Second Generation Instructional Design (ID_2)

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Sometime ago the editor of this journal suggested to the first author that there was very little that was new in instructional design. In a recent meeting a colleague suggested that all of the instructional design theory in current use was at least 20 years old and firmly rooted in behavioral psychology. Is current ID theory adequate to the needs of contemporary instructional designers? Does current ID theory provide the guidance necessary to take advantage of the new interactive technologies available to us for instruction? This represents the first in a series of articles exploring instructional design theory, technique and practice. We invite your reactions and input.

First Generation Instructional Design (ID_1)

The most widely applied instructional design theory is based largely on the work of Robert M. Gagné and his associates at Florida State University. This work is often equated with the term *Instructional Systems Development* (ISD). It assumes a cumulative organization of learning events based on prerequisite relationships among learned behaviors. Gagné's principal assumption is that there are different kinds of learned outcomes, and that different internal and external conditions are necessary to promote each type. Gagné's original work (Gagné, 1965) was based on the experimental learning psychology of the time, including paired associate learning, serial learning, operant conditioning, concept learning, and gestalt problem solving. Recent versions (Gagné, 1985) have incorporated ideas from cognitive psychology, but the essential characteristics of the original work remain.

Our own work, *Component Display Theory*, (See Merrill 1983, 1987a, 1988) is built directly upon Gagné's principal assumption. We extended the outcome classification system by separating content type from performance level. We also added a more detailed taxonomy of presentation types and clarified the prescriptions of the Gagné position. Nevertheless, *Component Display Theory* has the same roots as the Gagné position.

Other contemporary instructional design theories (See Reigeluth, 1983; 1987) are consistent with the *Conditions of Learning* and *Component Display*

Theory. Gagné extends cumulative prerequisite analysis by including *Information Processing Analysis* as suggested by Paul Merrill (Gagné, 1985). The recommendations for *Structural Analysis* by Scandura (Scandura, 1983; Stevens and Scandura, 1987) and *Algorithm/ Heuristic Analysis* by Landa (1983, 1987) are similar to *Information Processing Analysis*. Markle (1983), Gropper(1983, 1987), Engelmann & Carnine (1982) and Collins (Collins & Stevens, 1983; Collins, 1987) provide sets of recommendations for teaching concepts and rules that are similar to the recommendations of *The Conditions of Learning* and *Component Display Theory*. Most of these theories were developed relatively independently of one another, yet produce similar recommendations, thus providing some rough confirmation of the validity of the recommendations.

In this paper we refer to this body of theory and methodology as ***First Generation Instructional Design*** **(ID_1)**.[1] While there is a remarkable similarity in their prescriptions, they share a number of limitations: content analysis focuses on components, not integrated wholes; there are limited or no prescriptions for knowledge acquisition; prescriptions for course organization strategies are superficial; the theories are closed systems, asserting principles based on a subset of available knowledge, but not easily able to accommodate new knowledge as it becomes available; each phase of instructional development is performed essentially independently of other phases, as the theories provide no means for integration or for sharing data; the resulting instruction teaches components but not integrated knowledge and skills; the resulting instruction is often passive rather than interactive; and finally, all of these theories are very inefficient to use because an instructional designer must build every presentation from fundamental components.

The use of contemporary instructional design methodologies does result in instruction that is more effective than that based only on folklore and trial-and-error. However, these methods have not provided the hoped for increase in

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[1] These First Generation ID Theories were preceded by a series of transitional theories including "Operant Conditioning" and "Programmed Instruction" based on Skinner (1953, 1957), the "Meaningful Verbal Learning Theory" of Ausubel (1963) and the instructional theories of Bruner (1966).

instructional effectiveness that enable learners to more adequately and efficiently grasp, and to apply, the content presented. Most are based on the psychology of the 50's and 60's; they are analytical, not synthetic; they are component rather than model or schema oriented; and their application requires considerable effort. Because the theories upon which these methods are based predates the development of highly interactive, technology-based delivery systems, little guidance is provided for developing instruction for these systems.

Limitations of ID_1

Limitation 1. ID_1 content analysis does not use integrated wholes which are essential for understanding complex and dynamic phenomena.

First generation instructional design methods attempt to identify the components of subject matter. These constituent components are then used to prescribe course organization and sequence. The elements of this analysis are individual content components such as facts, concepts, principles (rules) or procedures. The resulting instruction may be effective in teaching these pieces of the content, but is often not effective in helping students to integrate these components into meaningful wholes. Hence, students are able to pass exams but cannot apply the knowledge in a wider context. The sheer amount of knowledge which must be learned continues to accelerate. New scientific knowledge is often complex and dynamic. It is difficult to understand the complex interrelationships of knowledge with only isolated concepts and principles. An integrated understanding is essential.

