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ABSTRACT

This is the first of a three-volume report on a National Science Foundation project called PARADIGMS. An overview of the PARADIGMS project, an analysis of the concept paradigm, and objectives of the project are presented in the first section. The next two sections cover some specific paradigms for research and action, including sample CAI curricular segments. The epilogue summarizes goals, activities, and products of the project and implications of the project regarding research and development within the curricular/instructional domain. (JM)

A STUDY OF PARADIGMS FOR THE CONSTRUCTION AND EVALUATION OF CAI CURRICULAR MATERIALS IN MATHEMATICS

Final Report

VOLUME I: PHILOSOPHICAL STUDIES

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INTRODUCTION

This is the first of a three volume report of a project (called PARADIGMS) conducted under support of NSF Grant GJ-102: A Study of Paradigms for the Construction and Evaluation of CAI Curriculum Materials in Mathematics. The other two components of the Report are: *Volume II: Empirical Studies*, and *Volume III: Compendium of Curriculum Materials*.

The philosophical studies reported in Volume I have been substantially aided and abetted by the fine work of *The TCU Texas Performance-Based Teacher Education Project*. This was made possible by the fact that Dr. John Lottes, one of the principal investigators on the PARADIGMS Project, doubled as Director of the TCU Project, and also by the fact that there was considerable overlap between the theoretical and conceptual pegs of the two projects. In particular, this report has drawn freely on ideas presented in a monograph written by Lottes and William Vanderhoof entitled: *A First Dynamic Paradigm for Teaching and Teacher Education*, and this fact is gratefully acknowledged.

A number of other people and organizations have made important contributions to the work of the PARADIGMS Project. Among them, very special thanks are due the State College (Pa.) Area School System for their cooperative endeavors in support of the empirical aspects of the Project.

TABLE OF CONTENTS

	Page
INTRODUCTION	
PART A: PROLOGUE	
1. THE PARADIGMS PROJECT IN PERSPECTIVE	1
1.1 General Aims and Objectives	1
1.2 Present Status of Knowledge	1
1.3 Two Conditions Necessary to Advance	3
1.4 Curricular/Instructional Research: The Necessity of a First Paradigm	7
2. ANALYSIS OF THE CONCEPT: 'PARADIGM'	9
2.1 Overview	9
2.2 Levels of Resolution	11
2.3 Levels of Abstraction	13
2.4 Analysis of 'R-Paradigms'	
2.4.1 The R-Paradigm in Perspective	15
2.4.2 Analysis of R-Paradigms	20
2.5 Analysis of 'A-Paradigms'	22
3. OBJECTIVES OF THE PARADIGMS PROJECT	24
3.1 [θ_1]: The Construction of R-Paradigms	25
3.2 [θ_2]: The Construction of A-Paradigms	25
PART B: PARADIGMS FOR RESEARCH	
4. AN R_V-PARADIGM: A SYSTEM OF AXIOLOGICAL PROPOSITIONS	27
5. AN R_L-PARADIGM: CONDITIONS OF ADEQUATE CURRICULAR/INSTRUCTIONAL RESEARCH	41

Page

6. AN R_K-PARADIGM: THE ANATOMY OF THE PARADIGMS PROJECT STUDIES 43

6.1 The Mode of Representation Studies 44

6.2 The Structure of Curriculum Hierarchy Studies . . . 55

6.3 The Choice-Behavior Study 57

6.4 The Research Studies in Perspective 57

PART C: PARADIGMS FOR ACTION

7. A_V-PARADIGMS: A SYSTEM OF AXIOLOGICAL PROPOSITIONS . . . 59

8. A_L-PARADIGMS: SYSTEMS OF PRACTICAL DIRECTIVES. 62

8.1 A Statement of Perspective 62

8.2 A_L-Instructional Paradigms 66

8.3 A_L-Formulation Paradigms 66

8.3.1 An A_L-Formulative Paradigm: A System of Propositions for Formulating Instructional Objectives 66

8.3.2 CAI Curriculum Production Paradigms 73

8.4 An A_L-Evaluative Paradigm: A System of Propositions to Guide CAI Evaluations 78

9. A_K-PARADIGMS: SAMPLE CAI CURRICULAR SEGMENTS 86

PART D: EPILOGUE

10. GOALS, ACTIVITIES AND PRODUCTS OF THE PARADIGMS PROJECT . 87

11. IMPLICATIONS 89

BIBLIOGRAPHY

PART A: PROLOGUE

1. THE PARADIGMS PROJECT IN PERSPECTIVE

1.1 General Aims and Objectives.

The general aims and objectives of the PARADIGMS Project were outgrowths of questions like: "What principles should guide the construction of instructional materials designed for computer presentation?", "Under what conditions can such materials be considered acceptable for widespread use?" and the multitude of logically subordinate queries prompted by them. Inevitably such lines of questioning lead to the fundamental problems of curriculum structure and design, and hence it was to these issues that the PARADIGMS Project addressed itself.

1.2 Present Status of Knowledge.

In every curriculum construction effort decisions must be made about how to formulate objectives, how to structure content, how to design and order instructional tasks, and how to adapt to unique student conditions. Unfortunately, however, at the present time neither adequately justified rules nor empirically testable systems of hypotheses are available for guiding such curricular decisions. It follows, by force of circumstance, that curricular and instructional moves characteristically are based either on imprecise, inadequately formulated "practitioner's maxims" or "hunches"--for which there is neither

adequate logical nor adequate empirical support--or they are made at a non-reflective level of awareness.

It is certainly legitimate to wonder why the knowledge structures concerned with the central issues of curriculum design are so poorly developed. It could hardly be argued that there has been little desire or effort to acquire such knowledge in view of (1) the virtual "mountain" of educational research that has been published over the past 50-75 years, and (2) the millions of dollars that have been invested, particularly over the past 15 years, for the purpose of improving educational practice. Yet, today we *know* little more than we knew fifty years ago about *cause-effect* relationships between instructional actions and learning outcomes.

Two more tenable reasons for the lack of advance in knowledge about curriculum and instruction are that the phenomena to be investigated are inherently extremely complex, and that, up to now at least, the tools, the conceptual structures, or the epistomological bases necessary to cope with problems of such a magnitude either have not been developed or have not been acquired by those who are responsible for such matters.

In any event, the perplexing issues remain of determining strategies and courses of action that hold some promise of permitting systematic improvement of the knowledge structures associated with the problems of curriculum organization and design.

1.3 Two Conditions Necessary to Advance.

In the view of the PARADIGMS Project, there are at least two fundamental conditions that are necessary to such advance. They are stated as propositions, and discussed briefly below.*

> *Proposition #1.* Curricular and instructional systems should be constructed and operate under the precepts of *rational action*

For purposes of clarity, the term *rational action* will be used to denote those actions for which the following conditions are satisfied.

(1) The agent or actor will be able to articulate the goal or objective, θ, of the action.

(2) The agent will be able to formulate a set of procedures, A, which he has reason to believe will lead to the attainment of θ . The agent also has reason to believe that whoever is to perform the action denoted by the statement of procedure (whether himself or another agent) can adequately perform such action.

(3) The agent will be able to make explicit what would count as evidence (in the phenomenal field of concern) that θ has been attained.

*A more complete discussion of these matters is presented in Section 4.

(4) The agent, having made explicit reference to the set of procedures, A, will utilize the procedures as a guide or mandate for his action; that is, his action will be the actions denoted by the statements comprising set A.

(5) The agent will evaluate the action, that is, the implementation of the set of procedures A, to determine the efficacy of this set of procedures in attaining θ .

The importance of the proposition requiring rational action in curricular and instructional development and operation can be most clearly perceived by conducting two examinations. First, examine the likelihood of substantial advance in curriculum and instruction if actions are not rational actions. In this event, there is no way to establish accountability; evaluation of actions cannot be carried out. In the absence of evaluation, weakness cannot be identified; hence the points at which changes should be made remain unknown and advance cannot occur. Second, examine ways of acting in fields characterized by clearly identifiable progress; for example, mathematics, the natural sciences, and fields of practical action such as medicine and military logistics. Each of these fields operates under the assertion requiring rational action. The authors know of no instance of substantial advance in the absence of the proposition of rational action.

The conditions of rational action require (1) specified

objectives, (2) specified procedures and reasons for believing that the procedures will lead to attainment of the objectives, and (3) specified criteria for judging whether the objectives are attained. If it is assumed that instructional actions should be rational, then there is an associated claim that a particular instructional action will influence a particular pupil to attain some specified set of objectives. Such a claim is entailed by the conditions of rational action. In generalized form, the *instructional claim* might be represented: "Under circumstances C, if action A is taken then objective θ will be attained." In more abstract form, the instructional claim can be expressed:

> *"Under circumstances C, if A then θ"* .

It is informative to compare the instructional claim against the hypothesis of empirical science. The hypothesis, or claim, of empirical science typically is expressed as:

> *"Under circumstances C, if X then Y," where C, X, and Y are terms having empirical referents.*

A comparison of the instructional claim and the scientific claim yields the conclusion that the two claims are of the same type; they have identical logical structures and the extralogical terms, in both claims, have empirical referents. Moreover, both claims demand

empirical test, and the test methods clearly are governed by a common logic.

The foregoing line of reasoning leads to the conclusion framed as proposition #2.

> *Proposition #2.* Curricular and instructional research programs should be modeled on the essential characteristics of empirical science.

The consequences of accepting the foregoing assertions are both numerous and significant. At the very least, they require a massive shift in the orientation and practice of research whose aim is to advance knowledge about the educational issues of central concern to the PARADIGMS Project. Perhaps an illustration is in order. On one hand, the conditions of rational action not only require the presence of objectives for guiding instructional or curricular actions (that is, to make them purposeful), but they also require presence of *procedures* that presumably can be employed to attain the specified goals. The requirements of science, on the other hand, demand that these procedures be explicit and precise, and that they form a coherent system. In a very real sense, therefore, the aforementioned procedures would amount to being systems of *practical directives*--the "theorems" of the field--which would specify relations between particular courses of action and their consequences in terms of achievement of specified

ends. Clearly such "theorems" are not now available.

1.4 Curricular/Instructional Research: The Necessity of First Paradigm.

Thomas Kuhn's highly illuminating explanation of scientific advances in *The Structure of Scientific Revolutions* [16] provides a potentially fruitful way of conceptualizing the requirements that must be fulfilled if "theorems" of the type discussed earlier are to become an item of reality. Two concepts are fundamental to Kuhn's explanation: (1) The concept of a "paradigm of science", and (2) the concept of "normal science."

A *paradigm of science* is an unprecedented and integrating achievement that provides "at least some implicit body of intertwined theoretical and methodological belief that permits [problem] selection, evaluation and criticism. ··· When a scientist can take a paradigm for granted, he need no longer, in his major works attempt to build his field anew, starting from first principles and justifying the use of each concept introduced."

Prior to the development of a *first paradigm* in a given area of study, there is no way to interpret the multitude of facts that may be collected; different practitioners describe and interpret the same phenomena quite differently and cannot agree on evaluative standards; the literature of the field consists of a body of isolated bits of disconnected information incapable of being related. In the

pre-paradigm period, confusion reigns and action is blind. With the general acceptance of a first paradigm, however, a field may become a science--or a profession. Given a first paradigm, it becomes possible to build on a common foundation and to utilize the information provided by others who are committed to the paradigm. The paradigm serves the purpose of generating intensive and concerted research efforts in a well-defined problem domain under common operating rules. Research conducted under these conditions is labeled *normal science* by Kuhn. With common conceptual foundations, common language, common problems, and common evaluative standards, periods of normal science are characterized by rapid increase of depth and scope of knowledge. This rapid advance ultimately leads to a new paradigm, and the cycle begins anew.

It surely must be obvious to all that the foregoing description of the nature and characteristics of the pre-paradigm period is an apt characterization of the present state of affairs in the study of curriculum and instruction. It follows by force of previously stated presuppositions that advance in knowledge in the curricular/instructional domain is contingent upon the development of a first paradigm (in the Kuhn sense). The primary product of such a paradigm would be the development of additional subordinate paradigms, hereinafter called *R-Paradigms* (research paradigms), whose purpose would be the development of the systems of practical

directives necessary for guiding curricular/instructional development and decision making. Such systems of practical directives would then, in turn, form the mortar for the construction of another order of paradigm concerned with operation at the level of practice; this order of paradigm will henceforth be referred to as an *A-Paradigm* (action paradigm).

