify and focus on the issue, evaluate the argument on content, organization and style and evaluate the outcome.

As she described it, C.H. "couldn't get into" evolution, a difficulty perhaps attributable to her frequent references to religious affiliation. She did not actively engage in discussion on this topic, stating that it "just wasn't that important to [her]". It could also be that she was guarding her developing confidence with the reasoning strategy. On the comparison of two contrasting papers she had difficulty focusing on the issue, wanting instead to get to the main body of the task. She was much more effective on that evaluation task and could sift out the essence of the argument well. She was indifferent to the discussion of the video tape on evolution although in her notes she had shown clear use of the strategy developed in class, assigning information within a grid sketched in her notes. In her book report she uses the strategy effectively, meeting all criteria.

An aside, but a benchmark in the course, was her compliment to D.D.'s abilities at this point. She had viewed D.D. as quite outrageous early in the course, but C.H. had come to appreciate the different perspective she represented as she opened up her thinking.

During the presentation of their science and society presentation C.H. suggested that using the strategy developed following the genetics discussion would be useful - her first independent recognition of the

usefulness of strategy and its self-conscious use. As a group, they followed the strategy effectively. C.H. could not, however, resist the temptation to cite her expertise in theology to lend credibility to her presentation of moral and ethical considerations of their issue, and she could not break out of a mainstream Christian emphasis.

C.H. explicitly used strategies developed in the course throughout her final exam. As to be expected, she experienced no difficulties with the straightforward application of knowledge in the first question. She fulfilled the problem criteria well on the video excerpt, excepting a somewhat limited development of the content of the argument. In her response to the science and society problem she outlines and utilizes strategy well. Specific questions show a train of thought developing each facet of the problem. She wavered only at the very last step - making a reasoned decision but one which may not please all parties. This difficulty likely reflects a lack of confidence in a relatively new found strategy when being evaluated. The attention to strategy in her responses suggests that she evaluated her results by these criteria, a component of the heuristics framework to which most students had not progressed.

These final exam results reflect quite a come around for a student whose confidence in content at first excluded any active consideration of process. She explained her own reaction best as she looked back over the course: " I like to be in control (of

challenges being presented) and was really uncomfortable not having direct answers but then I realized - hey - I am getting some skills here". It was at this point that she began to actively engage on the process strategy. She proceeded very cautiously, guarding any cracks in her confidence, but in the end was very aware of her progress and pleased with the results.

Case History # 4 (J.K.)

Students who had less confidence in their knowledge base were more typical of the students in this case study. There were a number of students, including J.K. who, from the outset of the course, indicated an ability to learn information for recall and comprehension but had difficulty in applying or reasoning with that information. J.K.'s profile shows one path of development from that point.

Assessment Period Summary

J.K.'s early efforts reflected an ability to deal effectively with comprehending new information and she made a consistent, conscientious effort to acquire new knowledge for recall level use. She showed a good understanding of the A.I.D.S. material and volunteered information from the articles in response to questions. She experienced difficulty, however, when asked to develop ideas from an information base or accumulate evidence to support an idea. Early in the structure

and function observations at the sea water tanks, J.K. could generate alternate ideas but found herself in quite a dilemma when asked to develop evidence to select the most likely alternative. Even with questioning, she was unable to move forward. She admitted no habit of attention to process but actively contributed to building a process strategy. She quickly acquired an understanding of the strategy developed in class to address these difficulties and used it effectively in her term assignment which featured not only clear strategy but much more tenacity in her reasoning. In class discussions, however, she still frequently reached into knowledge sources for the piece of information which would directly satisfy the question posed. Even when given a common sense approach to molecular structure from which she could have reached a solution, her strategy was to search through knowledge from first year chemistry. She did show greater confidence in reasoning from content on which she felt confident, as illustrated in her first literature presentation where she related well to the topic, elaborating on and evaluating the content.

Development Profile

J.K. was very quick to realize the process component of the instructional strategy and she engaged well on all tasks assigned. By the beginning of the genetics content, J.K. had reached a turning point regarding a know/don't know attitude to knowledge and ceased to rely solely on recall of existing knowledge as a strategy to answer

questions. During the development of genetics content she recognized gaps in her knowledge and asked questions which reflected thought beyond the information given.

She was openly disturbed by the nature of the genetic screening discussion, characterizing it as "too personal" and not a "reasoned discussion of ideas". Subsequently, she contributed heavily to developing a strategy for rationally dealing with topics. She used the strategy in her genetics term assignment, assessing the problem well but not developing fully the application of the strategy. She chose a non-class topic (which reflected confidence) and consequently was not quite clear on the scientific information. She outlined the symptoms and their social consequences well, but did not integrate all of the sources of information as a whole.

Her mid-term exam responses show progress in confidence and process. On the structure and function question she had a clear idea of what the problem entailed and gathered observations and some ideas in outline before beginning her formal response. She missed some observations but systematically developed those she covered. On the genetics theory question she showed a good command of the information and was well organized in her presentation. In using a framework to identify relevant information, J.K. indicated a good sense of the kinds of information which would be relevant, but did not develop lines of reasoning in her questions. On the social issues problem she provided a

good argument including scientific and social components.

In her literature presentations, J.K. made a strong first effort on a content area meaningful to her. She was comfortable with the information, elaborated from the text and judged its credibility, giving reasons for her conclusions. On her second effort she showed effective communication of information, some elaboration and little evaluation. On her third effort, J.K. related information well and volunteered an evaluation of the credibility of claims made in the article. These observations clearly illustrate a trend noticed in several students: confidence in the content area facilitates processing of information at higher levels. J.K. made a much weaker second effort when the subject matter is not as familiar or as meaningful, but eventually recovered some of the process skills with less familiar content as the course progressed.

During the development of the evolution content, J.K. worked effectively in the comparison of the two contrasting articles. She could identify the issue clearly when others in her tutorial group were having difficulty focusing. She spotted bias and the essential premises of the argument. In the discussion of the evolution video, she identified the issue, contributed to clarification of evidence and setting requirements for credibility. She was able and felt it was important to cite several coinciding sources of data and supported the use of a two sided argument for credibility, stating that "a two sided

argument would be favoured by educated people" but that "uneducated [unable to develop their own lines of thinking] people would prefer a single strong opinion". Her book report met all of the criteria established in the strategy developed.

In her science and society project, J.K. opted for a highly informational component of the project, slipping back into the security of firm information. She expended a high effort on getting that information from various sources however, and was effective in defining the group's problem to make it manageable and keeping discussions on track.

On her final exam, J.K. reflected a good command of the required information and how it applied. Her analysis of the video excerpt included an identification of the issue, comments on the use of information, development and style in the argument and a personal conclusion. She touched all of the points in the strategy but did not always support them well with evidence from the video, making general statements instead. The application of Darwinian theory problem gave J.K. some trouble. Her response indicates that she had the necessary information but had not assessed the information provided in the problem. In the science and society problem, she utilized both strategy and information effectively. She identified a variety of relevant sources of information and developed them well in generating a solution.

J.K. came to the course quite willing to engage actively on content and quickly realized and accommodated equally the process component of the course. Her efforts showed a conscious use of strategy and that she had made some evaluation that these criteria were met. As with other students, however, in situations where the information load was heavy, she was more likely to lose sight of strategy. Confidence in both content and process was an important variable in this student's performance. She carefully sought clarification of both content and process for assigned tasks in class and subsequently made strong responses on both fronts. In the exam situation, she tended to be more tentative. These observations relate to transfer of content and process to new situations as well, but J.K.'s consistent concern with clarifying expectations for exam and assignment questions also implicates confidence as an important factor in these situations.

Case History # 5 (T.A.)

Not all students who showed an ability to deal with information at the recall and comprehension level early in the course followed J.K.'s development pattern. The case history of T.A. illustrates clearly some of the factors which can limit the development of thinking skills: the amount and complexity of content, the number of practice opportunities and self-confidence in the reasoning process.

Assessment Period Summary

T.A. showed clearly an ability to learn content for recall and direct application. She was able to provide A.I.D.S. information in response to direct questions, was stronger on the direct information component of structure and function - noting structure, and could communicate the information contained in her early literature choices. However, it is also clear that in all three areas she accepted information passively. New information on A.I.D.S. did not shape her response to the problem and she continued to react on an emotive level. In structure and function tasks, she made adequate observations but tended to state related functions as fact, offering or seeking little evidence. In early literature presentations she could not follow through on more than half of the ideas raised.

The pattern which emerged is one of comprehension of problems at a superficial level, a good effort on direct recall of information, but difficulty in integrating, elaborating or using the information to develop a reasoned position and no conscious plan to facilitate the level at which the information can be used.

Development Profile

T.A. was present for the discussion of the genetics video and the strategy building which followed but did not contribute her comments.