Cognitive psychology, in postulating the notion of schema or frame, suggests that cognitive structure consists of mental models. Learning results in the construction and elaboration of these models which serve to organize the knowledge, and to facilitate recall and further learning. No ID_1 content analysis procedure takes this notion of mental models into account.

Limitation 2. ID_1 has limited prescriptions for knowledge acquisition.

While ID_1 methods prescribe content structure as a result of the content analysis, none prescribe the subject matter components necessary to build a complete knowledge base for this structure. Hence the resulting structures are little more than content outlines for which the designer must still gather considerable additional material in order to build the course.

The content structure resulting from content analysis is rarely used directly in the course materials. The form of representation, usually some diagram, is not in a form that can be used by the presentation. In fact, current design methodology often requires at least three different and separate specifications of the content: first, as a set of task descriptions or objectives; second, as a story board or script; and third, a program written in some computer or authoring language. In addition to being time-consuming, this separation of content analysis from course development decreases the correspondence between these two activities, resulting in course content that is not represented in the content structure or content structure elements that are not contained in the course materials.

Limitation 3. ID_1 has limited prescriptions for course organization.

For most ID_1 methods there is a gap between content analysis and course organization strategies. The prescription for course organization strategies is either not present or superficial. Prescriptions range from a one-to-one correspondence between content structure elements and instructional modules, to the bottom up sequences suggested by Gagné hierarchies. But none of these ID_1 methods adequately accounts for different levels of instructional outcomes, such as familiarity versus basic instruction versus remediation. And none of the ID_1 methods considers the highly interactive nature of the new technologies and how to prescribe highly interactive sequences.

Limitation 4. ID_1 theories are essentially closed systems.

There is no means of incorporating fine-grained expertise about teaching and learning, gained from research, and applying this in the design process. While there remains much to understand about how people learn, we in fact know a great deal already. The designer of instruction must however apply this knowledge separately from the application of ID_1 theory, as no obvious hooks are built into the theory to incorporate and apply new and better knowledge as it is discovered.

Limitation 5. ID_1 fails to integrate the phases of instructional development.

Methodology based on ID_1 usually defines five phases of instructional development: analysis, design, development, implementation, and evaluation. While the outcomes of each phase are inputs to the next, and the development cycle is iterative, that is the extent of the integration of the phases. Separate tools are used, and separate knowledge representations are maintained in each phase. Theory provides no prescriptions for how changes made in one phase should lead directly to changes in another. For example, in the analysis phase, information about the content to be taught is gathered, and represented in terms of the tasks that are performed by someone skilled in the subject matter to be taught. In the design phase, learning objectives are developed for each task. While the task analysis is preliminary to the objectives development, theory does not prescribe how the task analysis should be used. Guidance is available to the designer on the form to write an objective, but its actual selection and content is a matter of judgment and experience. At the next phase, development, learning activities are designed for each objective. Again, guidance is limited to what should go into an activity; there is no prescription for selecting activities. Moreover, at this point there is no direct connection between the task analysis and the learning activities, and no possibility that information could flow directly from the one to the other.

Limitation 6. ID_1 teaches pieces but not integrated wholes.

Each of these ID_1 methods attempts to prescribe the characteristics of the stimulus presentation to the student. These presentation components consist of elements such as definitions, examples, non-examples, practice problems, attention-focusing help, and prerequisite information. In every case the instructional designer must compose an instructional strategy from such elements to make a complete whole. Often these strategies take on a disjointed character in which one content element is taught after another but little is done to integrate a series of elements into a whole. [2]

Limitation 7. ID_1 instruction is often passive rather than interactive.

Most of the ID_1 theories were formulated before interactive media (computer based instruction, interactive video, intelligent tutoring systems, integrated multi-media systems) were readily available. As a consequence most of these models concentrate on the stimulus elements of the presentation rather than on input elements. Instruction based on ID_1 is frequently passive rather than interactive, requiring little mental effort on the part of the student. ID_1 theories are display orientated (our own work is called *Component Display Theory*) rather than transaction or interaction oriented. [3] They prescribe examples and non examples but have little to say about the use of experiential interactions, simulated environments or controllable worlds. (See Merrill, 1988b).