The primary mission of the PARADIGMS Project--as suggested by its name--was an attempt to focus attention on the problems and prospects of structuring something akin to a first paradigm (in the Kuhn sense) that would be appropriate for the advance of knowledge in the C/I realm. The actual efforts and contributions of the Project, however, consisted essentially of the construction of both R- and A-Paradigms, while a more inclusive framework involving conceptualization and interpretation was made possible in large measure by the collaborative efforts of the Teacher Center Project at Texas Christian University [17].

2. ANALYSIS OF THE CONCEPT: "PARADIGMS"

2.1 Overview.

As used in the PARADIGMS Project, the term "paradigm" labels a concept whose extension includes: model, template, pattern, map, exemplar, etc. A paradigm can be descriptive or prescriptive; it

can be a symbolic structure, an iconic structure, or a set of concrete objects or actions. Paradigms can function as guides to formulation or evaluation of axiological systems or logical systems, formal systems or empirical systems, or systems of either research or practical decision and action.

The varied usages of the term "paradigm" in this volume, and the varied usages of the term over the many disciplines and fields of practice, create a number of likely sources of confounding for the reader--and for the direct contributors to the PARADIGMS Project as well. In order to reduce the degree of confounding to a workable level, further analysis of 'paradigm' is necessary, and it is to this end that the present section is devoted.

Thomas Kuhn's meaning of a *paradigm of science* was described in the introductory perspective. Acceptance of the assertion that curricular/instructional research programs should be modeled on the essential characteristics of science entails the development of a concept of C/I paradigm that is the analogue of Kuhn's concept of scientific paradigm. An adequate concept of C/I paradigm requires analysis of the distinctions between a field of practice and a science. To conduct such an analysis is the first intention of the following discussion.

The concept of a paradigm of the curricular/instructional domain (C/I paradigm) includes two subordinate classes of paradigms: R-paradigms (research paradigms) and A-paradigms (action paradigms).

Since R-paradigms and A-paradigms can be represented at different *levels of resolution* and at different *levels of abstraction*, explanation of these concepts is also necessary, and so is a second intention of the following discussion.

A third intention is to delineate significant subsets of R-paradigms and A-paradigms, and a fourth intention is to distinguish between *construction* paradigms and *evaluation* paradigms.

2.2 Levels of Resolution.

Every system can be described by specifying its elements and their interrelationships. However, any description of a system is made relative to a set of elements, or basic units, which are treated as being devoid of internal organization or structure; on a different occasion and in a different context, the internal structures of those basic units in turn become the objects of description, and so on. If the first description is at a macroscopic level, some of the succeeding descriptions will be made at microscopic levels. These various descriptions might reasonably be viewed as descriptions made at different *levels of resolution*.

An illustration drawn from Bertrand Russell's *Human Knowledge: Its Scope and Limits* [24] will illuminate the point:

> To exhibit the structure of an object is to mention its parts and the ways in which they are interrelated. If you were learning anatomy, you might first learn the names and shapes of

> the various bones, and then be taught where each bone belongs in the skeleton. You would then know the structure of the skeleton in so far as anatomy has anything to say about it. But, you would not have come to an end of what can be said about structure in relation to the skeleton. Bones are composed of cells, and cells of molecules, and each molecule has an atomic structure which it is the business of chemistry to study. Atoms, in turn, have a structure which is studied in physics. At this point orthodox science ceases its analyses, but there is no reason to suppose that further analysis is impossible.

With respect to Russell's illustration, the bone was the basic unit of the system described at the first level of resolution; the cell was the basic unit of the system described at the second level of resolution; the molecule was the unit of the system described at the third level of resolution; the fourth level of resolution was concerned with the atom as the basic unit, and so on. Each successor level of resolution is more "refined" and more "microscopic" than the preceding level of resolution. Such representations at successively more refined levels of resolution conceivably could be carried out indefinitely, although there might well be strong pragmatic bases for a stopping point.

In one context, representation of a given object at a particular level of resolution may be relevant and productive. In some other context it no longer may be relevant, but a representation of the same object--or some part of it--at a different level of resolution may now be relevant and useful.

The point to this discussion is that paradigms are representations of systems--real or conceptual--and these representations can be constructed at many different levels of resolution, the appropriate level of resolution being determined in the presence of a particular context. This explains the fact that the PARADIGMS Project objectives require construction of paradigms at varied levels of resolution.

2.3 Levels of Abstraction.

The presuppositions underlying the PARADIGMS Project entail the conclusion that adequate curricular/instructional systems have empirical interpretations; that is, they can neither be tautological nor incapable of application. With reference to systems characterized by empirical import, the term "abstraction" has a particular meaning that differs from such common meanings as "abstruse," "insufficiently factual," "disassociated from any specific instance," and the like.

Terms of the empirical sciences are characterized by differing degrees of "abstraction." For example, 'x is related to y' is more abstract than 'x is kind to y;' and 'x is kind to y' is more abstract than 'John Jones always helps his mother wash the dinner dishes.' That is, 'John Jones always helps his mother wash the dinner dishes' is the least abstract of the foregoing set of sentences in the sense that its correspondence with concrete occurrences can be

judged in a more direct way than its predecessor. Similarly, 'x is kind to y' can be tested through a less complex procedure than 'x is related to y;' hence the former is less abstract than the latter.

It is characteristic of the empirical sciences to take theoretical constructs, or terms of the highest level of abstraction, as the primitive terms of a scientific system. These abstract terms are housed within primitive sentences called axioms. The abstract terms, and consequently the axioms, have no direct empirical interpretation. Through deduction, in conjunction with definitional chains, successive levels of less abstract statements are derived. The lowest level statements are couched in elementary terms which are connected to the plane of observation by the semantical rules provided by some sort of operational definitions. The elementary terms and statements, then, are directly interpreted with reference to observations; the terms of highest abstraction are interpreted only indirectly through deductive and inductive inference.

The foregoing viewpoints form a highly simplified backdrop for the development of R-paradigms and A-paradigms. The complexity of the curricular/instructional domain requires the construction of related hierarchies of paradigms, where each hierarchical system of paradigms bridges the abstract-concrete gap between values and actions, and where at least some paradigms within a hierarchical system also must bridge an abstract-concrete gap.

This line of reasoning explains the fact that paradigms presented in this volume are framed over varying levels of abstraction.

2.4 <u>Analysis of R-Paradigms</u>.

2.4.1 The R-Paradigm in Perspective.

In order for an achievement of science to merit the label "scientific paradigm" in the Kuhn sense of paradigm, several crucial tests must be satisfied:

(1) The achievement must include integrating conceptualizations capable of providing focus and evaluative methods and standards for a field of study;

(2) The achievement must be characterized by sufficient power and open-endedness to stimulate and guide research and development efforts for substantial segments of a profession or discipline over an indefinite period of time;

(3) The achievement is "sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity."

Although the PARADIGMS Project has operated under the proposition that curricular and instructional research should be modeled on the essential characteristics of empirical science, and consequently

should operate under a paradigm that passes each of the foregoing tests, there are significant distinctions between a science and a field of practice that entail corresponding distinctions between a paradigm of science and a paradigm of the curriculum/instructional domain. These distinctions now must be identified.

Although many practicing scientists may believe that their paradigms and actions as scientists are value-free or ought to be value-free, this belief or expectation is incapable of being achieved in fact. For example, the decision to have a science in the first place is a value decision, the selection of problems is dependent upon values, and values enter into every decision as to whether the evidence is strong enough to warrant acceptance of an hypothesis. Philipp Frank's little book, *The Validation of Scientific Theories* [6], is one of the best of a number of sources of reflections which make it quite obvious that every scientific enterprise is ultimately supported by an axiological base. It may be true, of course, that the axiological base remains implicit to a considerable extent, but future advances most likely will include explicit formulation and systematic study of the axiological bases as a crucial extension of the scope of scientific endeavor.

Thus, careful analysis seems to warrant the judgment that values do, in fact, govern scientific formulations and evaluations. This is also true of formulations and evaluations in the curricular/

instructional domain. Yet, there is a way in which values are introduced into the curricular/instructional domain that has no analogue in the sciences.

The curricular/instructional domain, in both the research and applied aspects, is the province of a *profession*. Moreover, every profession is characterized by three interrelated bases: 1) a pragmatic base, 2) a conceptual base, and 3) an axiological base, where

(1) the *pragmatic base* is defined by the unique service rendered to members of the society, and which is supported by the society. The professional is obligated to promote change toward more desirable client states, and this obligation entails a professional-client relation;

(2) the *conceptual base* is the body of knowledge--"know that" and "know how"--which provides the unique theoretical information and techniques for performing the service, and which is distinct from the conceptual bases of other fields of endeavor;

(3) the *axiological base* is defined by the system of statements that spells out that which the professional is obligated to do, permitted to do, and forbidden to do. This value system includes statements

of at least two kinds: (a) statements that specify the professional responsibilities and (b) statements that regulate the way in which the responsibilities are satisfied.

At this point it is necessary to examine the relations among curricular/instructional research, practical action with reference to curriculum and instruction, and professional values. Careful analysis of these relations will entail the conclusion that a significant distinction ought to be made between a *scientific paradigm* (in the Kuhn sense) and its analogue, *educational paradigm*. It is also believed that the analysis entails a new concept of adequate research in the curricular/instructional domain.

Assuming that instructional action is rational, then there is an associated claim of the type:

> "Under circumstances C, course of action A will influence pupil X to attain objective θ."

Note that instructional objective θ corresponds to the decision of some set of professionals as to what constitutes a desired pupil state. The replacements for θ that are obligatory, permitted, or forbidden, however, are determined by the statements of the axiological base to which the professionals are committed. For example, suppose one of the primitive

statements of the professional value system is:

> "The professional (teacher) is obligated to act in such a way as to treat the client (pupil) as a rational agent."

Let the concept of "rational agent," in this case, be extended to include the acceptance of any assertion, Q, by pupil X only if X can provide sound reasons for acceptance of Q. These conditions have significant consequences with respect to the objectives that are permitted as replacements for θ . Objectives only at the *knowledge* level of the Bloom Taxononomy: Cognitive Domain, for instance, would be ruled out by the professional obligation. That is, conditions of knowledge in the Bloom sense permits acquisition of principles with no supporting reasons; the foregoing professional value statement, however, requires that the pupil acquire only principles for which he can provide adequate supporting reasons. The Bloom taxonomy permits learning in the weak sense; the value statement permits learning only in the strong sense.

Since the professional value system has implications for the objectives permitted, and the objectives are taken into account as a component of the instructional claim, and the aim of instructional research is to develop systems of valid instructional claims (propositions),

then the professional value system imposes limits on those claims of interest. Consequently the professional value system imposes limits on the instructional research of interest.

Moreover, note that the foregoing professional value statement rules out the use of behavioral modification techniques based on operant conditioning, the use of drugs, or propaganda in the course of instructional action taken in order to influence the pupil to attain some set of objectives. Since this is the case, then research on educational uses of operant conditioning, application of drugs in school learning situations, and development and testing of propaganda techniques as models for instruction would be not relevant to either research or curricular/instructional action conducted by professionals operating under the specified value statement.

The consequence of this line of reasoning is that a paradigm of the curricular/instructional domain cannot be a research paradigm alone as is the case with scientific paradigms. A paradigm of the curricular/instructional domain must be a two-sided paradigm. It must have a research side and also a curricular side; it must be a research generator and also a curricular generator. Further, a paradigm of the curricular/instructional domain must be characterized by some associated axiological system or systems.

2.4.2 Analysis of R-Paradigms.

A commitment has been made to conduct the research and development activities of the PARADIGMS Project under the essential characteris-

tics of science. This commitment entails that three distinctly different, but related, considerations be taken into account. One necessary consideration is the system of axiological statements under which the activities will be conducted. A second necessary consideration is the system of logical statements that describe, prescribe, or explain practical actions and decisions. The third necessary consideration is the system of concrete actions, decisions, and constructions that "cash in" the logical and axiological statements. It should be noted that these three considerations correspond to the value, theory, and observational planes of the empirical sciences.