In the genetics term assignment she chose a topic developed in class, reflecting either low effort or a lack of confidence in tackling new information. She followed the strategy developed in class and provided information on the nature, cause and treatment, but was weaker when a strategy of providing individual pieces of information is not as effective: setting the social context and developing a personal decision. She has become aware of the heuristics framework but has difficulty in carrying it through.

Her mid-term exam responses continued to reflect some of the difficulties identified earlier, but did indicate some positive trends. The structure and function response indicated an obvious framework for observation, a systematic assignment of function but underdeveloped reasons supporting these connections. On the genetics information question, she did not answer the question posed, reflecting an inadequate consideration of the problem. A third exercise evaluated the students' ability to identify information relevant to a problem, given a general framework. Her response reflected a good sense of what information to seek, but specific questions became weaker on social aspects when direct information was less likely to apply. The final question gave students an opportunity to apply this same strategy to a new problem. T.A. did not make the leap. Her response was not systematic but jumped around on emotion and opinion. She did not use scientific information to shape her response, but let opinions on social perspectives stand alone. This synopsis indicates an inconsistent

approach to carefully assessing a problem before responding; some attention to strategy in structure and function; an ability to recognize and work with directly applied information, but an inability to independently recognize situations in which the framework applies.

Early literature presentations showed a good command of the informational component. She could relate and explain direct information and asked questions which reflected a recognition of gaps in information. When led, T.A. could develop about one-half of the ideas introduced, but did not independently operate at this level in her presentations. Later presentations (November and January) demonstrated more thought on validity and credibility and better definition of the issue, but the focus on information, rather than how it was used, persisted.

In contrast, her analysis of two contrasting papers on evolution was strong on assessing style and development and she articulated well the role of a reasoned presentation in developing strong and credible conclusions. The framework utilized in this analysis was evident in her book report, where she took care in looking at style and why it was effective and adequately met criteria for analysis, possibly reflecting an evaluation of her response in these terms.

The science and society project gave T.A. an opportunity to slip back into her comfort zone: direct application of knowledge. She

assumed responsibility for technical information. It was well researched, well organized in its presentation but was presented for its value as information and not integrated into a proposed solution.

The final exam responses indicate less attention to the process strategy than some of the later, more explicitly encouraged efforts, such as the book report. On the direct application of information question she assessed the problem accurately, had command of the required knowledge and could apply it appropriately. In response to the video excerpt she could identify the issue, but tended to describe rather than weigh the argument. On the evolution question she clearly has the required knowledge base, but fails to detect the inconsistencies between it and the representation provided. On the socio-scientific problem she jumps quickly to a solution without examining the source of the problem or the kinds of information which would be relevant.

This student was not unaware of the strategy undertaken. She commented that the approach "encouraged students to develop their thinking pattern and have their own opinions approach issues openmindedly and think things through logically". Her difficulty seems to be in conscious use of the strategy in all situations. On the later literature presentations and working with the literature on evolution, explicit and successful use of the strategy was quite evident. In situations where larger amounts of content are involved and independent application of the strategy is required, (e.g., exams) the limited

resource of attention is focused on content. Although her attention to carefully assessing the problem has progressively improved the whole strategy has not been internalized to the point where it forms the guidelines for monitoring and facilitating thinking in all circumstances. In situations where the content demands are lower however, T.A. can maintain attention on thinking strategy and the content to be operated on. She has understood the strategies, can apply them in moderately complex ways but has not had sufficient experiences to apply the strategy consistently in different content rich situations.

Case History # 6 (D.D.)

In contrast to students who base their thinking in directly recalled or available information, the basis for D.D.'s early responses was in personal experiences and feelings about issues. The evolution of a more rational posture towards issues and problems is described in the following case history.

Assessment Period Summary

From the outset, D.D. contributed readily to requests for information and contributions to discussions. She worked well with direct information (e.g., A.I.D.S. and early literature presentations) and could identify and contribute ideas inherent in that information. She did not overtly carry through these ideas or develop consequences

and, even when led, had difficulty with developing ideas into a reasoned position. In discussions, she was more likely to use examples of personal experiences or feelings than to utilize information shown to be known to her. There were clear difficulties with using learned information to elaborate existing knowledge, support opinions or in novel situations. D.D. recognized the components of the structure and function task and used the strategy developed quite explicitly, at this point somewhat awkwardly, leaving ideas underdeveloped.

Development Profile

D.D. was one of the first students to rein in a highly charged discussion on genetic screening, identifying her own first reaction as an illustration of the difficulties the class was having with "rational versus irrational reaction". In doing so, she helped set the stage for developing a strategy for rational development of an argument on such topics to which she contributed well. She followed the strategy closely in her term assignment and, although there were some gaps in her scientific information, she provided adequate descriptions of symptoms and treatment, stressed the importance of social context and developing a well founded personal opinion. In doing so, she had broken out of some of her earlier difficulties.

Her mid-term exam showed clearly the use of the general heuristics framework in that each problem and its relevant information

were outlined prior to launching a formal response. Generally speaking, the elaboration and building evidence aspect - reasoning with the information - was more weakly pursued. To illustrate these points, her information question was outlined in advance, comprehensive and well organized. The structure and function response followed a clear strategy but, because one function was overlooked, a whole block of information was not recognized, and reasoning links between structure and function showed gaps. The outline of information to be plugged into the framework touches important kinds of information but there could have been more detailed development of the relevant questions, reasoning from this outline. D.D. showed some difficulty in transferring strategy from the genetic disorder assignments to the exam context but was the student who contributed most actively to developing the problem in this context during the exam review session, indicating her recognition of new and broader applications of the strategy.

The literature presentations were recurring exercises and, in this case illustrate skill development over time. The first presentation was characterized by a good direct communication of the information contained in the article but great difficulty with developing ideas or considering consequences, even when encouraged with questioning. The next effort was also strong on information, but featured more elaboration, alternative examples of applications, and some development of ideas. The third effort introduced evaluating the "scare" value in debate, was more critical and showed expanded

elaboration. In the final effort in this series she had fully incorporated the strategy progressively developed in anticipation of the book report: identify the issue, use it as a focus, evaluate the argument for information, organization and style and identify and evaluate the conclusions.

The development of an understanding of the concepts of evolution included a number of pertinent activities. D.D. attended regularly and received all of the strategy development. In the comparison of two contrasting articles, she (and her tutorial group) had difficulty focusing on the issue, preferring to dive immediately into the analysis of the articles. Nevertheless, she compared the article styles to an earlier debate on genetic screening and established as desirable to develop the argument in the "educated . . . scientific" way and not to be "emotional and irrational" in their approach.

In the discussion of the evolution video, it is D.D. who points out that the framework was not fulfilled in the first session and suggests completion. With several others, she could identify pivotal points in the argument and reacts negatively to unsubstantiated fact. This conscious use of the framework extended into her book report where it was used explicitly and the criteria were adequately met, suggesting some evaluation against these standards.

The topic for their class presentation was personally significant to D.D. She showed a high effort, being nominated to chair the tutorial group's development of the topic and to moderate the class presentation. Later in the development phase, she showed an ability to focus information and keep the discussion on track and checked for adequate evidence for points to be covered.

Her final exam reflects effective representation of the tasks presented and outlines which show organization of information and some strategy development before launching a response. Her application of information in the first question was comprehensive and organized. In the third question she picked up the inconsistencies between the script presented and Darwinian theory. When she considered the video excerpt the strategy was clearly used as a framework but her response was not strong on evaluating the argument. On the socio-scientific problems she recognizes the problem, identifies the necessary information and how to get it but is not clear on how to proceed further to attain a solution. This final exam performance points to two hurdles in the strategy: slipping back into the security of external sources of information in an exam situation and the amount of content that must be processed while pursuing the strategy.

D.D. has clearly understood the cognitive goals of the strategy and made efforts to understand, try out and integrate in her thinking processes the strategies suggested. Her comments on "the educated . .

. . scientific" way of rational argument and her assessment that the course was "excellent in educating the citizen on evaluating issues " are supported by observations of her skill development over the course of the case study.

Case History # 7 (J.E.)

In contrast to D.D., who quickly recognized the shortcomings of an emotional approach to issues, J.E. experienced much more difficulty in breaking out of this approach. This case history illustrates that one of the major differences between these two students is the level of effort they are willing to expend to consider process and develop process skills.