There is evidence that learning is directly related to the level of mental effort put forth by the student. This mental effort must bear a direct relationship to the concepts and principles being taught. When the instruction is passive, learners are not forced to examine their cognitive structure and the resulting learning is poorly retained, does not relate well to previously learned materials, and is not easily transferred to new situations. Furthermore, much new scientific knowledge is dynamic in character and cannot be understood without a more active representation and student involvement.

Limitation 8. Every ID_1 presentation must be constructed from small components.

With ID_1 methods the designer must always compose every instructional strategy from basic display elements, e.g. definitions, rules, examples, and

[2] Elaboration theory (Reigeluth, 1983,1987) is an exception to other first generation theories in that it does attempt to provide some integration.

[3] Collins (1983,1987) inquiry based prescriptions is the only theory in the Reigeluth collection that is concerned with dynamic on-line adaptation of the instruction based on student interaction with the materials.

helps. This means that for each lesson the designer must analyze and select every display element for presentation to the student. If one were to consider a larger content element, a mental model, then it is conceivable that there is a corresponding instructional transaction for promoting the acquisition of this mental model. Composing instruction from larger transaction units means considerable savings in development time and resources. By analogy first generation instructional design is a little like limiting a chemist to the basic elements. The chemist can make anything but to get water you must start with hydrogen and oxygen and make the compound first. We need some instructional compounds that can be used as wholes. However, none of the ID_1 methods identify such transaction wholes.

Limitation 9. ID_1 is labor intensive.

Current instructional design and development practices are extremely labor intensive. Even though the hardware is affordable, the courseware frequently is not. **A development/delivery ratio of more than 200:1 is too high**. The current ratio for designing and developing instruction for the new interactive technologies exceeds 200 hours of design/development for each 1 hour of delivered instruction. (Lippert, 1989). Some estimates suggest ratios exceeding 500:1 just for programming.

The impact of computerization on other fields has been to increase productivity by reducing labor costs, or allowing greater production from the same labor. Personal computers probably owe their success to the electronic spread sheet. Every financial planner could immediately see the efficiency of using an electronic spread sheet. Tasks that at one time might require days or weeks could now be accomplished in minutes or hours.

In education and training the ratio is just the opposite. Educational experiences which can be planned and delivered in a few hours using conventional methods and technologies require days or weeks with the computer. It is often argued that the quality of the instruction justifies the increased effort. However, when data is gathered it often shows only a marginal advantage for the computer. This data rarely justifies the enormous increase in effort. Until now, computer based instruction has only been cost effective when large numbers of students are taught by the same program over a considerable period of time and the cost is justified by reducing personnel costs.

Second Generation Instructional Design ID_2

If interactive instructional technologies are to provide a significant part of the increasing amount of education and training demanded by society, then there is a critical need for significantly improved methodology and tools to guide the design and development of high quality interactive technology-based instructional materials. There is a need for **second generation instructional design (ID_2)**[4].

ID_2 will build on the foundation of ID_1, but will address the shortcomings noted above. Specifically, ID_2 will

- be capable of analyzing, representing, and guiding instruction to teach integrated sets of knowledge and skills,
- be capable of producing pedagogic prescriptions for the selection of interactive instructional strategies and the selection and sequencing of instructional transaction sets,
- be an open system, able to incorporate new knowledge about teaching and learning and to apply these in the design process,

[4] For the past three years the authors have been attempting to build an Instructional Design Expert System (ID Expert). Many of the ideas expressed in this paper have come from our work on this project (See Merrill, 1987c; Merrill & Li, 1988, 1989a, 1989b; Li & Merrill , in press). The ID Expert project has been supported in part by funds provided by the Army Research Institute in cooperation with the Office of Personnel Management and Human Technology Inc. Additional funds have been provided by United Airlines Services Corporation, IBM Corporation, The National Security Agency in cooperation with The US Air Force Academy, and Utah State University. The views presented are those of the authors and do not necessarily reflect the views of the sponsoring agencies.

- integrate the phases of instructional development.

ID_2 will comprise the following components:

- a theoretical base that organizes knowledge about instructional design and defines a methodology for performing instructional design,

- a knowledge base for representing domain knowledge for the purposes of making instructional decisions,

- a series of intelligent computer-based design tools for knowledge analysis/acquisition, strategy analysis and transaction generation/configuration,

- a collection of mini-experts, each contributing a small knowledge base relevant to a particular instructional design decision or a set of such decisions,

- a library of instructional transactions for the delivery of instruction, and the capacity to add new or existing transactions to the library,

- an on-line intelligent advisor program that dynamically customizes the instruction during delivery, based on a mixed-initiative dialog with the student.