The foregoing considerations form the backdrop for framing three different classes of research paradigms, or *R-paradigms*. These three classes of R-paradigms will be labeled R_V*-paradigms*, R_L*-paradigms*, and R_K*-paradigms*, where the labels have the following meanings:

> R_V*-paradigms* are paradigms that set forth axiological propositions serving these purposes:
>
> (1) set forth the aims of research;
>
> (2) set forth the basic obligations, permissions, and prohibitions under which the researcher operates;

R_L-paradigms are paradigms that set forth the logical conditions under which research activities will be conducted and under which constructions will be made and evaluated. R_L-paradigms at least implicitly represent logical propositions (*i.e.* "is" statements) which provide direct guidance for concrete action of the researcher and facilitate realization of the accepted axiological statements.

R_K-paradigms are paradigms that are concrete in nature. They are concrete achievements of a research enterprise that satisfy two conditions:

(1) the achievement is consistent with R_V- and R_L-paradigms, and

(2) the achievement has sufficient merit to serve as an exemplar for other research efforts.

2.5 Analysis of A-Paradigms.

One purpose of the PARADIGMS Project is to develop systematically organized directives which can act as valid guides for the activities

of constructing and evaluating curricular/instructional systems. These practical directives will be framed as "action paradigms," or *A-paradigms*.

It will be useful to distinguish among different classes of A-paradigms. The three considerations of the preceding section again seem to apply very nicely to the analysis. Therefore, A-paradigms will be framed in terms of three different classes, where the classes correspond to axiological, logical and concrete representations. The labels A_V*-paradigms*, A_L*-paradigms*, and A_K*-paradigms* will be assigned under the following meanings:

> A_V*-paradigms* are paradigms that set forth
> either
> (1) value theory which functions as a descriptive or explanatory system where values are the phenomena described or explained;
> or (2) propositions or directives to serve as guides in formulating or evaluating systems of axiological propositions in the curricular/instructional domain;
> or (3) axiological systems that have sufficient merit to serve as exemplars for other axiological systems in the curricular/instructional domain.

A_L-paradigms are paradigms which at least implicitly represent systems of logical propositions of either of these types:

(1) the propositions are descriptive or explanatory hypotheses;

or (2) the propositions are practical directives.

A_L-paradigms set forth the logical propositions which guide practical curricular/instructional decisions and actions; of course the propositions must be empirically interpretable.

A_K-paradigms are paradigms that are concrete in nature. They are concrete curricular/instructional constructions or evaluations that have sufficient merit to serve as exemplars for other curricular/instructional constructions or evaluations.

3. OBJECTIVES OF THE PARADIGMS PROJECT

As indicated earlier, the PARADIGMS Project was concerned with the problems of developing paradigms for guiding curricular and instructional decisions of different logical types and at a number of different levels of resolution. In order to be more specific, a more

detailed explication of the various project objectives is provided below.

3.1 [θ_1]: The Construction of R-Paradigms.

One of the major project objectives was to learn how to construct research paradigms for developing the practical directives required for disciplined decision making within the C/I domain. To this end, three subobjectives were formulated; namely to construct

1. *R_V-Paradigms* [$\theta_{1.1}$]: axiological propositions for governing C/I research;
2. *R_L-Paradigms* [$\theta_{1.2}$]: logical conditions necessary to adequate C/I research and development;
3. *R_K-Paradigms* [$\theta_{1.3}$]: an exemplar; that is, a complex of C/I research studies conducted under specified R_V- and R_L-Paradigms.

3.2 [θ_2]: The Construction of A-Paradigms.

A second major project objective was to learn how to construct action paradigms that are faithful reflections of the R-Paradigms. To this end, three subobjectives were formulated; namely to construct

1. *A_V-Paradigms* [$\theta_{2.1}$]: axiological propositions for governing C/I decisions and actions;
2. *A_L-Paradigms* [$\theta_{2.2}$]: logical conditions necessary to adequate C/I decisions and actions;

3. A_K-*Paradigms* $[\theta_{2.3}]$: an exemplar.

It should be pointed out that an A_L-Paradigm would consist of directives for *guiding* practical action in the C/I domain; on the other hand, an A_K-Paradigm would constitute an actual set of actions (an exemplar) which, presumably, would conform to the requirements and conditions specified by the directives.

PART B: PARADIGMS FOR RESEARCH

4. AN R_V-PARADIGM: A SYSTEM OF AXIOLOGICAL PROPOSITIONS

> *Proposition #1.* Curricular/instructional research ought to be conducted under the conditions of professional action.

The bases for justification of proposition #1 were provided in Part A, particularly Section 2.4, "Analysis of R-Paradigms", and they are elaborated upon below.

A profession is distinguished by three unique and interrelated bases; namely, a *pragmatic* base, a *conceptual* base and an *axiological* base. Action of a practitioner performed with reference to these bases is appropriately called *professional action*. The question at issue here is whether curricular/instructional research should be so restricted.

Curricular and instructional action is supported by the society for the purpose of satisfying the educational aims of that society. These educational aims, and identification of the clients to be served, constitute major aspects of the pragmatic base of the education profession. Members of the society supporting curricular/instructional research have the very reasonable expectation that the

research will be useful in achieving the goals which have been specified.

The nature and significance of the *instructional claim* have been examined at length at an earlier point of the volume, and an illuminating illustration of one is given in a subsequent section, 8.1 "A Statement of Perspective." A professional value system (*i.e.* axiological base) imposes restrictions on the statements which set forth the *ends* component and the *means* component of an instructional claim. The consequence of this fact, taken together with the arguments presented in the preceding paragraph, is that the pragmatic base, in conjunction with the axiological base of the education profession appropriately impose limits on the instructional research of interest.

It also should be pointed out that curricular/instructional research must have empirical import; its statements must be tested in a fashion that involves pupil behavior. The proposition that curricular/instructional research ought to be conducted under conditions of professional action requires that all statements and empirical tests be regulated by a professional value system. This guarantees against unscrupulous motives or actions in C/I research or in derived practices.

It is important to recognize that the conceptual base of the profession has played an important, although implicit, role in the foregoing discussion. For example, the very concepts of *profession, instructional claim,* and *falliability of claims* belong to the conceptual base. Reflections on the interactions among the bases of the profession is also enlightening. It is the case that the axiological and pragmatic

bases of C/I action are dependent upon, and limited by, the knowledge available at any given point in time. As the relevant knowledge (conceptual) base becomes more and more powerful, then concomitant changes in both the pragamatic and axiological bases are more likely to occur. Changes in the pragmatic or axiological bases will influence the research and development endeavors which, in turn, contribute to the conceptual base. It is true, however, that the conceptual base is likely to expand more rapidly than the other bases if research is conducted under a paradigm in the Kuhn sense.

> *Proposition #2.* Curricular/instructional research ought to be conducted under conditions of rational action.

The defining conditions of rational action were stipulated in Part A of this volume, "The Paradigms Project in Perspective." Briefly, the conditions required specified goals or objectives, specified procedures and reasons for believing the procedures will lead to goal attainment, specified criteria for evaluating outcomes, and consistency between planning and implementation. Partial justification of the obligation to act rationally in the curricular/instructional context was also provided in Part A.

The fact that curricular/instructional research has potential worth only if its products are capable of being applied in the professional-

client situation, in conjunction with the requirements of proposition #1, suggests the conclusion that C/I research be aimed toward construction of valid systems of practical directives in the C/I domain. That is, C/I research ought to be goal-oriented. The other conditions of rational action would seem to follow since they are necessary conditions for goal realization.

The foregoing view sharply distinguishes C/I research from research of the natural sciences, for example, where "pure" research is characteristically supported; there is no place for "pure" research in a *professional* domain. The point is that education is a field of practice whose advance depends, in part, on the basic research of mathematics, logic, linguistics, communications theory, value theory, cognitive theory, and other foundational disciplines. Although education is free to select and utilize information from foundational fields, the information must always be recast and incorporated into compatible and highly complex educational systems. Fruitful research in education is concerned with constructing, evaluating, and improving these complex educational systems in the presence of well articulated pragmatic and axiological requirements; hence, the obligation to operate under the conditions of rational action as asserted in proposition #2.

> *Proposition #3.* Curricular/instructional research ought to be modeled on the essential characteristics of empirical science.

The essential characteristics of science include at least: 1) the aim of science, 2) the ways of inquiry, 3) the nature of scientific systems; *i.e.* "scientific theory", 4) the ways of evaluating scientific theory, and 5) the way of advance. In the following paragraphs, these characteristics are expanded upon--as a precursor to an argument in support of proposition #3.

(1) *What is the aim of science?* Ernest Nagel [20] states the aim of science in this way:

> The major impulse which generates science is the desire for explanations that are at once systematic and controllable by factual evidence. The distinctive aim of science is therefore the discovery and the formulation in general terms of the conditions under which events of various kinds occur, the generalized statements of such determining conditions serving as explanations of the corresponding happenings.

A scientific explanation of empirical phenomena, or of particular empirical statements, is provided by some set of general propositions of which the empirical phenomena are instances, or from which the specified empirical statements can be deduced.

In Carl Hempel's excellent little book, *Philosophy of Natural Science* [10], he proposes two requirements for scientific explanations: 1) *explanatory relevance*, and 2) *testability*. The former demands good grounds for expecting or believing the empirical

phenomena will occur under the specified circumstances, and the latter demands that a statement constituting a scientific explanation must be capable, in principle, of empirical test.

(2) *What are the ways of scientific inquiry?* The ways of scientific inquiry--*retroduction, deduction* and *induction*--have been explicated and illustrated by Elizabeth Maccia in two papers: *Ways of Inquiry* [19] and *The Model in Theorizing and Research* [18]. Retroduction is the creative process of formulating theory statements. Although Maccia has attempted to develop retroductive methodology, neither she nor others would claim that there exist rules for generating fruitful theory statements. Nagel [20] places retroduction in this perspective:

> Without...hypotheses, inquiry is aimless and blind. However, there are no rules for constructing valuable hypotheses; and as Albert Einstein repeatedly observed, those systems of hypotheses that constitute the theories of modern physics are 'free creations of the mind', requiring for their invention and elaboration feats of imagination quite analogous to creative effort in the arts.

If a theory statement (an hypothesis) has been set forth, it must be tested. *Deduction* and *induction* are the ways of inquiry available for distinguishing adequate statements from inadequate statements. Deductive inference is invoked to explicate hypotheses in terms of lower level consequents. These consequents must be of such concrete-

ness and specificity that between-observer and within-observer invariance can be achieved in reporting relevant observational phenomena. Inductive inference, on the other hand, is invoked to bridge the directional gap from the reports of observational phenomena to the derived consequent statements, and ultimately to the hypothesis under test. The inductive inference is represented in the form of a judgment as to whether a hypothesis has been tentatively confirmed or disconfirmed.

Scientific inquiry consists of a continuing series of repeating retroduction-deduction-induction cycles. Either directly or indirectly, they are invoked over and over again on every aspect, and at every state, of the knowledge structures under development: the extralogical vocabulary, the statements of the structures, and the relations among the structures. No assertion is free from critical examination and judgment except the presuppositions under which all scientific inquiry operates.

The consequence of the series of retroduction-deduction-induction cycles is a non-terminating set of theoretical structures characterized by increasing predictive and explanatory power. Inadequate structures are identified and abandoned, or are replaced by modified structures which in turn become objects of evaluation. Strong constructions can withstand the most rigorous tests; investments can be made

in these strong constructions.

(3) *What is the nature of scientific theory?* Carl Hempel, in *Aspects of Scientific Explanation* [8], has described the *structural* characteristics and the *functional* characteristics of scientific theory.

The *structure* of scientific theory satisfies the requirements of a deductive system. The vocabulary of a theory (*i.e.* the extralogical terms; the constructs which have empirical referents--at least indirectly) consists of undefined terms (*i.e.* primitive terms) and defined terms. The set of sentences of a theory consists of axioms (primitive sentences) and theorems (derived sentences). In the theoretical structures of empirical science, the deduced theorems are typically called hypotheses. The structure is formulated under explicit rules for forming sentences and for judging the validity of a deductive inference.