Assessment Period Summary

From the outset, J.E. showed a definite orientation to passively receiving information. She actively sought clarification and further relevant information but withdrew quickly if asked for meaning or reasons. She prefers challenges to her knowledge to be based on recall or straight forward application. J.E. resisted considering process, and did not contribute to discussions of strategies developed for representing the problem clearly, planning a strategy or tactics for effective observations. Neither did she make any effort to note this information. In fact, in her sea water tank observations and in the

mouse tutorial she denied that a conscious strategy would facilitate her efforts. She was firmly committed to the value of authoritative sources of information, to the exclusion of other means. Even in the hand exercise, a simple application of structure and function, she quoted "They said" in discussion. When other students alluded to strategy in their term assignment, she somewhat facetiously described her strategy as "hanging out and picking the brains of the majors". She seized every opportunity to seek direct answers to questions raised or assigned and expressed frustration at not receiving direct answers to questions designed to provoke independent reasoning. She dealt superficially with tasks and avoided deep or sustained efforts, and consequently was left feeling that some tasks were boring or trivial.

Development Profile

In the discussion of the genetic screening video, J.E. spoke from her experiences with handicapped children and participated fully, including the parts of that discussion most heavily laden with unsubstantiated opinions. She was present, although she did not contribute actively, for the development of a strategy for dealing with such issues more effectively. Her genetics assignment topic was of particular interest to her and she showed careful research into information regarding symptoms, development and detection of carriers. Components of the assignment requiring understanding (inheritance) or independent reasoning (social context and personal positions) were much

less well developed.

J.E. was excused from writing the mid-term exam.

J.E. participated in two literature presentations. Although in the first instance her choice was based on a personal acquaintance with the topic her approach remained superficial, outlining the gist of the information contained in the article, with two references to her own example. In her later attempt she accepted and communicated the information component of the article effectively, but did not evaluate the perspective of the article which was, to other students, positively biased.

J.E. openly admitted feeling threatened by the development of evolution content, saying that it challenged her fundamental belief in God and all of the values associated with that belief. She could not separate these feelings from any discussion of the content being presented. In the comparison of two contrasting articles the focus of the discussion was on strategy rather than content and J.E. contributed freely in the tutorial session. She had difficulty focusing on the issue being pursued and was fixated on the contrasting styles. Still reflecting a reliance on authoritative sources, she was skeptical of scientific theory which was not really fact, but "only an interpretation of incomplete information". Further denigrating the value of reasoning, she defends the editorial, opinion based style of the article under

attack by claiming "facts don't explain anything to me it's how I feel about something that's important".

J.E. did not attend the evolution video presentation or contribute to a discussion on the validity of the claims being made. For her book report, she undertook to examine "the validity of the meaning extracted from [Genesis]" but the rambling discourse which followed did not focus on this task. She showed no attention to strategy or organization of relevant information. She admitted quite candidly that her book report reflected a low level of effort.

J.E.'s pattern of thinking only in terms of personal experiences and feelings about issues rather than also incorporating objective consideration of relevant information proved to provide a needed dimension to her group's final preparations for their science and society presentation. The group had become overburdened with the information they had collected, and needed a focus to develop their presentation further. J.E. suggested using some of the information to develop a solution to a hypothetical case. Unfortunately, J.E.'s motivation was that "it is easier for me" but other, more information bound students benefitted from this new perspective, identified a focus and applied the strategy developed in class. Her perspective is not inappropriate, but it is much too narrow, limited primarily by the effort she was willing to expend.

In her final exam, J.E. identified the nature of the first question accurately and made an adequate direct application of information. In her analysis of the video exerpt, J.E. uses the framework provided in the task in preparing an outline, but she slips out of the strategy as she begins her formal response. She enters into a telling discourse which makes some good points, but in the context of favouring "better, more factual answers" over logical arguments", persisting in her reliance on authoritative sources rather than judging reasonableness. On the question on Dawinian theory, J.E. does not compare the two interpretations effectively, missing the nature of the task. On the science and society question, she does identify the kinds of information that would be relevant, as they were outlined in the framework developed in class.

Unfortunately, a profile of the responses of J.E. illustrates a number of characteristics which impede the development of thinking skills. A low level of effort is primary among these. A strong reliance on information from authoritative sources, coupled with a failure to recognize the value of reasoning in developing and expanding knowledge, was very difficult to break through and persisted even in her final exam responses: she valued much more a statement that said it was so, than a well reasoned argument supporting the best conclusion. Despite explicit recognition of the emotional component in complex issues and the need to both consider this component, and keep it separated from other kinds of input, J.E. maintained an almost exclusive

socio-emotional perspective on issues raised. Experiences with this student indicate how formidable these hurdles can be.

Case History # 8 (D.H.)

Low effort and the tendency for personal feelings and beliefs to dominate responses are characteristics of ineffective problem solvers which inhibit the development of effective problem solving skills but there are others. Also evidenced in previous case studies were problems arising when students are fixed on authoritative sources of information. They tend to be passive toward these sources and depend on them as their only source of knowing. A particularly difficult case in this respect is illustrated in the case history of D.H.

Assessment Period Summary

D.H. was a regular class session attender but attended only one tutorial session during this period and did not make either of two literature presentations. She was reticent to contribute during class sessions or consult with faculty or other students on the structure and function activities. She did make comprehensive notes, but only on the content component of the class. There were quite distinct pauses in note taking during the development of strategy. It appeared that her orientation was to passively receive content as an end in

itself, an observation further evidenced in her structure and function assignment which reflected a statement of fact emphasis and lacked reasoned connections. At the end of this period she showed no indication that she was open to considering process and maintained a narrow focus on the content relevant to a task.

Development Profile

D.H. was present for the development of strategy for dealing with biological content in a social context but did not actively contribute to its development. She did use the criteria indicated in the framework in developing her genetics assignment. Her response was characterized by being written on a class example; strong on informational components like cause, risk, symptoms and treatments; slightly weaker on understanding scientific information; and much weaker in applying this content to developing the social content and a personal position. Her efforts reflect a more explicit manifestation of characteristics appearing more subtly earlier. She could identify and gather the relevant information for direct use but either had not identified further development as an essential component of the problem or was unable to develop the information, integrate several kinds of information or reason from that information.

The mid-term exam results demonstrated that D.H. was representing the problems adequately but that there continued to be a general, but not consistent, difficulty with developing information past the recall stage. On the structure and function question she did develop reasoning on three of five major structures but did not work the development of the other questions equally hard. On the genetics questions she left the information bare, although she indicated a better command of the knowledge than was illustrated in her response. On identifying relevant information, the questions on medical intervention and social support show shallow thinking with no systematic chain of reasoning from one question to the next. On the final question the problem was clearly defined, some information was used appropriately but inadequately, in that statements were left standing alone and she made weak claims. Together these responses indicate an ability to accurately represent a problem and to identify relevant information. Her responses indicate a stab at the general strategies discussed, but difficulties arise when information cannot be directly applied. There is little evidence that D.H. actively engages information to elaborate, integrate or provide evidence for points being made.

He book report shows the first strong illustration of a conscious application of strategy. She clearly identifies the issue, describes the arguments well, evaluates the organization and in a more implicit way, the vocabulary and style of the book. Comments on the argument are stated as facts, however, without reference to if or why they were

effective. That "it is", and not that "it is because it makes good sense", remains the focus.

In her tutorial group's efforts on a science and society issue, D.H. was a leader finding and sharing relevant information. This co-operation reflects much more confidence in communicating scientific information than previously shown by her conspicuous silence at every opportunity. Her presentation was still information bound but was noticeably improved in linking information together to reflect an understanding of the whole.

The final exam results continue to reflect the pattern of performance already established. On the first question requiring the direct application of information, D.H. recognizes the issue but is not systematic in her approach, thinks at a superficial level, omitting specifics, and overlooks relevant information. On the video excerpt she could identify the issue but relied on the authority of the commentator for credibility even though she conceded that he was "an authority, (on what I am not sure)". In drawing conclusions, she did experience the comparison being drawn, but the perceived expertise of the speaker remains influential in her conclusion. In the evolution question D.H. did not actively compare her own knowledge with the position stated, accepting the information and not detecting the inconsistencies. On the socio-scientific problem the strategy was focused on gathering the relevant information but was weaker on its use in the social context.

D.H. represents just how difficult it can be to engage a student in the process of thinking. A student firmly entrenched in the memory and recall of knowledge, she gave a very low effort to attending to, understanding or practicing the strategies encouraged throughout the course. Although there was some development from individual pieces of information to linking information into a comprehensive whole, evidence of active use of knowledge to develop a reasoned position in a new situation was not presented.

Case History # 9 (K.A.)

Although varying in degree, perhaps the most pervasive limiting characteristic illustrated in these case studies is confidence. To some extent, a lack of confidence has affected each student in the class. Some students have overcome this hurdle, others have gained some confidence but require further reinforcing experiences. There is one case in particular which illustrates the degree of difficulty which can be created when the lack of confidence characteristic of ineffective problem solvers dominates the learning process. Even in this extreme case, however, the teaching strategy undertaken to address the gap between effective and ineffective problem solvers appears to have helped the student gain some ground.