Analyzing and Representing Knowledge for Integrated Goals

Our concept of ID_2 is cognitive rather than behavioral. We start from the basic assumption that learning results in the organizing of memory into structures, which we may term *mental models*. To this we adopt two propositions about the learning process from cognitive psychology:

- organization during learning aids in later retrieval of information, and

- elaborations generated at the time of learning new information can facilitate retrieval.

Organization refers to the structuring of knowledge; while elaboration refers to the explicit specification of relations among knowledge units.

From ID_1 we retain Gagné's fundamental assumption:

- there are different learning outcomes and different conditions are required to promote each of these different outcomes (Gagné 1965, 1985)

We propose to extend these fundamental ideas as follows:

- a given learned performance results from a given organized and elaborated cognitive structure, which we will call a mental model. Different learning outcomes require different types of mental models,

- the construction of a mental model by a learner is facilitated by instruction that explicitly organizes and elaborates the knowledge being taught, during the instruction,

- there are different organizations and elaborations of knowledge required to promote different learning outcomes.

However, we make no claims about how cognitive structure is organized and elaborated, as this is not well understood. We stand on the weaker, and more defensible assumption, that we can analyze the organization and elaborations of knowledge outside the mind, and presume that there is some correspondence between these and the representations in the mind.

Addressing the limitations of ID_1 in regards to the teaching of integrated wholes, we propose that ID_2 should be capable of teaching the organized and elaborated knowledge needed to facilitate the development of mental models. A necessary precondition to the design of such instruction is the development of detailed prescriptions for a knowledge acquisition process to identify all of the information necessary for a student to build a mental model. The outcome of this process is a representation of the knowledge to be taught in terms of its structure and its elaborations.

Classes of Knowledge Representations

The means chosen to represent knowledge about a domain depends upon the use to which that knowledge will be put. We distinguish for the purposes of this analysis three classes of knowledge representations (KR).

KR_r is a class of representation for the purpose of *retrieving* the knowledge in various formats. A representation of this class is most appropriate for database applications, and emphasizes descriptors, keys, and relations.

KR_e is the class most often used in artificial intelligence, where it is desired that the representation be *executable*. The emphasis here is on modeling the domain in terms of propositions, scripts, etc., which can be executed under the constraints of several variables in order to simulate a natural or hypothetical system. (See Brachman & Levesque, 1985, for a review of this area).

KR_i is the class of interest here, in which key information about the domain is represented in a way so that instructional decisions may be made. Here the emphasis is on categorizing the elements of the domain for the purposes of selecting instructional strategies, and identifying the semantics of links among domain elements in order to prescribe instructional sequences. ID_1 approaches to knowledge representation (referred to as content, or job/task analysis, see Bloom et al, 1956; P.F. Merrill, 1987; Gagné, 1985) are insufficiently precise and comprehensive, and are particularly lacking in describing linkages among domain elements.

Knowledge Representation for ID_2

The key to ID_2 is the acquisition and representation of course content. We propose to represent knowledge in terms of objects which we call *frames*; each frame has an internal structure (slots, which contain values for the structure), and links to other frames. These (both internal and external) are termed *elaborations* of the frame. The set of all elaborated frames together, which contains all the knowledge to be instructed by a course, is called an *elaborated frame network*.

It is hypothesized that there are three fundamental frame types:

- entities, which correspond to some thing, for example a device, object, person, creature, place, or symbol,
- activities, sets of related actions to be performed by the learner, and
- processes, sets of related actions which are entirely external to the learner.

There are also three types of elaborations. These are:

- components, which correspond to the internal structure of a frame. For an entity, the components are parts of the entity; for an activity, steps; and for a process, events and causes,
- abstractions, which correspond to a "kinds-of" class/subclass hierarchy into which the frame may be classified,
- associations, meaningful links to other frames in the network.

The network structure of the knowledge representation allows information to move through the structure, so that data contained in one part of the net affects the data stored elsewhere. Two principal means by which this occurs are:

- inheritance, in which attributes of a class or superclass in an abstraction hierarchy are passed to a subclass or instance,
- propagation, in which the contents of a frame influence the contents of another frame connected to it via an association link.

Knowledge analysis and acquisition is the process of gathering and organizing all of the information required for the student to acquire a given mental model or set of mental models. The product resulting from the knowledge analysis and acquisition process is an elaborated frame network. Each elaborated frame in this network corresponds to the knowledge required to facilitate the development of a mental model in the cognitive structure of the student.