On the other hand, the *functional* characteristics of a theory of empirical science are defined by the power of the theory to predict and explain empirical phenomena. Explanatory and predictive power is made possible by the deductive rules governing the theory in conjunction with operational definitions which give the extra-logical terms empirical import. These are the means for bridging the gap between the abstract statements constituting a theory and the concrete observational objects and events to which the theory is relevant.

To claim to have formulated a theory is not sufficient. The theory formulated must be examined and judged. Adequate evaluation of

scientific theory must include examinations relevant to both the structural characteristics and the functional characteristics of the theory.

(4) *What are the ways of evaluating scientific theory?* Karl Popper, in *The Logic of Scientific Discovery* [22], has identified four different ways of evaluating scientific theory: 1) assessing the coherence of the theory by making logical comparisons among its statements to determine if there are inconsistencies; 2) assessing the logical form of the theory to determine if it has the characteristics of a theory of empirical science; 3) assessing the potential of the theory for contributing to scientific advance if it should withstand all logical and empirical tests; comparison with other theories is the methodology for this assessment; and 4) assessing the correspondence of the theory with real world objects and events; the methodology for this assessment requires both deduction of more concrete statements from the abstract theory statements, and inductive inference based on empirical observations which result in judgments of support or non-support for the truth of the theory statements.

(5) *What is the way of scientific advance?* Until a first *paradigm* (in the Kuhn sense) exists, there is no science. In the presence of a paradigm which focuses research efforts and minimizes debate on first principles, problems of significance, and evaluative standards, a period of *normal science* occurs which is characterized by

rapid knowledge development with reference to the paradigm. Eventually, this very knowledge development leads to the recognition of anomalies and unresolved puzzles, and finally to a competing paradigm or paradigms; commitment to the original paradigm gives way to commitment to a successor paradigm with its associated period of rapid progress, and the cycle repeats.

Although the swift summaries displayed here and in section 1.4, "Curricular/Instructional Research: The Necessity of A First Paradigm", do not do justice to Thomas Kuhn's potent explanation of the way of scientific advance, they act as pointers toward a powerful point of view that is relevant to educational advance.

Now that the essential characteristics of science have been identified and discussed, the proposition that curricular/instructional research ought to be modeled on those characteristics needs to be justified. One line of justification of the proposition was provided in Part A; namely the correspondence between instructional claims and scientific hypotheses, or claims, was demonstrated.

As a second line of justification, it is important to note that, as in science, explanations that are both systemic and empirically valid are necessary outcomes of curricular/instructional research of worth. C/I research conducted in the absence of this aim is blind, and fruitful results are highly unlikely. Therefore, the aim of C/I research and the aim of science appear to be congruent.

A third line of justification for proposition #3 is based upon a demonstration that curricular/instructional systems and scientific systems have similar functional requirements. Consider first the common curricular/instructional problem of determining the degree to which students have progressed toward some set of abstract educational goals. Somehow the gap must be bridged from the abstract goals to the construction of particular tasks relevant to those goals, and then to the behavior of a student interacting with the tasks. Then the gap again must be bridged, but this time in the opposite direction beginning with an examination of correspondence between pupil behavior and task performance standards, and terminating with an inference as to whether the student is characterized by the defining properties of the abstract goals.

Consider next the common scientific problem of determining the degree to which observational phenomena are explained or predicted by some set of abstract axioms and hypotheses (*i.e.* a "scientific theory"). The gap must be bridged from the abstract statements to particular indicants or measures relevant to the abstract statements, and then to the particular observational phenomena of concern. At this point, the gap must again be bridged, but in the reverse direction. First, the behavior of the phenomena under study is compared against the standards associated with the indicants or measures; then, based upon this comparison, a judgment is made as to whether the abstract statements accurately explain or predict the observed phenomena.

In the second instance, the problems associated with testing the degree to which abstract statements correspond with observational evidence have been studied extensively, and the methodologies for handling these problems are well developed. The abstract-to-concrete gap is bridged by deriving more specific statements from the abstract statements. It is this *deduction in conjunction with operational definition* that makes it possible to construct logically relevant indicants or measures. *Induction* is the method available for bridging the gap in the concrete-to-abstract direction. It should be noted that these methodologies also entail certain restrictions on the abstract statements themselves. That is, the first statements, or axioms must meet certain logical requirements, *e.g.* consistency and independence.

At this point the third line of justification can be fully explicated by the following statements:

(1) The functions of both curricular/instructional systems and scientific systems require methodologies for bridging the abstract-concrete gap.

(2) Scientific systems *are characterized by* the *presence* of successful development and use of *the required methodologies.*

(3) Instructional systems *are characterized by* the *absence of the required methodologies.*

It seems only reasonable, therefore, that curricular/instructional systems ought to borrow the required methodologies from the scientific systems.

It should be noted that although only a single component of an instructional system has been taken into account in the foregoing argument, *i.e.* goals or objectives, the argument can be extended to include instructional procedures and systems of instructional claims of the type previously described. The argument also obviously extends to associated evaluation systems since it would be clearly contradictory to build a structure under one set of specifications and then to ignore those specifications in evaluating that structure. The implication is that evaluation must include both logical tests and empirical tests of the instructional system.

A fourth line of justification of the proposition that C/I research ought to be modeled on the essential characteristics of science is provided by Tadeusz Kotarbinski [15]. Kotarbinski analyzed the circumstances under which substantial advances in a field of practical action are most likely to occur. Kotarbinski's analysis yielded the conclusion that advances are most likely to occur in the presence of some combination of these conditions:

(1) There is an advance in the theoretical foundations of potential relevance to the field of practical action.

(2) There is an advance in the technological foundations of potential relevance to the field of practical action.

(3) Available, but previously ignored, information from potentially relevant theoretical or technological foundations is utilized by the field of practical action.

(4) There is a different selection or different ordering of actions in the field of practical action.

With reference to curricular/instructional advance, under Kotarbinski's analysis C/I research and research endeavors should include search of theoretical foundations for new or previously not utilized information of potential usefulness. In the C/I domain, certain theoretical formulations are of special interest: psychology (particularly learning theory), sociology, the disciplines underlying the various curricular areas, logic, semantics, philosophy of action, philosophy of science, and so on. For example, the development of Piaget's theory of cognitive development (an advance in psychological theory) may provide information which leads--if utilized--to advance in the validated directives of education. As another example, information in a discipline underlying a school curriculum--for instance, the language of sets, relations, and functions in mathematics--may eventually be taken into account with resulting advances in teaching; this, in fact, was the case with the substantial improvements of school mathematics curricula in recent years.

Similarly, the ways of organizing information and the methods

of evaluation in the empirical sciences constitute clear methodological advances capable of application to the curricular/instructional domain. These advances never have been fully utilized in education, even though other fields have progressed by modeling on the natural sciences in particular; and the natural sciences themselves have modeled their scientific systems on mathematical structures.

The PARADIGMS Project has attempted to utilize fundamental advances of the sciences to a degree not previously conceptualized nor implemented in curricular/instructional research. It is believed that by such means as these that substantial advances are likely to occur in education.

5. AN R_L-PARADIGM: CONDITIONS OF ADEQUATE CURRICULAR/INSTRUCTIONAL RESEARCH

The foregoing axiological propositions have consequences for curricular/instructional research conducted in the presence of commitment to them. These consequences are based on the obligations of the researcher to act under conditions of a professional value system, rational action, and the essential characteristics of science. The following conditions are set forth as a crude initial attempt at framing crucial consequents.

> *Proposition:* A program of curricular/instructional research is adequate if and only if the following

conditions are satisfied:

(1) There exists an adequate professional value system to which the researchers are committed.

(2) Research aims, strategies, and evaluative standards are specified and implemented.

(3) Inquiry in the curricular/instructional domain should satisfy the essential conditions of the scientific model:

a) the knowledge structures of C/I studies should satisfy the structural and functional characteristics of scientific theory;

b) the knowledge structures formulated should be judged under each of the four ways of evaluating scientific structures;

c) the research strategy should be built and conducted under an educational analogue of a scientific paradigm.

(4) Development of the extralogical vocabulary of C/I theorems should take into account knowledge of the potentially relevant theoretical and technological foundations. This requirement demands continuing research into these foundations, as well as the philosophical foundations.

(5) Alternating philosophical and empirical inquiries should be deliberately undertaken to develop the extralogical language to more refined levels.

(6) Continuing study should be undertaken into the full range of scientific C/I inquiry and the relations between the different logical levels of curricular and instructional knowledge structures; that is, the strategy should be a comprehensive strategy.

6. AN R_K-PARADIGM: THE ANATOMY OF THE PARADIGMS PROJECT STUDIES

In addition to the theoretical and practical constructions of the present volume and the cooperative efforts with Texas Christian University toward developing an educational analogue of a scientific paradigm, eight empirical studies were conducted under the PARADIGMS Project.* The eight empirical studies constitute a related set of investigations directed toward development of a theory of sequencing.

*All eight empirical studies are reported in full in VOLUME II: EMPIRICAL STUDIES.

All of the studies satisfied essentially the same conditions of adequacy--which, in turn, were determined mainly by the acceptance of the propositions stated earlier. One important condition that was invoked, for example, was the requirement to carry out all of the investigations under management of an IBM 1500 CAI Instructional System--for the purposes of maintaining control of potentially critical variables, and hence to enhance the likelihood that each study could be *replicated* down to the most minute detail.

The eight studies were divided into three subclasses--*modes of representation, structure of curriculum hierarchies,* and *choice behavior*--according to the particular class of variables with which they were concerned. The authors view these studies as related elements of a single integrating structure. The remainder of this section is intended to bring that structure into sharp focus. The research anatomy that is displayed constitutes an R_K-paradigm; that is, concrete research activities of sufficient merit to be used as a model for other research endeavors.

6.1 The Mode of Representation Studies.

One class of studies which has been initiated is concerned with modes of representation (MR) variables, their effect on mathematics learning, and the resultant implications for the design of instructional sequences. In this connection, Bruner [2] has observed that:

> Any domain of knowledge (or any problem within that domain of knowledge) can be represented in three ways (a) by a set of actions appropriate for achieving a certain result (enactive representation), (b) by a set of summary images or graphics that stand for a concept without defining it fully (ikonic representation), and (c) by a set of symbolic or logical propositions drawn from a symbolic system that is governed by rules or laws for forming and transforming propositions (symbolic representation).

In the MR studies, as well as all of the others, a detailed format for preparing instructional objectives was developed in which each objective is viewed as consisting of three components:

(1) *The Given:* This component of the objective is a statement of the condition(s) under which the task is presented. It is a description of the stimulus conditions and represents the *input* phase;

(2) *The Required Performance:* This component of the objective is a statement of the expected task performance. It is a description of the response requirements and represents the *output* phase;

(3) *The Criterion:* This component of the objective provides the means for evaluation. It is a description of the conditions by which, for a given *input*, the *output* is adjudged to be satisfactory or unsatisfactory.

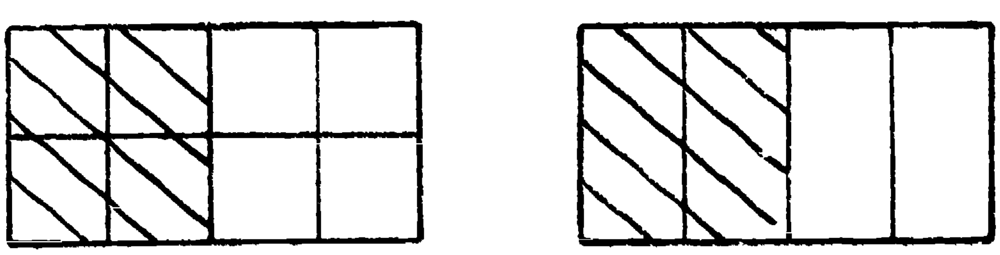
Interestingly, the interaction of the study of MR variables and the task of designing a framework for formulating instructional

objectives led to the idea of classifying objectives as MR-ordered pairs (M_i, M_o) according to the mode of representation, M_i, of the stimulus condition (input), and the mode of representation, M_o, of the required performance (output) specified by an objective. For example, consider the objective:

Given	Required Performance	Criteria
Two partially shaded rectangles which depict a pair of equivalent fractions.	Write the pair of equivalent fractions suggested by the diagrams.	3 of 4 items in time *t*.