Assessment Period Summary

K.A. acknowledged a lack of self-confidence at the outset of the course and this characteristic dominated her thinking. She showed a strong reliance on text book information and had great difficulty in venturing beyond that strategy. Her hand assignment came directly from a textbook and she specifically requested a text to end her troubles in working out structure and function at the sea water tanks. She was firmly entrenched at the learn-recall level and expressed apprehension when asked questions not directly answerable from available information. K.A. was not incapable of reasoning her way through a problem when encouraged by a series of questions. The problem then became that she had little confidence in the outcome and experienced confusion on the arrived conclusion. This extreme lack of confidence threatened to impede any strategy aimed at the development of thinking skills.

Development Profile

Observation and written specimen data for this case was erratic throughout the case study. K.A. attended class sessions intermittently and contributed only several times over a period of weeks. She consistently avoided tutorial sessions where she would be called on until late in the first term and did not complete her genetics term assignment. Some of these difficulties were contributed to by a heavy employment obligations, but she admitted that the tutorial absenteeism

was by choice.

K.A. was present for the genetics video and the strategy building session which followed but did not actively contribute to either. Without a genetics assignment or observation data it was impossible to determine any effect.

K.A. did attend a literature presentation late in the first term marking a turning point in her confidence level and her performance in the course. In this presentation, she communicated the information in the article effectively and, using the example in the article, made an excellent point that, given the history of such issues, presently controversial issues (using class examples) were apt to become widely accepted in time.

Her responses on the mid-term exam regress somewhat from this literature presentation. She did illustrate an observation framework, but the depth of observation was shallow. She made stabs at function but provided no well developed reasons for the suggested functions. On genetic theory, K.A. did not appear to have identified the essential components of the question posed. Her use of the framework to identify relevant information was adequate for more direct information (scientific, medical) but weak on social issues which were more complex and common-sense based. Her response to the social issue problem was characterized by misinformation and a failure to acknowledge the

importance of the social context. The exam placed K.A. in a position where she had only her own resources to work with and although her responses were weak they represent the first real data on a number of fronts. Her structure and function response represented the first time she captured the spirit of the task and there was some recognition of the observation strategies developed in class. She clearly had difficulty assessing the nature and essential components of each task. Her responses were dominated by individual pieces of information: observations, fact type statements. They did not feature more complex integration or development of information, or placing the information in context. K.A. was having problems at the comprehension level and she was not able to detect inconsistencies in information or apply the information appropriately. The development of skills to address these problems, coupled with increased confidence had to be nurtured as a preliminary strategy.

K.A. provided little specific evidence of why, but mid-way through the evolution segment she became more active and began to engage content and process at noticeably higher levels. She contributed well to the comparison of the contrasting articles and showed productive use of strategy, identified the issue moderately well, recognized chains of reasoning versus opinions and identified problems with creationism as a science. During the discussion of the video she distinguishes between the perceptions of science as fact and science as well reasoned inferences. In her book report she follows the strategy developed,

effectively identifying the issue and adequately evaluating the information in the argument. Although she did not consider style, her analysis of the organization of the argument and its conclusion was quite satisfactory. In discussions around the topic, K.A. showed greater depth of thinking, expressing amazement at the amount of diversity and the evolution of whole communities. She often raised quite significant points (e.g., "different ways to see the data") but did not recognize or pursue their importance.

In the early planning stages of her group's science society project. K.A. was very productive in gathering government reports and suggesting strategy based on available information. She soon lost contact with the group, however, and arrived on the morning of the presentation to do her own thing. Her presentation was based on providing information directly from the report.

On the final exam, a number of problems surfaced. There is a lack of basic information because of erratic attendance and effort. On each problem attempted there appeared to be difficulty with inadequate assessment of what the task required. On the video excerpt she ignored completely the explicit direction to evaluate the argument vis à vis several given criteria. There was no clear use of the strategies she had recognized in earlier efforts. The most extreme example is that in her socio-scientific problem she jumped immediately to a solution without identifying the problem or the relevant information.

This student provided perhaps one of the most frustrating performances in terms of development, at one moment showing good potential and at the next, a dismal performance. Two points do emerge: K.A. has made gains in confidence with content and she has shown much more effective thinking and articulation in discussion than in her written responses. She labored under a heavy work schedule and, in addition, was inconsistent in her efforts and was often unable to meet the prerequisite requirement of knowledge on which to operate.

IV. OBSERVATIONS ON THE IMPLEMENTATION PROCESS

In addition to the development of characteristics facilitating more effective thinking in individual students, there were more general observations on the implementation of the explicit process component of the course. Some of these observations focus on the students' reaction, others on the response of the professor.

The student centered implementation concerns were of two general types: attention to strategy and the interaction between content and strategy. One of the primary lessons learned from this case study is that many students are not conscious of or concerned with the thinking process, and it was not valid to assume that all students would readily attend to and actively engage in elements of the course explicitly geared to the development of process skills. Although some literature advised explicit teaching strategies such as outlining or highlighting

strategy as one would content, there was no preparation for the fact that some students lay down their pens and relax as strategy is discussed or developed. The obvious solution to this dilemma was strategy only tasks. Early in structure and function, students were asked to develop a general strategy, not knowing the specific content on which it would be applied. Only half of students completed the task, and only one student completed it adequately. All admitted that they found it a very strange assignment. In general, attention to their own thinking processes was better accepted in the context of content based situations as a preparatory step to solution. Most of these students were more successful in finding strategy in the products of others, if they were provided with a framework for analysis. This was illustrated clearly in book reports, discussion of videos and articles and later literature presentations. Such attention to the process of others may be productively used in relevant examples as an intermediate step towards self-conscious thought earlier in the course.

A related implementation lesson was that if process was pushed too hard, or for more than ten to fifteen consecutive minutes in a class period, students were deterred from participating.

The interaction between content and process appeared in two aspects of these students' performance. One was that students were more likely to be able to exercise higher order thinking skills and sustain a strategy on content familiar to them or that remained available to them

external to memory. Some students who had great difficulty exercising higher order thinking skills or maintaining strategy in some situations were able to come up with stronger performances when the content on which they operated was well learned and meaningful. With regard to external sources of content, some students who generated strong efforts on tasks where the content was accessible external to memory (e.g., assignments, book reports) were considerably weaker in an exam situation where content and strategy must be accommodated in memory.

This last aspect of content and process interaction did not stand alone, but was complicated by the students' confidence in content originating with authoritative sources and their insecurity with process skills. In situations where grades were at stake, they much preferred to have good, sound information from other sources stand on its own than to rely on their own reasoning on such information.

The primary professor centered implementation concerns in some ways parallel to those observed in the students. Most clear in this relationship is that early in the course the professor experienced difficulty in sustaining strategy while monitoring content, student interaction and where to go next. The human information processing system simply cannot accommodate all of that activity in a single working memory. The professor had to gain enough experience with the strategy so that it became internalized, operating more at the intuitive level, freeing the working memory for attention to detail.

The most effective use of strategy came in the second half of the course, and, at its best moments appeared spontaneous, fit the context in a very natural way and was meaningful to the students.

Getting to this stage paralleled the experiences of the more successful students, in that it required not only a commitment to the ideas involved, but reflection on how to make those ideas personally relevant. One can speak of "explicitness" or "articulating process in order to make it learnable", but it must be experienced to realize the difficulties. Making process explicit to this group left me groping for a new conceptualization of explicit, and the professor, in his own words, "a piece of two by four". Only slightly less difficult to achieve early in the course, but an aspect which developed much more quickly once a window was realized, was the ability to understand the process of a complex, automatic skill such as observation or analysis. This understanding then had to be articulated to the students so that it became learnable. By early in the second term this professor clearly had become quite adept in this area, the example in mind being a strategy for analyzing the arguments of others. This strategy evolved quite naturally from class activities, proved to be meaningful to the students, was learnable and produced effective results.

A discussion of these observations and their implications follows in Chapter Seven.

CHAPTER SEVEN: EVALUATING THE OUTCOME

I. INTRODUCTION

In terms of the heuristics framework, the objective of chapter one was to "define the problem" to be pursued and, in addition, to establish why it is an important issue. In chapter two, the theoretical and research foundations for the strategy outlined in chapter three and applied in specific detail in chapter four are presented and developed. Together these three chapters combine to illustrate the heuristic to "plan a strategy". In chapters five and six, the implementation of the plan and the students' responses are described. This description of how the "plan was carried out" entailed some analysis of how students responded to the strategy but the task of "evaluating the outcome" of the teaching strategy in a broader context remains.

It was classroom practice which precipitated the research into the literature which generated the hypothesis regarding the teaching strategy explored in this thesis. It is the responses to this teaching strategy in the classroom by which the outcome should be judged. The hypotheses generated from a review of the literature (which took into account the special constraints of university teaching were):

1. that it is possible to use the characteristics of good and poor problem solvers as a productive way of defining the ineffective learning and thinking which has been shown to affect a large proportion of university students; and

2. that the explicit application of heuristics based on these characteristics is a practical and effective strategy to move students along the continuum to better developed higher order thinking skills within the broader context of knowledge acquisition.