By representing the organization and elaborations of knowledge structures, it will be possible to select and sequence instructional units which make the structure of the knowledge explicit to the student. However, in order to do so effectively, we need more than just a description of the knowledge structures. We need instructional strategies for teaching integrated wholes, and rules, or prescriptions, for selecting these strategies. In addition, we need larger instructional units, transactions, designed to teach an entire knowledge structure, rather than a single knowledge component.

Knowledge analysis and acquisition system.(KAAS).

Because of the complexity of the associations, keeping track of inheritance and propagation and the amount of information involved ID_2 knowledge analysis and acquisition, as described above, is not practical without an intelligent computer-based tool, a knowledge analysis and acquisition system (KAAS). A knowledge analysis and acquisition system guides the designer/user in providing information about the subject matter to be taught. This system consists of frames for different content structures.[5] A given content structure frame knows the necessary knowledge components required for its instantiation. This knowledge includes the components of the content structure frame, the level of abstraction (instance, class or superclass) associated with the content structure frame, and the rules for inheritance from one abstraction level to another. In addition KAAS knows the possible links between various frames and how to propagate knowledge from one frame to a linked frame. The knowledge

[5] "Frames" here refer to entities defined by the artificial intelligence community consisting of slots and required legal values for these slots. We are not referring to instructional displays or programmed instruction frames.

base (rules) underlying KAAS is used to prompt the designer/user to supply the necessary values for various content structure frame slots. The designer/user is led to identify the frames, frame abstraction level, frame components, and frame links necessary to describe the subject matter content to be taught. This subject matter information comprises the *domain knowledge base* which is built by KAAS.

Instructional Strategies and Transactions

We believe that instruction for ID_2 is best accomplished via instructional transactions. Consistent with our assumption that learning results when mental models are organized and elaborated in memory we also assume that instructional interactions should be organized around all those activities necessary to promote the acquisition of a particular mental model. We propose the following propositions:

- integrated interactions, which focus on all of the knowledge and skill which comprise a particular knowledge structure, aid the formation of a corresponding mental model and hence enable the learner to acquire the ability to engage in enterprises requiring this mental model.

- there are different classes of transactions required for efficient and effective acquisition of different types of mental models.

<u>Transactions and Transaction Classes.</u>

An instructional *transaction* is a particular instructional interaction with a student. A transaction is characterized as a mutual, dynamic, real-time give and take between the instructional system and the student in which there is an exchange of information (Li & Merrill, in press). Transactions include the entire range of instructional interactions including: one-way transmission of information (e.g. video, lecture, or document - which are not very good transactions because they lack interaction), discussions and conversations, tutoring (e.g. traditional CAI and Intelligent Tutoring Systems), simulations and micro-worlds (with or without coaching).

The effectiveness of a transaction is determined by the degree of the relevant active mental processing required and the nature of the learner's interaction with the content to be learned. An adequate transaction can assume both expository and inquisitory modes; it allows the degree of learner or system control to be adjusted; it includes display and response parameters which allow the transaction to customized for different learners, different subject matters and different delivery systems. It is important to realize that the delivery method for a transaction is not constrained by ID_2 .

Different transactions involve different kinds of interactions with students. In ID_2 all transactions which require a particular type of interaction are grouped into a *transaction class*. It is the nature of the interaction which determines whether a particular transaction belongs to a particular transaction class. The specific implementation of this interaction may differ widely depending on the nature of the specific entities, activities or processes involved; depending on the delivery system involved; and depending on the characteristics of the learners. Nevertheless, for all transactions included within a given transaction class the essence of the interaction remains the same.

The interactions necessary to completely acquire all of the knowledge and skill associated a particular instantiation of an elaborated frame in a knowledge structure (the knowledge necessary for the acquisition of a particular mental model) will almost always require more than a single transaction. From all of the possible transactions identified for a particular transaction class only a small subset will be required for a particular instantiation of an elaborated frame. Furthermore a particular elaborated frame may require specific transactions from several different transaction classes. This subset of transactions is called a *transaction frame set.* A transaction frame set is the specific individual transactions selected from one or more transaction classes which are required to promote the acquisition of a particular instantiated elaborated frame from the knowledge structure. A transaction frame set implements those interactions necessary to teach a particular elaborated frame in a particular domain, in order to promote the acquisition of a given mental model by a given student. Many different transaction frame sets might be configured depending on variations in the type of subject matter, the attributes of students and the attributes of the instructional environment.