The above objective defines an unambiguous "test" pool, as did all of the objectives that were written. An instance in the present case would be:

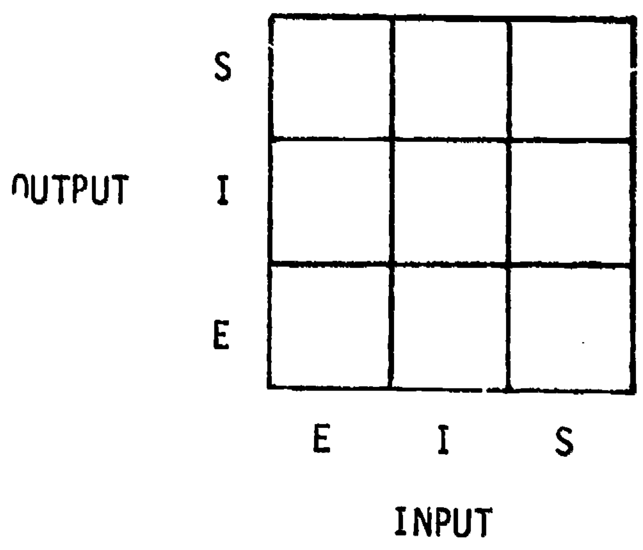
Write the pair of equivalent fractions suggested by the following diagrams. ________________



The foregoing objective would be classified as an (I, S) ordered pair since the mode of representation of the given (the *input*) is ikonic, and the mode of representation of the required performance (the *output*)

is symbolic.

The scheme of classifying objectives in the manner described above then led to the idea that for a given unit of content or concept, it is possible to construct up to nine *content-equivalent* objectives which differ only in terms of the mode of representation of their input or output. The possibilities are revealed by a modes of representation matrix:



A collection of objectives arrived at in this way was called a *cluster* of objectives, and an illustration of one is provided in Table 1.

Table 1

A Cluster of Objectives for the Concept of Equivalent Fractions

OUTPUT MODE			
S	Given: A pair of equivalent fractions depicted with Cuisenaire rods. Required Performance: Write a pair of equivalent fractions suggested by the rods.	Given: Two partially shaded rectangles depicting a pair of equivalent fractions. Required Performance: Write a pair of equivalent fractions suggested by the diagrams.	Given: A fraction. Required Performance: Select from a set of 4 fractions the one that is equivalent to the given fraction.
I	Given: A pair of equivalent fractions depicted with Cuisenaire rods. Required Performance: Select from a set of 4 diagrams the one which depicts the same equivalence.	Given: Two partially shaded rectangles depicting a pair of equivalent fractions. Required Performance: Select from a set of 4 diagrams the one which depicts the same equivalence.	Given: A fraction. Required Performance: Select from a set of 4 diagrams the one which depicts an equivalent fraction.
E	Given: A pair of equivalent fractions depicted with rods. Required Performance: Construct the same equivalence using different colored rods.	Given: A pair of partially shaded rectangles depicting two equivalent fractions. Required Performance: Demonstrate the equivalence of the fractions suggested using Cuisenaire rods.	Given: A pair of equivalent fractions. Required Performance: Demonstrate the equivalence using Cuisenaire rods.
	E	I	S
	INPUT MODE		

This procedure for constructing clusters of objectives led, in turn, to the formulation of questions about how such a network (cluster) of objectives should be attended to. In an attempt to consider these questions, the first step that was taken consisted of trying to develop a *theory-level* representation of the system. This necessitated the construction of a symbolic language which it was hoped would afford an opportunity to draw upon the underlying logical meta-system, and hence increase the generative power of the representation. The basic elements of the MR language that was constructed are summarized below.

$\hat{\theta}$: A cluster of objectives, $\hat{\theta}$, is defined to be a set of objectives all of which pertain to the same mathematical content, but which differ in the mode of representation of their inputs or outputs.

θ_k: An arbitrary objective from some cluster $\hat{\theta}$.

E: The *enactive* mode of representation; it is considered to be synonomous with the object mode, and is such that the physical characteristics of the exemplar can be felt and manipulated.

I: The *ikonic* mode of representation; it is synonomous with the picture mode, and is such that the physical characteristics or qualities can be viewed, but cannot be felt or manipulated independent of the medium in which it is presented.

S: The symbolic mode or representation; it is taken to be a form of words or symbols (usually mathematical) having only ideational relation to the referent.

M: The set consisting of the modes of representation;

$$M = \{E, I, S\} .$$

$C(\theta_k)$: The classification of the objective θ_k as an MR ordered pair (M_i, M_o) where M_i is the mode of representation of the input phase of θ_k, and M_o is the mode of representation of the output phase.

$M_i \rightarrow M_o$: An instructional sequence expressly designed for the purpose of enabling a (qualified) learner to attain an objective θ_k, where $C(\theta_k)$ is (M_i, M_o).

$M_i \overset{\overline{A}}{\to} M_o$: An instructional sequence deemed adequate according to some well-formulated criterion. (For example, let n be the number of the students who fail to reach criterion on a pre-test for an objective θ_i, let s be the number of students reaching criterion after instruction, and let t be the greatest integer less than 0.8n + 0.5. Then the instructional sequence for θ_i is deemed adequate if and only if $s \geq t$.)

$\overline{A}(M_i, M_o)$: The achievement of an instructional objective without explicit instruction.

By using the foregoing symbolism, the original questions of interest can be expressed succinctly--as illustrated by the following example.

$$(I \overset{\overline{A}}{\longrightarrow} S) \Longrightarrow \overline{A}(S, I) .$$

This statement may be interpreted to mean that if explicit instruction to criterion is given on an objective with ikonic input and symbolic output, then without explicit instruction, achievement of an objective of like content with symbolic input and ikonic output will occur. Altogether, some 72 (=9·8) conditional statements of the above type

can be formed from the 3x3 MR matrix of objectives, and each can be subjected to empirical test. Moreover, the outcomes could have significance for the design of instructional sequences; for example, suppose that the statement

$$(S \xrightarrow{\overline{A}} I) \Longrightarrow \overline{A}(I,\ S)$$

receives empirical support over some specified class of objectives, but that the statement

$$(I \xrightarrow{\overline{A}} S) \Longrightarrow \overline{A}(S,\ I)$$

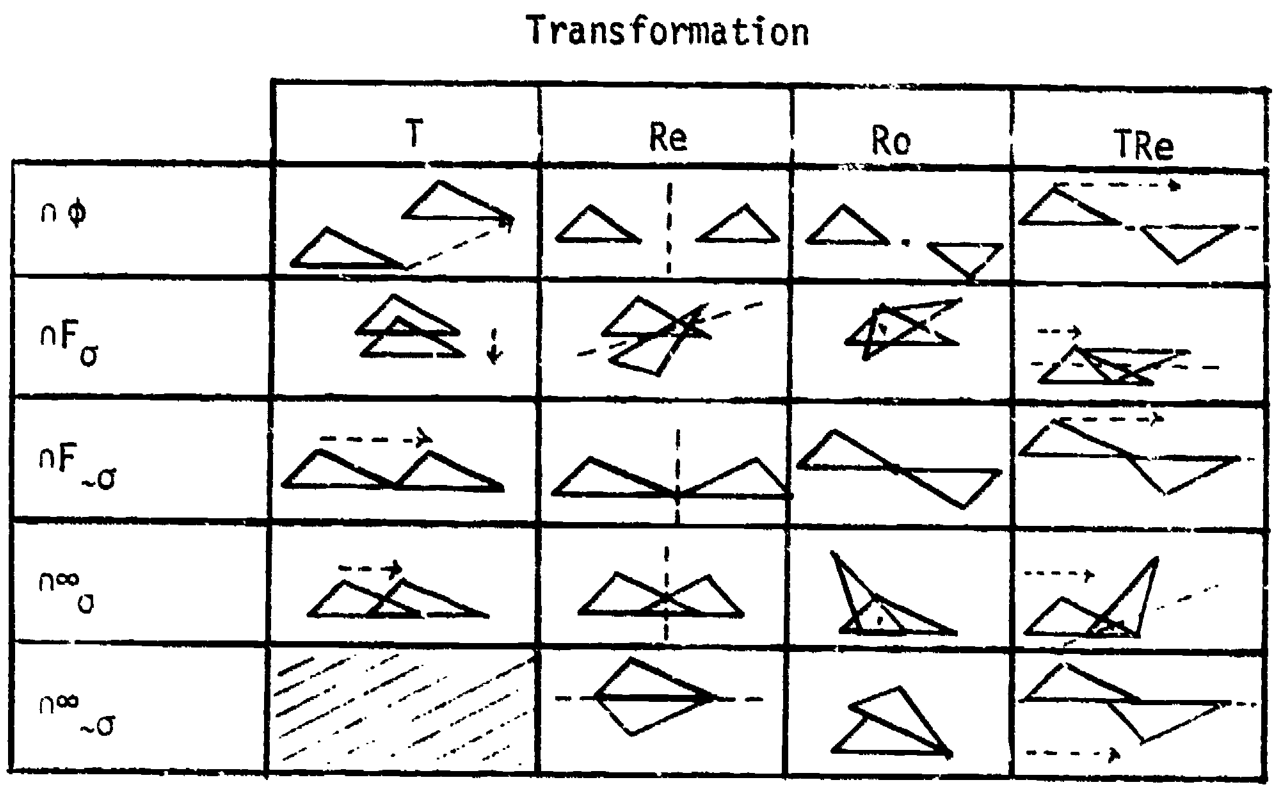
does not. In such a situation, if it is desired that both the $(S,\ I)$ and $(I,\ S)$ objectives be achieved, the presentation order would call for the $S \rightarrow I$ sequence first--in the interest of instructional efficiency. Actually, some of the outcomes of the research that has already been conducted hint at the possibility of outcomes of this sort.

The first MR study conducted along the lines described above was done by Klein [14], and it has served to define the central issues and modes of attack for resolving the "traversal problems" related to MR matrices. Two additional studies, by Farris [5] and Hirschbuhl [11] were constructed out of the same framework, but

tested other hypotheses generated by Klein's conceptual structure.

Among the informal outcomes of the foregoing investigations was 1) a concern for developing more adequate definitions of the various modes of representation, and 2) a commitment to examine *within-mode* representations and their effects on learning. These concerns led to another class of MR studies initiated by Paquette [21] and Bowers [1]. In these studies, attention was focused on perceptual problems encountered in teaching the concept of congruent triangles. The basic question raised by Paquette was whether there are certain triangle configurations which, if attended to explicitly in instruction toward the attainment of specific behavioral objectives, imply achievement of the same objective over other triangle configurations without the need for additional explicit instruction. Bowers' study, on the other hand, was concerned with selected effects of multi-configuration instructional treatments. The attack on these problems was systematized by the development of a *transformation* × *position* classification grid for congruent triangles, as shown below. The use of the transformational variable is based on the fact that of any two congruent triangles, one is necessarily a translation, a reflection, a rotation, or a translation-reflection of the other [4]; the positional variable deals only with the relative position of one triangle to another. An exemplar of each class is pictured in the corresponding cell of the matrix.

Congruent Triangles Configuration Grid



In the above grid, the symbols have the following meanings:

T	means translation
Re	means reflection
Ro	means rotation
TRe	means translation-reflection
$\cap\phi$	means empty intersection
$\cap F_{\sigma}$	means finite intersection with overlap of interiors
$\cap F_{\sim\sigma}$	means finite intersection without overlap of interiors
$\cap\infty_{\sigma}$	means infinite intersection with overlap of interiors
$\cap\infty_{\sim\sigma}$	means infinite intersection without overlap of interiors

In essence, the studies conducted by Bowers and Paquette were intended to be a first step in determining how the attainment of objectives over given configuration classes affects attainment of the same objectives over other configuration classes. Their results are interesting to say the least.