Evidence from this case study for each of these hypotheses is presented in chapters five and six, respectively. As this evidence was presented, there was some analysis of student performance which linked behaviors to these hypotheses, but several broader questions remain to be addressed.

There are a number of issues which, when developed, would help draw together these classroom experiences and the theoretical underpinnings of the strategy. They include:

1. the role of the strategy in defining the classroom experience more precisely;
2. whether the strategy is effective for faculty who wish to make process an explicit component of their teaching;

3. whether the strategy results in process skills being learned and effectively used by students; and
4. whether the strategy is practical in the context of the university classroom.

II. DEFINING CLASSROOM EXPERIENCE MORE PRECISELY

One of the major contributing factors to ineffective learning in the university classroom is the invalid assumptions made by faculty in their teaching. The assumptions many faculty make about the reasoning, writing and numeracy skills of their students do not reflect students' true abilities (Arons, 1979). Most simply put, faculty need to become aware of the abilities of their students. In the area of reasoning and problem solving skills, it has been useful, in this case study, to view student performance in terms of the characteristics of good and poor problem solvers but also to test the assumptions underlying teaching and the kinds of tasks required in this context. The evidence in chapter five indicates clearly that students most often resembled ineffective problem solvers at the outset of the course. The characteristics observed coincide with incompletely developed abstract reasoning abilities (Nickerson, Perkins and Smith, 1985).

When this framework was applied to the kinds of tasks usually required in the course, it became clear that successful performance on these tasks required the attributes of effective problem solvers or, in

other words, a capacity for abstract reasoning. The application of the characteristics of good and poor problem solvers to both the student performance and the demands of the tasks assigned illustrates that this framework can serve as a tool for the analysis of the skill requirements of a task and to detect invalid assumptions in individual teaching situations.

The advantage of characterizing student performance and task requirements in terms of the characteristics of effective and ineffective problem solvers is that it transforms the very diffuse symptoms of ineffective learning described by faculty or even the broad difficulties ascribed to inadequate abstract reasoning skills (page 3) into much more well defined problems. These more well defined problems then become solvable.

The evidence presented in chapter five illustrates a number of points regarding the use of problem solving characteristics in the classroom situation to characterize student performance and task requirements. The first point is that, while not all characteristics identified in thinking protocols manifest themselves in classroom performance, a variety of characteristics in each category of the general heuristics framework are observable and form a comprehensive framework for identifying student abilities and task demands. A second point demonstrated by this evidence is that the kinds of tasks in which these characteristics apply are quite varied and the use of this

strategy would not be restricted by the kinds of tasks undertaken. A third point indicated by the evidence is that the effective use of the framework is facilitated in situations in which there is active interaction with or between students, and this teaching style, known to have other advantages (Anderson, 1985; Gagne, 1975), is particularly appropriate to this strategy. At the very least, application of this tool requires attention to the process components of the students responses, in terms of the characteristics outlined in the framework.

There is no doubt that the characterization of student performance and task demands in terms of problem solving characteristics contributed in this case study to a more precisely defined understanding of the problem. This understanding was essential to developing a strategy to address the teaching problems experienced in the course. The observations presented in chapter five would also indicate that this strategy is generalizable to other learning situations, and particularly those characterized by active interaction. The specific content or kind of task did not appear to restrict the applicability of the strategy.

III. WAS THE TEACHING STRATEGY EFFECTIVE?

A. Introduction

Once a gap between student abilities and task demands in a course has been realized and the criteria which characterize that gap have been

identified, the task becomes to close that gap. One strategy to address this problem is the main focus in this thesis: the explicit application of heuristics based on the characteristics of effective problem solvers. The original hypothesis sets out two criteria by which the outcome should be evaluated: whether the strategy was effective and whether it is practical to use in the university classroom. These criteria involve the acquisition and use of the strategy by both faculty and students. Much of the evidence underlying a judgement of effectiveness is described in chapter six, but there will also be some effort to place these observations in the broader theoretical context.

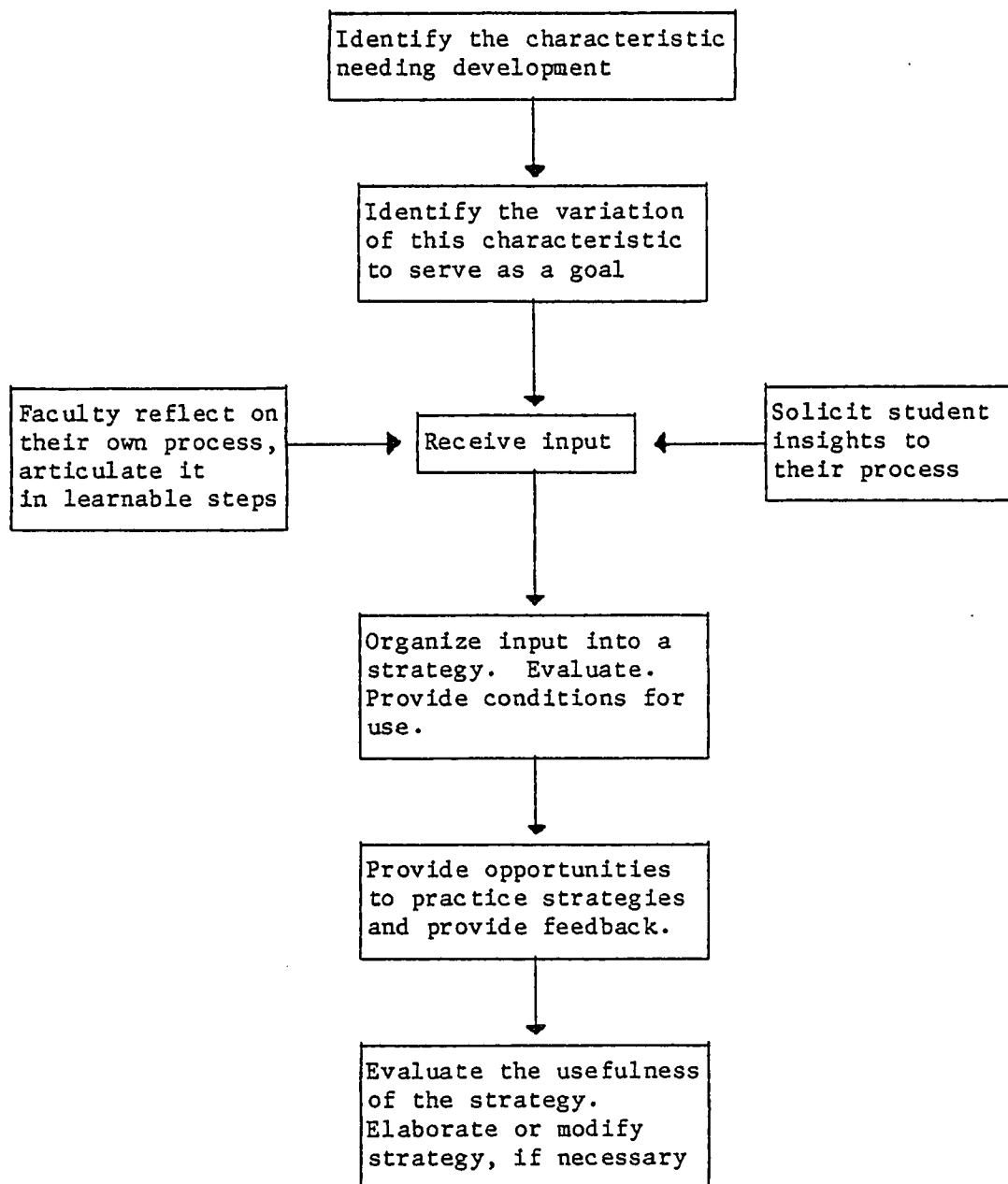
B. Faculty Acquisition and Implementation of the Strategy

A fundamental premise underlying this strategy is that faculty, by virtue of their expertise in a discipline, possess the process skills they wish their students to acquire. The requirement of faculty in this strategy is that they draw appropriately from their own scholarship to help students develop process skills. A review of the literature suggested that, to make process skills learnable, these skills must be made explicit. This turned out to be no easy task. The first difficulty was that, as the literature on expert thinking indicates (Anderson, 1985), the skills of experts become condensed and highly internalized and no longer resemble the processes of novices. It takes some effort to reflect on the skills required for a task, structure them in learnable steps and articulate them so that they become meaningful to

the students. An example of this process is drawn from the structure and function tasks. The professor's original description of the skill required was "relate structure and function". An experienced biologist may well perceive this as a single skill but to a novice the process involved is highly complex. In previous cycles of the course the professor had identified the essential components of the task: to observe, identify functions and relate structure to function. Students still had difficulty in meeting these criteria. Each of these skills required further specification. For example, what tactics contribute to more effective observation?. After some reflection, it was possible to generate six or seven strategies for more effective observation from which students could choose. The list included suggestions to draw the organism or consider the organism in the context of its environment. These articulations of the skill were meaningful to the students and their observation skills were enhanced. The initial difficulties with reflection and articulation were overcome with practice and by the beginning of the second term the professor had become quite adept at making skills explicit and learnable. The approach which evolved over that time and which may facilitate future applications of the strategy, is represented in Figure 7-1. This strategy often draws on the characteristics of problem solvers to identify problems and set goals. It recognized the importance of coupling strategies with conditions for use to maximize retrieval at appropriate times. The role of feedback on process (as it is described in the strategy), as well as content, is especially important.