The adequacy of a transaction frame set depends on the completeness with which it promotes the acquisition of the target mental model and the degree to which it elaborates (builds upon or extends) a prerequisite mental model (one previously acquired by the student).

The possible sequences of individual interactions within a transaction frame set is called the *transaction strategy*. An individual student follows one of these possible paths. Part of transaction strategy is the decisions as to which transaction should be next for a particular student and when the student should begin the next transaction . These decisions are called *traverse management*. The adequacy of a transaction frame set also depends on its ability to be configured via a variety of different sequences and its ability to allow a range of student to system control of the management decisions to determine a sequence for a particular student.

Instructional strategy exists at several levels. There is strategy embedded into a transaction that controls the presentation of the transaction. This may be termed *interaction strategy.* Above this level, there is the strategy which directs the sequence and traverse of a set of transactions in a transaction frame set. This is the *transaction strategy.* There is the higher-level strategy which integrates the instruction for a set of elaborated frames, each with its own transaction frame set, into a larger instructional unit which corresponds to an instructional goal. This may be termed *goal strategy.* All of the transactions necessary to promote the acquisition of a given integrated goal or enterprise are called *a transaction goal set.* A transaction goal set is usually comprised of a number of transaction frame sets. A goal strategy is the sequence and traverse management among the transaction frame sets which comprise the transaction goal set. At the highest level there is strategy to integrate all goals into a course. This may be termed *course strategy.* Course strategy is the sequence and traverse management among the transaction goal sets which comprise the course.

<u>Strategy Analysis.</u>

Strategy analysis provides a strategy link between knowledge acquisition and transactions. Strategy analysis involves three activities: 1) gathering information about the course, student, and environment for later reasoning; 2) providing prescriptions and filters to assists the knowledge analysis and acquisition process; 3) generating course organization for a given elaborated frame network and related enterprise, student, and environment attributes.

Information gathering. Information gathering is the first requirement of strategy analysis. The identification of integrated instructional goals is critical to ID_2 instruction. An integrated goal corresponds to some learned enterprise (an integrated set of knowledge and skill) which the student will attain as a result of the instruction. See Gagné & Merrill, in press). The achieving of an integrated goal may require the acquisition of one, or a set, of mental models by the learner. Strategy analysis helps the designer/user identify the enterprise to be taught (the integrated goals of the instruction) and relevant characteristics of these enterprises. Relevant information also includes attributes of the learner population, and attributes and constraints of the environment and delivery system in which the instruction will be administered.

Prescriptions and Filters. Using information about a particular instructional situation, strategy analysis provides both *prescriptions* and *filters* for the knowledge acquisition process. The knowledge acquisition process is general, that is, a knowledge acquisition system knows about frame components, organization and elaboration but not which of these elements may be appropriate for a given situation. A *prescription* indicates that a particular enterprise requires a given level of abstraction (organization) and certain links between frames (elaboration). A *filter* indicates that a particular enterprise does not require certain frame components, certain organizational structures and certain elaborative links. Strategy analysis is based on rules for selecting prescriptions and filters that correspond to particular kinds of enterprises. Strategy analysis requires the user to select an enterprise (integrated goal) type consistent with the knowledge and skills to be developed and provides prescriptions and filters which direct the knowledge acquisition process.

Course Organization. Based on an instantiated knowledge structure and information about particular learners and a specific instructional environment, strategy analysis prescribes rules for sequencing the elaborated frames which comprise the instantiated elaborated frame network (knowledge structure) for the course. Strategy analysis recommends a course organization consistent with the eventual role of the learners and the enterprise to be acquired. These rules take into account the interrelationships between frames in the knowledge structure including the inheritance and propagation among these frames.

Course organization includes the selection and sequence of a set of transaction goal sets corresponding to the instantiated elaborated frame network. It also includes the determination of course strategy. For each transaction goal set, strategy analysis involves the selection and sequence of a set of transaction frame sets together with an appropriate goal strategy. For each transaction frame set, strategy analysis involves the selection and sequence of the individual transactions together with an appropriate transaction strategy.

Strategy Analysis System (SAS).

Strategy analysis for ID_2 is a much more complex process than that required for ID_1 . Consequently it is likely that the effort and training required for an adequate ID_2 strategy analysis is much more demanding than for ID_1 analysis. If we are to attain our goal of instructional design efficiency, as well as increased effectiveness, then it is necessary to have an intelligent computer-based strategy analysis system.