6.2 The Structure of Curriculum Hierarchy Studies.

A pair of closely related studies that were concerned with the structure of curriculum hierarchies were conducted by Hopkins [12] and Sawada [25]. Interestingly, these investigations were a logical outgrowth of the MR studies--particularly those conducted by Klein, Farris and Hirschbuhl--in the sense that they employed the MR matrix as a frame of reference for the identification, selection and assessment of other constructs which they hoped would lead to the creation of additional basic structures in the development of a science of sequencing.

When Klein, Farris and Hirschbuhl probed the relationships among objectives differing only in modes of representation, they focused on one general kind of hypothesis: Given an adequate sequence of instruction designed explicitly to ensure mastery of an objective characterized by a given ordered pair of modes, will that same sequence of instruction also ensure mastery of other "content-equivalent" objectives characterized by a different pair of modes? Thus, the basic

question asked by the aforementioned investigators dealt with the general notion of transfer within a given cluster of objectives.

Sawada noted that, by recasting the notion of *intra-cluster* transfer into Piagetian terms, the question of transfer can be couched in terms of conservation (invariance) over the cluster (matrix). He also noted that any viable theory of sequencing also would have to attend to the problem of going from one cluster to another; that is, *inter-cluster* transfer. It was this latter issue to which Sawada addressed himself--by drawing from Piaget's theory of the development of intelligence in children. To be more specific, Sawada was primarily concerned with the construction of a Piagetian model for building *systems of objectives* that explicitly provide for both intra- and inter-cluster transfer, the basic constructs of the model being operational *reversibility* and *composition.* The appeal to Piagetian theory of intelligence was based on the idea that when reality is organized into a system having basic structural similarities with the structure of the learner's intelligence, then the learner will be more apt to be able to cope with the reorganized reality than he would otherwise.

In an effort to begin to explore the tenability of the foregoing hypothesis, Sawada concentrated his study on an investigation of sub-hypotheses relating specifically to reversibility, while Hopkins examined a set of specialized compositions.

6.3 The Choice-Behavior Study.

Another class of potentially fruitful investigations was opened by Hostetler [13] who conducted a study in the general area of learner choice-behavior. The major kinds of questions that Hostetler raised were as follows:

(1) How does *presentation order* affect the choice of an algorithm to solve a problem when two (or more) algorithms have been taught for solving the specified type of problem?

(2) How is choice-behavior affected by knowledge of the fact that the scope of applicability of one algorithm is greater (or less) than the other?

It is interesting to note that all of Hostetler's hypotheses were strongly rejected; indeed, their negations would have received strong support.

6.4 The Research Studies in Perspective.

The paradigm-like conceptual framework that generated the research complex under discussion focused attention on instructional objectives, instructional procedures, and the relations that link the two. The deductive structure of scientific systems, in conjunction with the methodologies for providing empirical interpretations of the abstract systems, constituted a model for developing systems of instructional objectives, systems of procedural statements, and systems of

instructional hypotheses. The conceptual framework directed attention to extra-logical language development as well as to logical aspects of curricular structures and empirical test; it also established rigorous evaluative standards as consequences of the requirement of replication and the concept of curricular/instructional structures as dynamic systems.

The initial *modes of representation* and *choice behavior* studies were exploratory studies not only toward the establishment of fruitful variables with reference to sequence, but toward the development of a powerful language for framing hypotheses; they also established a base for more sophisticated development of systems of objectives, procedural statements, and instructional hypotheses. The second generation MR studies will represent an increasing level of precision with respect to the concept "mode of representation;" that is, future studies will continue to refine the language of "modes of representation" and to formulate and test systems of hypotheses which utilize the refined concepts.

Although the first generation curricular structures were crude, the very fact that their structures were made explicit rendered them subject to analysis and improvement. The *structure of curriculum hierarchy* studies capitalized on the richness of the first generation MR studies, and introduced the new concepts of *reversibility* and *composition*. An advance of the greatest significance--in the view of

the authors--was the idea of modeling systems of objectives on formal properties of mathematical function (see the investigation reported by Sawada in Volume II, this report). This conceptual breakthrough opens new research veins to be exploited.

In summary, the authors have been impressed with the new perspectives gained and the rapidly increasing levels of sophistication developed over the brief period of existence of the PARADIGMS Project. The paradigm-like conceptual framework under which the project has operated seems to have permitted the researchers to work under conditions similar to those described by Thomas Kuhn as "normal science." It may be that the lessons to be learned from the history of scientific advance do indeed provide the key to educational advance.

PART C: PARADIGMS FOR ACTION

7. A_V-PARADIGMS: A SYSTEM OF AXIOLOGICAL PROPOSITIONS

The following statements constitute an attempt to specify a *consistent* set of crucial axiological propositions for governing curricular/instructional actions. These axiological statements are purposely very general in scope. As a system, however, it is intended that they incorporate the attribute of leading to a collection of lower-level (axiological) consequents of considerably greater specificity. The process for doing this would be similar to the one that is employed in a deductive system where theorems are derived on the basis of the logical implications of statements of the axiom set. At the present stage of development of the axiological base, no claim is made that the derivation of more specific or lower level axiomatic statements is as rigorous a process as is found in a formal deductive system. Furthermore, no claim is made that the specified axiological statements are either *complete* or *independent*.

> *Proposition #1*. Every C/I system ought to function in such a way as to promote changes toward a more desirable state in the client,

One of the major consequences of proposition #3, in conjunction with other previously stated assumptions, is that every C/I system should be constructed so as to incorporate those characteristics necessary to system improvement.

Proposition #4. Every set of C/I actions ought be be consistent with the conditions of

(1) professional action;

(2) rational action;

(3) scientific action.

The primary effect of proposition #4 is to assure that C/I actions are not incompatible with the research actions which accrue from the axiological statements specified in Section 4 of this volume. As an example of the nature of the requirements imposed by this proposition, observe that given a set of alternative C/I actions appropriate to a given situation, there would be an obligation to select that action, if any, which is judged to be most effective. Moreover, the proposition also would entail the obligation to provide adequate justification for the choice that is made.

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8. A_L-PARADIGMS: SYSTEMS OF PRACTICAL DIRECTIVES

8.1 A Statement of Perspective.

This section is concerned with A_L-paradigms. A_L-paradigms set forth the logical propositions which guide practical curricular/instructional decisions and action. These paradigms seem to belong to at least three different classes:

(1) Paradigms that are *instructional claims or components* of an instructional claim. These will be called *instructional paradigms*.

(2) Paradigms that guide the *formulation* of instructional claims or their components. These will be called *formulation paradigms*.

(3) Paradigms that guide the *evaluation* of instructional claims or their components. These will be called *evaluation paradigms*.

As previously described (see Section 2.4), an instructional claim is a statement of the form: "Under circumstance C, course of action A will influence (with a certain probability) pupil X to attain set of objectives θ."

An instructional paradigm may be a component of an instructional claim. For example, the very framing of such a claim requires making the course of action, A, explicit. Thus, the course of action

must be set forth as a set of statements, S. If the instructor, or instructional system is rational, then the various decisions and actions of instructing will correspond to S. If the instructional actions in fact correspond to S, and the circumstances, C, and objectives, O, of the instructional claim are properly delineated, then there is reason to expect that the objectives will be achieved and hence that the claim can be tested. The set of statements, S, guides the concrete instructional actions and appropriately is labeled an *instructional paradigm.*

The *statements* of instructional objectives also must be realized in the form of concrete tasks if the instructional claim is to become testable. At least some tasks, then, must be justified directly against the set of instructional objectives. Thus, it is appropriate also to view a set instructional objectives as constituting a paradigm that directly guides concrete instructional decision and action.

An instructional claim, or a system of instructional claims, sets forth a relation or set of relations connecting three components: *circumstances,* statements specifying *procedures,* and statements specifying *objectives.* Not only is each component comprised of propositions relevant to different aspects of the concrete instructional situation, but the instructional claim itself is a more complex proposition that links components which consist of simpler propositions or sets of

propositions. That is, the instructional claim reasonably may be viewed as an *instructional paradigm* of quite a complex nature; its components also are considered to be *instructional paradigms*, but of a simpler type.

These notions are illustrated by the following example. Note that the conditions of each of the three major components of the claim are framed as propositions testable against real instructional events. If this were not so, the claim would be empty and there would be no meaningful way to judge the worth of the specified course of action against outcomes.

Under the conditions that:

(1) the pupil is in the concrete operations stage of cognitive development (re: Piaget theory),

(2) the pupil is characterized by properties (s_1,r_1),* (s_2,r_2), (s_3,r_3), ... (s_j,r_j) with reference to curricular structure S,

and, IF a course of action defined by the following conditions is taken:

(1) the episode logic specified in Figure 1 [this volume] is used for each instructional episode,

(2) for all episodes, the episode is implemented in the context of a 1500 system,

*Each ordered pair (s_i,r_i) denotes a stimulus-response pair.

(3) the episodes are sequenced in the order T_5, T_4, T_3, T_2, T_1 where 'T' means "task set" and where T_1 satisfies the conditions of a Sawada curricular structure (see Volume II: Empirical Studies, pp. 561-562),

then the pupil will attain the objective defined by the following conditions:

(1) given a concrete-object representation of any fraction $\frac{a}{n}$, the pupil will be able to construct a concrete object representation of $\frac{b}{m}$,

(2) the replacements for a, n, b, m are limited to the set of possibilities defined by the use of Cuisenaire rods for the concrete-object mode of representation.

Having established instructional claims and their components as paradigms, the question arises as to how one might go about constructing these *instructional paradigms*. Systems of propositions specifying techniques or standards for instructional paradigm construction could be highly useful, although the testing of their validity would be highly indirect and tenuous. Such systems of propositions will be called *formulation paradigms*; in the subsequent sections these will include paradigms for CAI course production and paradigms for formulating

instructional objectives.

If there is a commitment to rational action, once instructional and formulation paradigms have been developed, then they must be evaluated. Hence the concern for the construction of systems of statements to guide evaluations, or *evaluation paradigms*.

8.2 A_L-Instructional Paradigms.

Brief syntheses of the various empirical investigations conducted under the auspices of the PARADIGMS Project were reported in Section 6 of this volume, and they will not be repeated here. Suffice it to say that each individual study was designed, among other things, with the thought in mind that it might provide useful information leading to the construction of practical directives for guiding C/I actions at the level of practice.

Though it is not argued that any A_L-paradigms have actually been constructed, the results of each investigation do have implications for the development of potentially valuable practical C/I directives. These implications are discussed in detail in VOLUME II: EMPIRICAL STUDIES.

8.3 A_L-Formulation Paradigms.

8.3.1 An A_L-Formulative Paradigm: A System of Propositions for Formulating Instructional Objectives.

The following definitions and propositions constitute a set

of specifications to guide the framing of instructional objectives. These specifications are intended to act as conditions against which to judge the adequacy or inadequacy of a given set of instructional objectives. Justification of the statements of the paradigm for formulating objectives is provided by the preceding A_V-propositions.

> *Definition #1.* An *instructional objective* is a statement of the form "*X will be characterized by property Q*", where
>
> (1) the permissible replacement set for X is a set of clients, or pupils; and
>
> (2) the permissible replacement set for Q is defined by the combinations of cognitive, affective, or psychomotor properties that are *possible*, but not *necessary*, characteristics of a member of the species *homo sapien;* and
>
> (3) Q is relevant to societal aims for education.

The effect of its logical form, in conjunction with the requirements of the extralogical terms, is to make an *instructional objective* a statement that is testable in principle. Moreover, the state of affairs delineated by an instructional objective must be capable of being realized in fact.

It should be noted that an instructional objective is a proposition. Furthermore, since we are attempting to operate under the scientific model, and systematization of its propositions is a fundamental characteristic of science, then we are concerned with casting instructional objectives as coherent systems. Indeed, the following proposition asserts that a hierarchy of related systems is needed in order to adequately frame objectives.

> *Proposition #1*. A curricular/instructional system is adequate if and only if its *objectives are set forth as a hierarchy of at least two systems:* a first-order system in which the objectives are set forth in terms of abstract properties or constructs, and a second order system in which the objectives set forth the desired properties as operations framed in observational terms.