Figure 7-1

A Strategy For Making Process Skills Learnable



A second requirement of faculty in implementing this strategy is described in chapter six. The demands of content, monitoring group dynamics and maintaining strategy are not compatible with the finite amount of attention available. It was necessary to gain experience with the strategy before it could be effectively used while dealing with content and student interactions.

A major concern of faculty in the implementation of any new component into an existing course is how it will affect existing content. This is especially true when the component is as pervasive as this strategy for explicit attention to process was proposed to be and the concern ought to be given serious consideration. If one reads carefully the development of the strategy from the research literature, the integration of explicit attention to process into content teaching is not meant to replace content. For many good theoretical reasons cited earlier, the strategy should enhance the acquisition, retention, retrieval and ability to use content. Most of the tasks undertaken in this course were already in place to facilitate other course objectives. The strategy was, and is for all applications, to carefully structure the tasks, to make explicit the process components of those tasks as they are approached, carried out and evaluated. Nevertheless, a departure from the traditional course presentation to consider process does take time, and the questions were if, from a faculty perspective, the time constraints were unreasonable and secondly, if there were any perceived payoffs in the content area.

The findings in this case study, from this perspective, are several. The first is that process demands content. It was not possible to discuss process in a way that was meaningful to the students without content to operate on and existing course content provided a quite adequate source. Generally speaking, students attended much better to process embedded in course content than process discussed for its own sake. A second point on this issue was that the students often limited the time over which it was productive to emphasize process. As already pointed out, they were most receptive to process skills in the context of content based problems but even then, there appeared to be a ten to fifteen minute limit on the period over which most students remained receptive. A third point is that attention to process in this course helped link together quite distinct components of the course. The commonalities in the framework for approaching problems in each of these areas provided a thread which linked together diverse examples of the nature of the discipline and which resisted the tendency to isolate pieces of information or skills. The outcome, from the faculty perspective, was one which reflected more closely scholarship in the discipline.

Apart from learning outcomes, which will be considered separately, there were a number of other effects from a faculty perspective. On one plane, it encourages faculty to reflect their understanding of the important concepts and processes of a discipline in their teaching. At a more mundane level, using a strategy in which

tasks and content are structured to develop thinking skills directs faculty in setting clear goals, pursuing focused lines of instruction and requiring a greater consciousness of the cognitive objectives not always well served in university classrooms (Kolodiy, 1975; Larkin and Reif, 1976).

C. Student Acquisition and Use of the Strategy

The presentation of the case histories in chapter six was an effort to construct a comprehensive description of the learning outcomes observed during the case study. Reflection on these descriptions raises a number of general observations on the nature of the positive learning outcomes and the problems which were encountered.

At the most superficial level, the learning outcomes in this case study can be characterized as follows:

1. Students who actively participated in the development and use of skills within the heuristics framework were most effective in their acquisition and application.
2. Students who were not active contributors to building the strategy, but who showed high effort in using the strategy also demonstrated effective acquisition and use.

3. Students who remained fixed on content and did not attend to or try out the heuristics frameworks demonstrated the poorest learning outcomes in terms of acquiring the characteristics of effective problem solvers.

A multiplicity of factors underlies these observations. One way to structure an elaboration of these general observations is to return to Perkins' (1986) steps for effectively learning thinking skills and consider the positive and negative influences observed in the acquisition, internalization and transfer of thinking skills.

1. Acquisition

Acquisition is the stage in learning process in which the students understand the strategy learned, with some conditions for its use, but may still find that its implementation requires their conscious attention and feels awkward to use (Perkins 1986, 1987a). The case histories outlined in chapter six speak to this aspect of the learning process in a number of ways.

One of the earliest points to be reinforced in this case study was the requirement for an explicit description of the process, why it is useful and the conditions for its use. The professor in the course modelled process on an early structure and function exercise in a clear and exemplary demonstration but the students' attention was fixed on

content and they showed no recognition of his process. The students attention did not shift to process until explicit references to this component of the task, at a level which was meaningful to the students, were made. The requirements for why and when the strategy would be effective were also observed to influence acquisition, in that process was more meaningful to the students and generated more motivation to try out the strategy when these factors were made explicit and then experienced by the student.

Just as faculty cannot take all of the credit for their students learning, neither can they bear all of the responsibility. Explicitness on the part of faculty was essential, but the disposition of the student toward process skills was also important. An active disposition towards developing process skills was a critical factor. Students who attended well to process, actively contributed suggestions and tried out process strategies invariably made strong gains in acquisition over a period of several weeks (e.g., A.N., J.K., D.D.). Actually using the strategies and receiving feedback on process, as well as content, seemed to be particularly important. Students who were quite passive toward the strategy in the beginning (e.g., C.H.) made strong gains once, through application, the process became meaningful. Students who persisted in a passive disposition toward process skills (e.g., D.H., J.E.) showed poor acquisition. Regardless of their disposition, most students were much more receptive to process embedded in content based problems but, even then, resisted efforts to push process too hard or for more than ten or

fifteen minutes at a stretch.

Once the process skills were made explicit and students actively engaged in the strategy, acquisition was further facilitated by content familiar to the student, new content which was not complex or content which remained available external to memory. In each case, the students' attention was freed from content detail to concentrate on process and the evidence of process acquisition increased.

Those students who remained passive towards process skills presented a major challenge. They did not attend to making process and its uses explicit and responded only weakly to process only tasks. Some of these students did, however, respond more actively to an analysis of process in the work of others (e.g., D.H., K.A.) and this strategy may provide a useful intermediate step to considering ones own process in these students.

The observations in the case histories described underline the importance to effective process skill acquisition of (1) explicit attention to the process skills, in what ways and under which conditions they are useful; (2) embedding process instruction in content based problems and focusing on process for short periods; (3) the active disposition of students towards understanding and trying out process skills; and (4) the careful selection of simple, familiar or externally available content during the process acquisition stage. They also point

out how strongly students can resist process skill development. If the source of the problem lies in a reluctance to explore ones own thinking process, then analyzing the products of others did show some promise in this case study as an intermediate step. If the problem is seated in chronic low effort, however, the hurdle becomes much higher.

2. Internalization

Internalization refers to the stage in learning process at which the process has become automatic and can be used fluently in simple and similar cases (Perkins, 1986, 1987a). For most students who progressed through the acquisition stage internalization was achieved but the internalization period appeared to be more variable in the time and amount of practice required, the kind of content involved and whether the product was to be written or oral.

The essential role of successful experiences with the strategy to be learned is particularly important at this stage. It is a realization of the usefulness of the strategy which facilitates the incorporation of the strategy into a way of thinking (Bransford, Sherwood, Vye and Rieser, 1986; Simon, 1980). Students who gradually overcame the unwieldy use of strategy, reflected in their efforts a process which has taken on a smoother, individually modified character (e.g., A.N., C.H., D.D., J.K.).

Not all students moved easily through this stage however, and there appeared to be a number of limiting factors. One such factor was the amount and complexity of content to be processed, and whether the content had to be held in memory or was externally available. In early efforts especially, it was important for many students to have a measured amount of content and complexity or to have more challenging content situations available other than in memory. Repeatedly in this case study, students were observed to show much higher process skills on simple or familiar content or on tasks like book reports, assignments or literature presentations where content remained externally available (e.g. J.K., T.A., H.E.). Although confidence was almost certainly a contributing factor in exam performance, the information load created in this situation did appear to inhibit conscious attention to process. Students slipped back noticeably on their exam performances relative to other tasks with regard to process skills, indicating that information load was at least a contributing factor. Some students (e.g., A.N., C.H., J.K., D.D.) showed a noticeable improvement on the process component from one exam to the next while having to carry similar information loads. These observations indicate that internalization of process may have contributed to the result.

One of the observations which became evident during the variety of tasks in which these students engaged was that there was frequently a gap between written and oral manifestations of process. Early in the course, students typically showed deeper processing in class discussions

and tutorial sessions than they did in their written products. Some students (e.g., K.A., H.E.) persisted in this pattern throughout the course. The problem is not only to encourage students to think at higher levels, but to have their writing more closely reflect the development of an idea and to evaluate their written work for evidence of that thinking.