A strategy analysis system (SAS) queries the user/designer to obtain specific information about enterprises, learner and environmental attributes. Using its build-in strategy rules and the information provided by the user/designer, SAS guides the designer/user in strategy analysis. SAS provides filters and prescriptions to the KAAS (the knowledge analysis and acquisition system). In addition SAS recommends course organization and strategy, with its component transaction goal sets and strategies, and transaction frame sets and strategies. The recommendations of SAS comprise the *strategy knowledge base.*

Transaction Configuration.

An adequate transaction can vary considerably in the nature of its interaction strategy, its mode of presentation (expository or inquisitory), the degree of learner/system control allowed, its display parameters and its response parameters. A given transaction may assume different values for its parameters depending upon where it is used in a given transaction strategy. A given transaction may assume different values for its parameters for learners with different attributes. A given transaction may assume different interaction parameter values and different display and response parameter values for different delivery systems. Transaction configuration is the determination of appropriate values for each of these customization parameters. A transaction can be configured with default values during the design process or these values can be supplied dynamically during the execution of the instruction by means of an intelligent advisor system.

Transaction Configuration System (TCS) and Library .

ID_1 requires that every transaction be built from scratch using a few instructional primitives. Instructional design efficiency can only be realized if the designer has readily available transactions which have already been coded and which can be easily adapted and included in a course under development. ID_2 requires a library of transaction instances and the means to easily configure these transaction instances for a given subject matter, learner population and delivery system. A transaction generation system and transaction acquisition system enable new transaction instances to be easily added to the transaction library or existing transaction instances already in the library to be modified .

A *transaction instance* is a piece of computer code which when executed causes a given transaction to take place. A transaction instance knows what knowledge it must have in order to execute its interaction with the learner. It is able to query the domain knowledge base to find the required knowledge and thus be able to instantiate its knowledge slots. If the domain knowledge base does not contain the necessary knowledge the transaction instance can direct the user/designer to supply the required content.

A transaction instance can be adapted to a variety of instructional functions via its mode and control parameters. A transaction instance can be adapted to a variety of delivery systems via its display and response parameters. A transaction instance can query the transaction configuration system for values for its various parameters. If the transaction configuration system is unable to supply the values based on its knowledge about specific learners and a particular environment then the TCS can query the user/designer to supply the necessary parameter values. The transaction instance, during the execution of instruction can query the intelligent advisor system to obtain parameter values for adapting the instruction to the needs of the specific student involved in the instruction.

Transaction instances reside in a *transaction library*. Based on specifications provided by strategy analysis the transaction configuration system selects appropriate transaction instances from the transaction library for inclusion in a given transaction frame set. Based on information obtained from the strategy analysis the transaction configuration system supplies the transaction instance with values for each of its parameters and queries the user/designer for those values not available from strategy analysis.

During the instruction the intelligent advisor system has access to the transaction library. If based on its own strategy rules the intelligent advisor determines that a given student needs a particular type of interaction, which was not originally included in the transaction frame sets of the course, the advisor can select this transaction, configure it and include it dynamically into the instruction provided for this student.

An Intelligent Advisor System (IADV).

An intelligent advisor system can customize instructional delivery in real time. The strategy analysis system will prescribe a default path through the course organization. A default path is that sequence through the material, based on the information available prior to the commencement of the instruction, thought to be best for a given group of students. As a particular student progresses via this default path performance data is accumulated (a model of the student). When this data indicates that the default path is not the optimal path for the student, the advisor will alter the parameter values of a given transaction or the sequence of transactions to more adequately adapt the instruction to the student.

In addition to changing parameter values and sequence from a default path the advisor system can enhance the instruction by selecting transactions not previously recommended for the course organization by the strategy analysis system. An intelligent advisor system can design a course organization and transaction sequence strategies on the fly. These new transactions are instantiated with content data from the domain knowledge base and their parameters configured as the instruction progresses. An intelligent advisor system is essentially a strategy analysis system in real time.

An Open System -- Mini-Experts

A limitation of ID_1 is that there is no means of incorporating fine-grained expertise about teaching and learning, gained from research, into the design process. An example of this type of expertise is a set of rules for determining the level of motivation of a student, and prescriptions for adjusting the instruction based on that level. Most of this detailed knowledge is not made explicit in ID_1 systems. To the extent that such knowledge is incorporated, it is "hard-wired" into the system: there is no means to easily upgrade such knowledge as new findings appear in the literature.