Support for this proposition is provided by the A_V-*Proposition #4* making it obligatory that C/I action be consistent with scientific action. Under this obligation, one is confronted with the problem of bridging the gap between abstract educational aims and the real world of pupil behaviors. The abstract objectives must be reduced to

operations in order for reliable judgments to be made as to correspondence with observable events. Hence, at least two systems of instructional objectives are required: (1) a *first order system* in which the statements delineate the abstract aims and (2) a *second order system* in which the abstract properties (*i.e.* constructs) of the first order system are reduced to observable stimulus-response pairs.

> *Proposition #2.* A first order system of instructional objectives is adequate if and only if the following conditions are satisfied:
>
> (1) The system is a deductive system, where *deductive system* entails:
>
> a. explicit rules for forming sentences [*e.g.* "X will be characterized by Q"];
>
> b. explicit rules for judging the logical validity of any proposed sentence [*i.e.* transformation rules];
>
> c. primitive sentences;
>
> d. derived sentences.
>
> (2) The system is characterized by internal consistency.

(3) The system is partially justified against a professional value system.

(4) The system is partially justified against theoretical or technological foundations.

(5) The predicates contain only abstract terms (*e.g.* particular space-time points, specific objects, occurrences, and instances are not permitted).

(6) The system is capable, in principle, of empirical test.

It is important to note that the structural and functional characteristics of scientific theory have been invoked as a model for the structural and functional characteristics of a first-order system of instructional objectives. Under these conditions, it becomes possible to *explain operational* (or *behavioral*) *objectives* and consequent instructional tasks. Such explanatory power is typically absent in curricular/instructional systems. The absence of the power of explanation of behavioral objectives and tasks in the CAI context constitutes a defect of crucial proportions.

Condition (3) is necessary under the view that all curricular/instructional action ought to be conducted under competent and responsible professionals.

Condition (4) guarantees a comprehensive perspective, and is justified by *A_V-Proposition #3* in conjunction with the earlier Kotarbinskian analysis of the relations between a field of practice and its theoretical and technological foundations.

> *Proposition #3.* A second-order system of instructional objectives is adequate if and only if the following conditions are satisfied:
>
> (1) Each statement of the system is an instructional objective whose predicate is framed as an ordered pair (C, P), where C is a representation of a set of test conditions or stimulus conditions, and P is a representation of a set of reactions or response conditions (*i.e.* formulation rule).
>
> (2) Predicates of the primitive statements of the system contain only abstract terms.
>
> (3) Transformational rules are specified for judging the logical validity of proposed derived statements.

(4) The system is characterized by internal consistency.

(5) Each predicate (C,P) is explained by some subset of an adequate first-order system of instructional objectives in conjunction with a comprehensive map of the universe of situations to which the first-order system applies.

(6) The lowest level derived statements are framed in observational terms.

(7) For each lowest level statement, there is a corresponding set of tasks, indeterminant in number, that can be constructed.

On one hand these conditions are justified against the conceptualizations of Rudolp Carnap in *Testability and Meaning* [3] and Carl Hempel in *Fundamentals of Concept Formation in Empirical Science* [8]. On the other hand, they are justified against the scientific value of *comprehensiveness*. It is freely acknowledged that certain logical problems have not yet been ironed out; nevertheless the methodology proposed here appears to be justifiable and has proved useful in practice.

Construction of instructional objectives under the foregoing

propositions has these significant effects:

(1) Behavioral objectives and tasks are linked to abstract educational aims through explicit logical chains.

(2) Decisions as to instructional conditions are made deliberately on the basis of a comprehensive map of maximal scope.

(3) Totally new classes of instructional tasks are created.

(4) Each instructional task can be explained against basic educational aims.

(5) Coherence among instructional tasks can be achieved and validated.

8.3.2 CAI Curriculum Production Paradigms.

There are a multitude of problems associated with the task of getting course segments programmed, coded, debugged, and generally ready for implementation on most CAI systems. In the main, the foregoing problems can be traced to one or more of the following sources:

(1) The limitations imposed by the functional characteristics of the particular computer system that is available (*i.e.* the hardware, itself);

(2) The limitations imposed by the functional characteristics of the author languages, and other attending software, available for course preparation and presentation;

(3) The limitations imposed by the non-existence of a validated pedagogical knowledge structure relating C/I actions and learning outcomes.

The sources of difficulty cited in item (1), although outside the major concern of the PARADIGMS Project, are perhaps the most worrisome to educationists--since they (educationists) are basically unable to exert direct control over the characteristics that are indigenous to a particular computer (CAI) system. In any event, every CAI configuration imposes a set of restrictions on curriculum developers which has the effect of placing bounds on the range of instructional moves open to them. Such a restriction would be serious under conditions where a particular set of C/I actions were called for (in order to achieve a specified objective), but could not be performed because the CAI system did not incorporate the characteristics necessary to be able to do so. At the present time, the problem is tempered somewhat by the unavailability of practical directives (A_L-paradigms) for guiding instructional actions,* and hence a tendency on the part of CAI curriculum developers to "bend" to the technology. In the view of the

*This matter was discussed briefly in Section 8.2.

PARADIGMS Project, this is an unfortunate state of affairs that can be rectified only in the presence of a serious and disciplined effort to construct A_L-paradigms of the type mentioned above.

The sources of difficulty cited in item (2) also fell outside the scope of the PARADIGMS Project, and hence were not explored in any formal way as part of the work of the Project. It should be pointed out, however, that the design of author languages is a crucial factor in deciding whether CAI course segments can, in fact, be developed so as to conform to the requirements specified by the paradigms which have been constructed. In Section 7, for example, proposition #2 suggests that every C/I system ought to function in such a way as to allow the client freedom to be a rational agent relative to the actions of the system. Some author languages as normally invoked, *e.g.* COURSEWRITER, are in clear violation of this value statement. This is, in the view of the PARADIGMS Project, but one of a number of serious "software" problems that can, and should, be given serious attention by specialists in the field.

The difficulties specified in item (3) above have been discussed extensively in other sections of this Report, and these arguments will not be repeated here. Suffice it to say that a validated, pedagogical knowledge structure relating C/I actions and learning outcomes cannot be constructed "overnight." In recognition of this fact,

the investments made by the PARADIGMS Project to develop improved procedures for constructing CAI course segments were directed toward the formulation and documentation of (untested) C/I rules and logics that at once incorporated the attribute of permitting swifter and more efficient CAI course construction, as well as the attribute of pointing up a whole host of fundamental C/I issues that need to be carefully examined.

Specifically, all CAI course segments were conceptualized as consisting of a collection of what are termed *instructional episodes*--where an episode is considered to be a basic unit of instruction. All episodes were constructed in flow chart form. For purposes of illustration, a sample episode is displayed in Figure 1. The value of constructing episodes in the form of such flowcharts rests in the fact that the episodes cannot be developed in the absence of giving explicit attention to the nature of the instructional rules being employed. Furthermore, the flowcharts also serve as an ideal form of documentation--not only of the actual communications, but of the instructional logic, *in toto*, (feedback rules, etc.) that has been employed.

The instructional logics employed in the construction of curricular episodes, of course, must themselves be subjected to critical analysis, though such investigations were not undertaken as part of the PARADIGMS Project. In the work of this project, however, certain logics

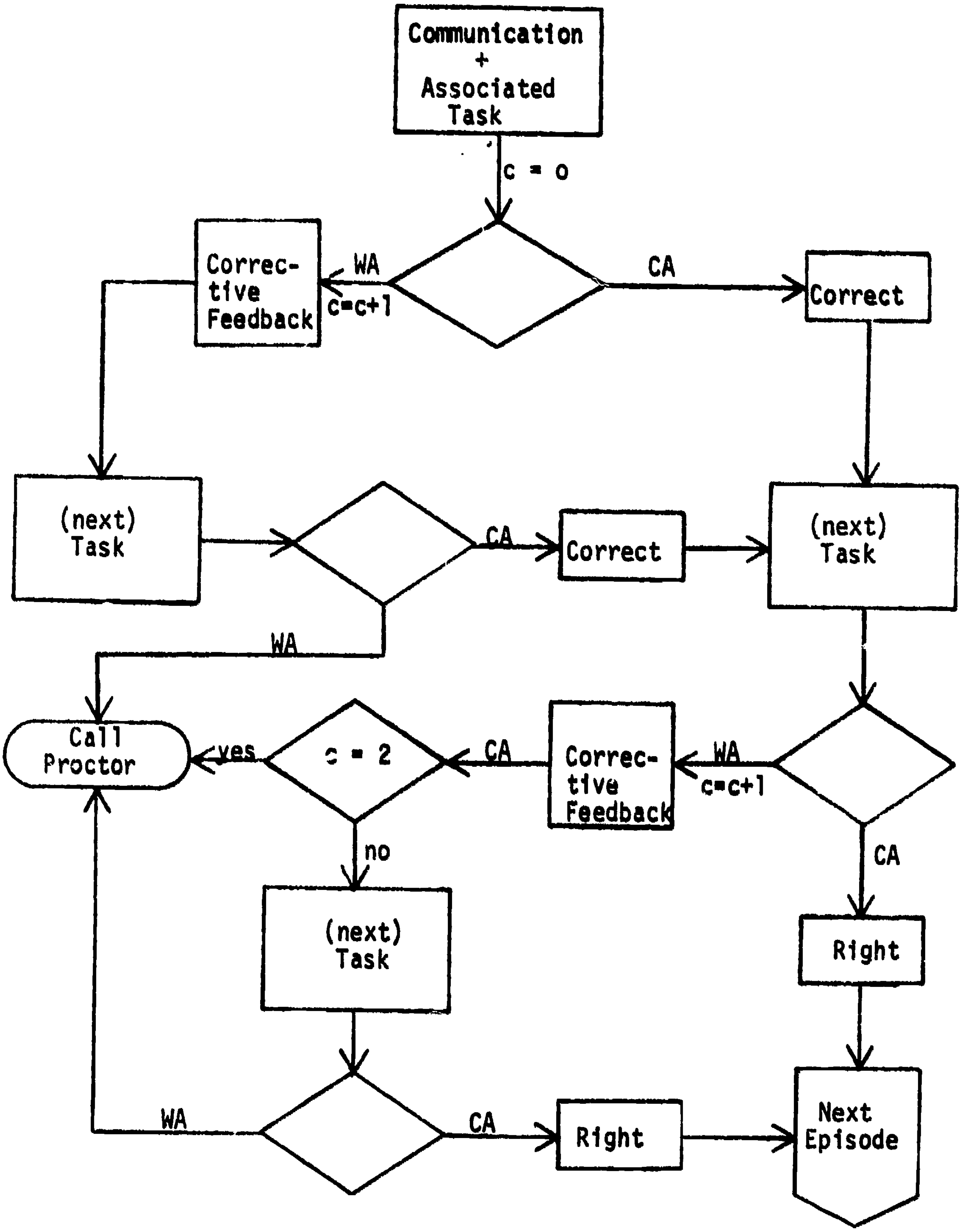

FIGURE 1

A Sample Episode Logic That Involves Multiple Tasks (Criterion: 2/3)

seemed to have rather wide applicability, and hence became somewhat standardized. This fact was capitalized upon by the PARADIGMS curriculum programmers and coders--enabling them to significantly improve the speed with which they could write instructional sequences and get them ready for system presentation.*

8.4 An A_L-Evaluative Paradigm: A System of Propositions to Guide CAI Evaluations.

A third class of A_L-paradigms to be considered for use pertains to the issue of *evaluation* of actions within the C/I domain. The so-called A_L-*evaluative paradigms* that have been formulated are stated as a system of propositions. Before stating them, however, the meaning and purposes of evaluation should be clarified.

Definition of Evaluation. A set of actions, E, is *evaluation* if and only if

1) E is performed in the presence of an explicit criterion;
2) E includes assignment of a value term to an object or event where the basic value terms are *good, fair, bad,* or approximate substitutes;
3) E includes justification of the value term assigned.

*The interested reader should consult VOLUME III of this report: COMPENDIUM OF CURRICULAR MATERIALS, which consists of a "hard copy" version of virtually all of the instructional episodes that were constructed.