3. Transfer

Transfer represents full success in the learning of process. It has been reached when students can independently apply strategy in a wide range of contexts not necessarily similar to the context in which it was learned. In this case study, transfer is best indicated in the exam situations where students are faced with new situations, some familiar and some not, and with varying degrees of independence from the process framework. The pattern which emerges from the case histories is not surprising. Both the mid-term and final exam were structured to test at the comprehension - simple application level, higher levels of thinking with a framework provided and higher levels of thinking independent of a given framework. Most students showed general improvement in their abilities to deal with the exam questions from the mid-term to the final exam. There was, however, a distinct pattern when the final exam questions were surveyed. Most students could deal effectively with comprehension-application situations, slightly fewer with a situation where the framework was provided, slightly fewer again

where there was no framework but where the situation should be recognized as familiar and only one-third of the students could apply the framework independently in a novel situation. This distribution indicates that not all of the students who had internalized the strategy had reached the transfer stage in their learning.

This pattern is complicated somewhat by a factor which permeates almost every level of process learning - confidence. In practically every case history, it was observed that students slip back into the security of authoritative sources and do not depend on their own reasoning when marks are at stake. Students typically showed much stronger process skills in discussions and later literature presentations. Particularly strong also were their book reports, which were assisted by an effective heuristic. On their final project and exam, however, they hesitated, as a group, to confidently use the strategies which had been developed. The role of developing confidence in process to facilitate transfer should not be underestimated.

There also is a pattern in the degree to which elements of the general heuristics framework were learned. Most students by the end of the course had been successful in acquiring and transferring the skills involved in effectively identifying the problem, although their performance was not always consistent. Likewise, they performed reasonably well in generally identifying the kinds of information relevant to a solution and a strategy for how it might be used. If

students engaged in the first two steps, there was usually some evidence of a plan in their responses. On each of these heuristics, however, and on "evaluating the outcome" in general many students fell short on evaluating the products of the framework and their response in general. They identified the problem but did not evaluate their representation; they identified information and strategy for a solution but did not evaluate their plan; they generated a solution but did not evaluate it for purpose, content or reasoning. It is certainly no accident that Bloom's taxonomy places evaluation as the highest cognitive skill. It is obviously difficult to achieve, and a number of our students required more explicit attention to the acquisition of this skill. The degree of difficulty that evaluation would present in implementing the framework was not anticipated and it became coupled with a second factor. The major heuristics were introduced in order so that "identify the problem" received the earliest attention and most practice whereas "evaluate the outcome" was introduced into the strategy last and, as the course progressed, was almost always explicitly applied to examples of literature and other media. Clearly, more students may have benefitted to a greater degree if this difficulty had been realized earlier, and the cognitive skill of evaluation had received more explicit attention.

Some students did achieve transfer under the conditions provided which included explicit attention to varied contexts and using old strategies in new ways (Sternberg, 1983). It may be that some students require more time to achieve this level of learning, but it may be, too,

that more intensive attention to evaluating their own processes would have facilitated transfer.

IV. IMPLICATIONS FOR FURTHER MODIFICATIONS

Many of the premises which underlie the teaching strategy applied in this case study and the strategies derived from them have proven to be both valid and helpful to students in developing more effective thinking strategies. Observations from the case study do, however, underline several issues which, if addressed in other applications of the strategy, might improve the level of process learning which students acquire or the proportion of students who acquire these skills.

The first modification would be to devise strategies which cause a greater proportion of the students to actively engage on process tasks. Such active participation clearly facilitates effective learning of process skills. One suggestion emerging directly from this case study is to integrate more analysis of the processes of others early in the course as an intermediate step to being aware of ones own process.

A second suggestion would be to address the confidence problem. A lack of confidence in content and process restricted these students in many tasks. Some tasks may be modified so that there is an explicit advantage to risking the use of reasoning skills, and students should be

provided with appropriate feedback.

A third concern would be to place a greater emphasis in every stage of the strategy on the development of evaluation skills. It is a thinking skill which can be demonstrated to give some students problems at each step in the framework. Although it represents a high level of thinking, it is an essential component of the development and management of thinking skills and must be addressed.

V. THE PRACTICALITY OF THE STRATEGY

An analysis of learning and teaching experiences during the case study indicates that the strategy is an effective one for most students and probably can be made even more effective. A second criteria for analysis was whether the strategy was a practical one in the university setting. There are a number of points on this issue that are, by now, largely self-explanatory:

1. The strategy draws on the existing scholarship of faculty, demanding only that they make the skills inherent in their scholarship learnable for their students.
2. The strategy fits with and may enhance existing class content. Changes involve not so much specific content but how it can be structured to support process tasks designed to facilitate the learning

of content and process. By making explicit the use of process in content, that content becomes more meaningful to the students enhancing memory, retrieval and use of that knowledge (Bransford, Sherwood, Vye and Rieser, 1986).

3. The strategy was compatible with many different kinds of tasks and media. Not only is this convenient for faculty, but it provided a common framework for diverse tasks and content and also enhanced learning for transfer.

4. The flexibility within the strategy accommodates students learning styles. Students with very different approaches to learning benefitted significantly from exposure to the strategy (e.g., A.N., C.H., D.D.).

V. CONCLUDING THE ARGUMENT

Although it is highly desirable for students to derive their own organizational structures (van Patten, Chao and Reigsluth, 1986) and their own problem solving strategies (Collins and Stevens, 1982) it is not a common occurrence (Gick and Holyoak, 1980; Perfetto, Bransford and Franks, 1983; Simon and Hayes, 1976). Neither is it common for these kinds of knowledge to be explicitly developed through instruction (Derry and Murphy, 1986). There is a growing body of research that makes the explicit teaching of the organization and use of information a viable

option, particularly in meeting head on the problem of ineffective thinking skills among university students. This case study has illustrated that, by viewing students learning problems from the perspective of the characteristics of effective and ineffective problem solvers, it is possible to move from a general awareness of the problem of ineffective thinking towards a more functional way of understanding and acting on the problem in terms of cognitive skills and appropriate strategies for their development. It has also illustrated that, by thoughtful planning and careful working of the heuristics option, in the context of these characteristics, it is possible for experts in individual disciplines to use their understanding of their disciplines to facilitate effective learning. Using the same framework faculty can then evaluate the strategies suggested by the literature, based on their experiences with students.

This thesis has been an effort to model that approach and at the same time move toward an understanding of a teaching problem and the nature of its solution. On both fronts, the results have been encouraging. The application of the teaching strategy developed has shown positive results and new directions for increasing its effectiveness. There is also some indication that this approach will be more generalizable. The same heuristics framework has provided a productive model for applying the scholarship of faculty to teaching problems: identify and define the problem, identify and gather relevant knowledge, develop a response and evaluate the outcome.

Shaw, Wilson and Larkin (1976) suggest that every classroom become a laboratory, and in the university context this suggestion need not be trite. Effective transmission of the knowledge of a discipline is essential to the maintenance and development of the discipline. With self-conscious thinking on how to use the knowledge of a discipline to facilitate the development of higher order thinking skills, it will be possible to move away from what Lauren Resnick (1974) aptly terms "strategies of selection" and move towards "strategies of instruction" in higher education.

APPENDIX ASpecific Examples used in the Structure and Function Component

1. Introduction
 - (a) mechanical examples: tea strainer
collapsible pointer
 - (b) cursory biological examples: skeletons
seed covers
skull
 - (c) indepth introductory example: leaves
2. First Student Effort: the Hand
3. Tutorial Assignment: a Mouse
4. Individual Assignment: students own choice from the sea water tanks, included the crab, hermit crab, periwinkle, sea cucumbers, sea anemones, sea urchins and starfish.
5. Scientific Applications: toadflax
fungi

owl head feathering

concept of surface area to volume

nerve cell

blood cells

6. Introduce molecular biology using a structure and function approach: begin with hemoglobin in red blood cells.

APPENDIX B

Specific Materials Chosen in the Science in the Popular Media Component

1. Sources

(a) Science Magazines: Discover and Omni were chosen most often by students but other sources include New Scientist, National Geographic, Scientific American and Popular Mechanics.

(b) Newspapers: current articles from local papers.

(c) Books: students were urged to choose from the holdings of public libraries.

(d) Video Tapes: television science documentaries.

2. Examples of Specific Content Chosen

(a) Literature Presentation #1: students chose articles on the psychology of twins, testosterone levels and violent

behavior, using leeches in medicine, videophones, Down's Syndrome and under sea craters.

(b) Literature Presentation #2: students chose articles on attitudes toward pollution in a mining town, designer proteins, the ethics of death, creationism, joint replacements, the immune system, fossil pollen and technology for forest fire alerts.