Purposes of Evaluation. The *purposes* of evaluating a C/I system are to

1) determine the *efficiency*, *effectiveness*, *power*, and *economy* associated with the (C/I) system;*
2) provide the bases for increasing the efficiency, effectiveness, power, and economy associated with the (C/I) system (this requires identification of weaknesses and formulation of recommendations for changing the internal state of the program).

Proposition #1. An adequate evaluation system will take into account at least 1) the foundational A_V-paradigms, the directive A_L-instructional paradigms, and the message sets from the operating C/I system to the pupil, and conversely; and 2) the relations among those foundational, directive, and operating systems.

Proposition #1 requires that evaluation in the C/I domain be *comprehensive* in the sense that value statements, statements of

*The meanings of the terms "efficiency," "effectiveness," "power," and "economy" are included as an aspect of the discussion following the statement of Proposition #3, page 82.

objectives, procedures, instructional claims, C/I system--pupil interactions, and their various interrelationships are examined and judged. Justification for this proposition is supplied by A_V-*Proposition #4*, which requires that all C/I action be consistent with the conditions of scientific action.

Since even the initial postulates of a scientific system are considered *fallible*, and all lower level statements, measurements and observations as well, then none of these various statements or activities are beyond the range of scrutiny and judgment. The proposed proposition merely subjects the full range of C/I statements and activities to similar assessment.

> *Proposition #2.* An adequate evaluation system will invoke criteria of at least each of the following types:
>
> (1) coherence;
>
> (2) status of the C/I system (e.g. has it the properties of an empirically testable system?);
>
> (3) potential for contributing to C/I advance;
>
> (4) empirical test.

Proposition #2 also is justified by A_V-*proposition #4*. The types of criteria set forth in the preceding statement are those

delineated by Karl Popper in *The Logic of Scientific Discovery* [21] and discussed in Section 4 of this volume.

Coherence implies *logical consistency* among statements and *interrelatedness among elements*. If one A_V-statement contradicts another A_V-statement, then commitment to both is empty for realization of one corresponds to failure to realize the other. Inconsistency between A_V-statements and A_L-statements also makes it impossible to realize the A_V-statements.

The second type of criterion is concerned with whether a C/I system is testable in principle. The statements might be tautological, for example, and provable on the basis of logic alone; that is, they may have no empirical import in which case they would be of little interest as the values, objectives, directives, or claims of a field of practice.

The third type of criterion is concerned with the "so what?" question. For each new or proposed curricular/instructional system, including those of the CAI variety, those who are proposing its use should be able to make a strong case to support the belief that its properties are significantly different from those of existing systems and can be expected to lead to some non-trivial improvement. The methodology for the third kind of assessment normally will include comparisons with existing systems, carried out in rigorous fashion. The embarrassments that would result if curriculum builders and

users characteristically were expected to justify the expectation of advance are at once both alarming and amusing to contemplate.

The fourth type of criterion is that of empirical test. Empirical test should include examination of correspondence between claims and occurrences. It also should include tracing the pattern of change on a number of significant criteria as the curricular/instructional system is modified.

> *Proposition #3.* An adequate evaluation system will yield at least judgments of *efficiency, effectiveness, power,* and *economy*; and the *trajectories* relative to these criteria.

The conditions of proposition #3 can be justified directly against the specified purposes of C/I system evaluation and indirectly against the A_V-propositions.

Although there exists a clear obligation to define *efficiency, effectiveness, power, economy,* and *trajectory,* it will suffice for present purposes to provide some loose pointers as to how those terms are being used.

Efficiency means roughly *the probability of attaining an objective if a particular course of action is taken.* If a C/I system is deliberately changed in a way such that a distinctly higher proportion

of students attain a particular objective, then that condition will be said to constitute an *advance in the program's efficiency.*

Of course, a C/I system is a complex system concerned with influencing students to attain a complex set of objectives. Changing a C/I system to increase its efficiency relative to one objective may have the side effect of a decrease of efficiency relative to some other objective. The problem then becomes one of deciding which objectives should be assigned the highest values (importance), and of deliberately increasing efficiency relative to important objectives while perhaps paying the cost of reduced efficiency relative to less important objectives. A measure of *effectiveness* must take into account the various C/I system efficiencies relative to some set of objectives in conjunction with the values assigned those objectives. That is, *effectiveness* loosely means *combined weighted efficiencies.* If a C/I system is deliberately changed in a way such that the *combination of weighted efficiencies* is increased, then an *advance in effectiveness* will be said to have occurred.

Power is assessed in terms of the scope of applicability of the conceptual system represented by the C/I system objectives. Power is a function of the utility of that conceptual system in generating new information or in judging the validity of decision or action. Advance in *power* can occur in two ways: 1) by utilizing new knowledge external to that already available in the C/I system

structure or evaluations of the program and 2) by re-defining basic C/I system concepts or by specifying a new set of relations among those basic concepts.

The concept of *economy* is a tremendously complex one that is the object of future development and merely will be introduced here. For example, an *advance in economy* will be said to have occurred in the presence of either one of these conditions:

(1) There is a decrease in time required while efficiency, effectiveness, coherence and power remain constant or increase;

(2) There is a decrease in cost while time, efficiency, effectiveness, coherence and power are held constant (or while time is not increased and efficiency, effectiveness, coherence and power are not decreased).

Economy is a concept which extends far beyond the bounds of time and cost considerations, however. For example, the economy of a C/I system might be assessed in terms of the power obtained in relation to the degree of *simplicity* of the predicate bases of the system [22]. As advances are made in spelling out the structural relations of adequate C/I systems, it will become possible to cash in such extensions of economy and other complex concepts of significance.

Under *A_V-proposition #3*, "Every C/I system ought to be subjected to a non-terminating set cf adjustments aimed at system improvement." Fulfillment of these conditions will result in distinguishable C/I system states, S_j, at different points of time or on different occasions, O_j. The relation between the system state and occasion is defined by a set of ordered pairs

$$\{(S_1, O_1), (S_2, O_2), (S_3, O_3), \ldots, (S_n, O_n)\} .$$

This set of ordered pairs is called the *trajectory* of the C/I system.

Similarly, for each set of students interacting with the C/I system, there is an associated set of *initial* characteristics, C_{ij}, called inputs. There is also an associated set of *terminal* characteristics, C_{oj}, called outputs. The *trajectory of inputs* is defined by the set of ordered pairs

$$\{(C_{i1}, O_1), (C_{i2}, O_2), (C_{i3}, O_3), \ldots, (C_{in}, O_n)\} .$$

The *trajectory of outputs* is defined by the set of ordered pairs

$$\{(C_{o1}, O_1), (C_{o2},)_2), (C_{o3}, O_3), \ldots, (C_{on}, O_n)\} .$$

If the student characteristics are measured in terms of attainment of a single objective, then a probability statement, or efficiency function, can be specified which relates the objective, the C/I system state, and student performance. As student sets interact with each system state, and as the C/I system is identified by different distinguishable states, a set of efficiency functions can be generated for each objective and each state. Moreover, a trajectory of *efficiency* for each objective is obtained which traces the C/I system progress relative to that objective.

In analogous ways, though more complex and subjective, the trajectories can be developed relative to the other output criteria as well as input-output relations.

9. A_K-PARADIGMS: SAMPLE CAI CURRICULAR SEGMENTS

Sample CAI curricular segments corresponding to particular sets of A_L-paradigms are provided in VOLUME III of the report of the PARADIGMS Project: COMPENDIUM OF CURRICULUM MATERIALS. For a full understanding of the conditions employed in the construction of the various segments which are displayed, it is necessary to consult the investigations reported in VOLUME II: EMPIRICAL STUDIES.

PART D: EPILOGUE

10. GOALS, ACTIVITIES AND PRODUCTS OF THE PARADIGMS PROJECT.

The primary mission of the PARADIGMS Project was to explore the conditions and requirements which must be fulfilled in order to design potentially fruitful paradigms for guiding the development of curricular materials--with particular reference to those intended for CAI presentation. Simply put, the major concerns centered around questions about how to develop, evaluate and improve CAI curriculum materials, and to make reasoned and defensible judgments about their worth.

The strategies employed to deal with the foregoing issues consisted essentially of endeavors to construct paradigms for 1) guiding practical action within the curricular/instructional domain (called action paradigms), and 2) advancing the conceptual (knowledge) foundation upon which to base (formulate and justify) such practical actions (called research paradigms), as well as to attempt to clarify the family of special meanings and significance attached to the term "paradigm" itself. Furthermore, the aforementioned paradigms were framed under an integrated complex of axiological, conceptual, and methodological conditions analogous to those employed in a paradigm of (normal) science (in the Kuhn sense)--the major benchmarks being 1) the concept of rational

action, 2) the essential characteristics of science with reference to its aims, methods of inquiry, and methods of evaluation, and 3) the concept of a consistent value system and its role in the determination of practical actions.

The activities of the PARADIGMS Project, therefore, consisted of attempts to advance on three major fronts:

1. Philosophical studies were undertaken in an effort to construct a comprehensive conceptual framework under which the activities of the Project would be conducted--one that would guarantee their coherence and potential for impact. The philosophical studies that were conducted are reported in this volume of the Report of the PARADIGMS Project.
2. Empirical studies were undertaken to serve either as exemplars or as empirical tests of the validity and merit of the constructions laid down as part of the aforementioned philosophical studies. The empirical studies that were conducted are reported in Volume II of the Report of the PARADIGMS Project.
3. Curricular (CAI) segments were developed so as to conform to requirements imposed by selected

philosophical constructions, and hence permit tests of them. Volume III of the Report of the PARADIGMS Project consists of a "hard copy" version of virtually all of the CAI course segments that were developed.

11. IMPLICATIONS

The perspectives of the PARADIGMS Project regarding research and development within the curricular/instructional domain entail a multitude of implications; accordingly, in the remaining paragraphs, an attempt is made to summarize the major arguments which have been presented together with a brief assessment of the consequences of their acceptance.

(1) Much of this volume was aimed at the problem of articulating the need for the development of a variety of types of paradigms for guiding research and development within the C/I domain (including CAI)--as a necessary precursor to advance in the field. Efforts were made to formulate classes of paradigms that not only permit specialists to be able to distinguish

among the fundamental C/I problems that need to be studied, but that at the same time have the attribute of preserving their interrelationships.

(2) The point of view has been presented that curricular (including CAI) construction, programming decisions, and evaluation are *professional* matters. This view links curriculum construction and assessment not only to the pragmatic base of a profession, but to the axiological and conceptual bases as well. This idea requires a much more comprehensive perspective particularly relative to CAI curricular construction for, as a result of it, explanation and justification of programming decisions becomes a far more critical consideration than would be the case where *technicians* (non-professionals) are engaged in curriculum construction activities.

(3) Under the concept of CAI as a professional endeavor, it is necessary to *articulate* and *justify* the *values* under which curriculum development and programming are conducted.

These values must be examined for compatibility with the values of the teaching profession at large. Also, there are entailed the obligations of a) assessing the logical consistency of the values that are articulated and checking the consequences of operating under those values, including side-effects, and b) attempting to engage in efforts toward continuing improvement of the value system governing CAI.

(4) Under the more abstract propositions proposed by the PARADIGMS Project, much more precise and comprehensive documentations are demanded in all phases of C/I (including CAI) activity. These documentations must include:

a) setting forth instructional objectives *and* the logical relations among them;

b) explicit articulation of the instructional theorems or rules that guide task construction, sequencing, and implementation;

c) explicit articulation of the instructional claims that are being made, including the circumstances under which the specified relations are believed to be valid; and

d) complete episode logics and programming constraints.

Generally the principles of the PARADIGMS Project require a much greater degree of openness and honesty in setting forth ones claims as well as the information necessary to be able to subject them to critical examination.

(5) The concept of a *paradigm of education* having characteristics analogous to those of a *paradigm of science* carries the connotation of common values, common language, common problem areas, and common ways of evaluation. Therefore, an *educational paradigm*, as conceived in this project, is both a research generator and a curricular generator. Under these conditions it is possible for researchers to utilize each others' information, and for curriculum builders to utilize information of the researchers. When these circumstances prevail, in fact, with reference to the field of CAI, then advances of great magnitude reasonably can be expected.

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