(c) Literature Presentation #3: students chose articles on toxic wind, dealing with the terminally ill, a smell survey, DNA sequencing, diet and cancer risks, the making of the pill, faith healing, the ozone layer, atomic cars and organ transplants.

(d) Book Review: the book review topic was restricted to evolution related topics. Titles included:

Can You Speak Venusian? (Patrick Moore)

Life on Earth (David Attenborough)

How Life Began (Irving Adler)

Chariots of the Gods? (Erich Von Daniken)

African Genesis (Robert Ardrey)

Until the Sun Dies (Robert Jastrow)

Bones of Contention (Richard Lewin)

- (e) Compare two different approaches to arguing a similar point: two articles on the creationism/evolution debate were presented to students. One was written in an editorial style, based on opinion, the second was written in a highly rational style based on well evidenced arguments.

APPENDIX CSpecific Topics Chosen in the Citizen Action and Decision Making Component

1. Introduction: A.I.D.S. biology, epidemiology and the complexity of the social context.
2. Genetic Disease Report: the topics chosen for the genetic disease report included Duchenne's Muscular Dystrophy, Down's Syndrome, Huntington's Chorea, Klinefelter's Syndrome, cystic fibrosis, alcoholism, hemophilia and pyruvate carboxylase deficiency.
3. Introduction to making decisions based on scientific-social issues: as senior management, develop an office smoking policy.
4. Major Project topics included acid rain, death and dying, and sewage pollution in Halifax Harbour.

APPENDIX DMid-Term and Final Exam QuestionsMid-Term Exam Questions

The exam consists of 4 questions. Question 2 has a choice: Do either 2a or 2b.

1. Structure and Function

The two large plants in the sketch below are both very successful lawn weeds (dandelion on the left, plantain of the right). Relate their structure to this success.

(Diagram Provided)

2. Genetics. Do only one of 2a or 2b.

(a) Illustrate the steps in protein synthesis and then use your illustration to show how a change in the DNA can result in a change in the protein. (RNA codon tables available).

Mid-Term Exam Questions (cont.)

(b) A number serious genetic diseases; e.g., Down's Syndrome, are a result of trisomy (3 copies of a chromosome). Explain how trisomy can occur. Trisomy can be detected before birth. Explain how this is done.

3. Your family history has a number of incidences of death in early childhood. You have just married (How traditional!) and are anticipating having kids and are concerned that the child deaths might have a genetic cause.

You have access to the following experts. What questions would you ask them?

Scientist

Doctor

Social Worker

Religious leader, village elder, or philosopher.

4. A news item last week reported that a volunteer driver for the Winter Olympics has been rejected by the Olympic Committee when he told them he was HIV positive.

Mid-Term Exam Questions (cont.)

He had volunteered, been selected, trained and finally certified as a driver of dignitaries and athletes. When he found out he was HIV positive he reported it to the committee.

The committee then told him he was no longer wanted as a driver.

He asked why? The committee said, "Drivers might be involved in accidents and be required to give mouth to mouth resuscitation".

Develop a coherent argument for either reinstating the volunteer or for upholding the Olympic Committees decision.

Final Exam Questions

1. Sweet peas are beautiful garden plants that can form root associations with symbiotic, nitrogen fixing bacteria. Dick is planting two beds of sweet peas this year. In one bed he is adding no fertilizer, in the second bed he is adding Nitrate (NO_3^-). How do you think the nitrogen cycle in the two beds will differ?

Final Exam Questions (cont.)

(Nitrogen Cycle Provided)

2. I want you to watch a short segment from CBC's "Nature of Things" and then to:

- (a) State the central argument.
- (b) Evaluate the credibility of the argument and its presentation (e.g., information, logic, bias, etc.).
- (c) State your position in the argument and support it.

You will get to see the video twice. Watch it once. Then take 15 minutes to develop your answers and then watch it again to review and revise.

(Don't panic! I will mark your answers knowing you only had two chances to see it. It is the same exercise you did in tutorial on the evolution video.)

3. The human species has become the densest, most widely distributed mammal on earth. In addition, through modern transportation the species is constantly migrating between countries and

Final Exam Questions (cont.)

continents. In so doing it has become the perfect host for disease organisms like the viruses.

To take advantage of the perfect host, viruses have evolved to leave their traditional hosts and to infect humans. An example would be the HIV (A.I.D.S.) virus which used to infect the green monkey, but mutated so it could infect humans. In just two decades the HIV virus has increased to very high populations on six continents.

Does this explanation make sense in terms of the modern Darwinian explanation of evolution? Why? and/or Why not?

4. (a) A small maritime town has two major industries, a pulp mill and the lobster fishery. The pulp mill discharges wastes into a river which is used by sport fishermen. The river discharges into a large bay which, in the past, was a rich lobster ground.

The lobster fishery and the sports fishery has declined over the last ten years and the fishermen blame the pulp mill's pollution. The pulp company says the decline is due to

Final Exam Questions (cont.)

overfishing.

You are on the town council and must develop a plan for resolving this conflict. Describe your plan. (I'm not asking for the solution just the plan of how you would go about finding a solution.)

OR

(b) You are a resident of a small agricultural town in which the agricultural supply company's warehouse burned down and the firemen fighting the fire with water washed unknown quantities of pesticides and fertilizers onto the adjoining land. The government officials have quarantined the building site but say that other areas are safe. You think your well water tastes funny. You have small children and plan more. You are worried.

Develop a plan for finding out if the area really is safe.

APPENDIX ETime Line for the Implementation of the Instructional Strategy

Week Of:

- September 09 Orientation/Administration
- September 16 History of the A.I.D.S. virus, assigned reading on the detection and course of the disease, discussion of this information.
- September 23 Spread and epidemiology of A.I.D.S., scientific predictions, first literature presentation.
- September 30 Discussion questions: was A.I.D.S. ever containable?
What are the options for controlling its spread?
- Tour of research facilities, introduction to structure and function, assign hand exercise.

Week Of :

October 07 Class effort to develop structure and function on the hand, attention to an understanding of the requirements of the task and a method for gathering and organizing relevant information.

Assign strategy development including knowing what the task entails, strategies to meet these requirements and how to evaluate the product. Tutorial groups work on structure and function of the mouse after discussing strategies. Class development of strategy based on experiences.

October 14 Further examples of structure and function using scientific concepts. Discuss major structure and function assignment. Initial sea water tank observations.

October 21 Further scientific applications of structure and function, explicit discussion of the role of reasoning, examples to help with assignment. Transition to structure and function of molecules.

Week Of:

- October 28 Background to chemical bonding, characteristics of polar and non-polar molecules. Second literature presentation, with encouragement to question the content and reasoning of the article.
- November 04 Protein shape and function. Students present structure and function assignments.
- November 11 DNA structure, replication, transcription and translation.
- November 18 Meiosis, genetic screening video.
- November 25 Discussion of genetic screening video (a verbal free for all), analysis of the discussion, develop a plan for keeping information and reasoned development on track, illustrate approach in a class effort, use it in individual efforts on the genetic disorder assignment. Third literature presentation.

Week Of:

- December 02 Review framework for considering science and society issues, emphasize diagramming strategy before starting response. Students work through example. Present Genetic Disorder Assignments.
- December 09 Find the general framework in structure and function and genetic disorder approaches. Apply as a general guideline to exam questions, especially "to evaluate the response".
- January 06 Review exam outcomes, highlighting strategy as developed over the term, reinforcing planning on paper. Strategy for literature presentations and book report. What is the issue? How do the authors develop the argument with regard to information, development and style?
- January 13 Introduce evolution, relate to genetics. Assign articles on evolution. Review strategy and apply to contrasting articles from the creationism/evolution

Week Of :

debate in tutorial sessions. Highlight the detection of perspective.

January 20) Information and discussion on evolution. Fourth

January 27) literature presentation.

February 03)

February 10 Video on a debate among evolutionists. Analyze the arguments, using the framework. Class session development within the framework. Relate strategy to the general framework.

February 17 Conclusion of the analysis, highlighting criteria for credibility of sources. Set criteria for a credible theory for the origin of life. Book report presentations. Prepare for major project by considering the strategy required (following the heuristics framework).

March 02 Review strategy and apply to smoking policy in a public office. Groups 3 to 4 develop a response.

Week Of :

March 09 Select topics and formulate strategy for the science and society project.

Explicit attention to how the strategy developed over the course applies in this case.

March 16 Assess and organize information gathered for project. Plan next action.

March 23 Information on ecological principles and how students will have to use information, with a short review of the strategies required in the Christmas exam as examples.

March 30 Continue with ecological principles. Translate strategies for thinking into strategies for studying - find ways to apply the strategy in different kinds of situations.

April 06 Project presentations.

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