In the early days of artificial intelligence research, efforts were directed towards developing a general problem solver, capable of dealing with any situation. The first breakthroughs in artificial reasoning came, however, when the focus shifted to the design of systems limited to a specific, and highly constrained domain.

The typical expert system today contains a large rule base, and an inference engine that applies these rules to available data to reach decisions or to make recommendations. These rule bases, however, tend to be monolithic, and directed towards a single decision or set of decisions. The instructional design process, on the other hand, is not one decision but a very large number of different decisions. For this reason, we choose to represent pedagogic expertise in a set of mini-experts, each of which functions relatively independently at different parts of the process, and each of which is responsible for a relatively narrow decision. The theory is intended to prescribe the function of these mini-experts, and to provide a means by which the various individual decisions can be coordinated and combined to make the larger decisions involved at various steps in the process of design.

An important aspect of this approach is that it provides a means for opening instructional design systems based upon $ID_{2.}$ While there is much we do not know about teaching and learning, there is nevertheless a large amount of available data. To the extent that a research finding can be expressed as a rule in one of the mini-experts, that knowledge can be incorporated into the system. The system is thus open to new knowledge that is accumulated as a result of research. The development of mini-experts will also help to identify more precisely the knowledge that is currently missing. The mini-experts are the key to the evolution of ID_2. Should ID_2 be successful, we can anticipate that research will be directed towards discovering knowledge upon which prescriptions of specific mini-experts can be based, and toward validating the prescriptions of the mini-experts.

Integration of the ID Phases - A Single Knowledge Representation

A critical limitation in the systematic application of ID_1 theories has been the lack of integration of the phases of instructional design. The work in each phase is relatively independent of the work in other phases. When similar data is used across phases, it typically must be translated into another form. This translation process is manual, hence no direct linkage exists among these different representations. Thus changes made in one phase cannot automatically cause corresponding changes in another. The practicing designer, working to a schedule, will usually maintain up-to-date only the data for the phase currently worked on, and is reluctant to revisit decisions made at earlier phases. These earlier phases, over time, become outdated and not representative of the actual instruction as developed. Because each phase of design results in a sharpening of focus to smaller and smaller units of instruction, important contextual information is lost when data from earlier phases cannot be manipulated concurrently. This is in no small measure responsible for the shortcomings in developing instruction that teaches integrated goals.

ID_2, when implemented by intelligent design tools, resolves this limitation by maintaining a single representation of the data throughout the development process. Changes made in one area automatically flow through to other areas and create corresponding changes. Consistency and completeness checks are facilitated. And the designer may more easily return to earlier decisions and observe the effects of changing these without having to redo large portions of the design manually. In addition, there are close interconnections among the phases. As discussed earlier, the strategy analysis phase directs and constrains both the knowledge acquisition and the configuring of transactions.

Comparison with Other Approaches

We have characterized the solution of ID_2 to the problems previously stated as the development of a theory capable of producing pedagogic prescriptions for integrated learning goals, and being an open system so that research results may be incorporated into the design process in the form of rule-based mini-experts. The problem of effective instructional development for interactive technologies could be, and is, approached in other ways. We will examine two classes of alternative approaches: ID_1 Expert Systems and Intelligent Tutoring Systems (ITS) and Micro-worlds.

ID_1 Expert Systems

One major approach is to improve the efficiency by which current instructional design theory and methods are applied, by developing expert systems for advice and guidance of designers (for example, Jones & Massey-Hicks, 1987; Ranker, in press; Gustafson & Reeves, in press). This is a conservative, knowledge engineering approach which focuses on representing existing expertise about instructional design in an expert system. The drawback of this approach is the state of knowledge about instructional design, which we have stated is inadequate for the task to which it is put.

Intelligent Tutoring Systems and Micro-worlds.

Another approach which has received considerable attention is the development of micro-worlds to simulate a domain, and intelligent tutoring systems (Sleeman & Brown, 1982; Wenger, 1987; Polson & Richardson, 1988). These approaches attack the far more difficult problem of creating strong domain and student models capable of executing the knowledge of the domain (KR_e). There are a number of difficulties with these approaches. First is the inherent difficulty of the problem, and the expense of creating these systems. Second is an over-reliance on discovery learning as a means of teaching. Discovery learning (Dewey, 1937; Bruner, Goodnow & Austin, 1967; Papert, 1980) is without question useful, but is not equally desirable in all situations. Important limitations of discovery learning are the additional time that is usually required, the fidelity of the simulation that is required, and the inability to easily overcome large gaps in prerequisite knowledge or skills. It is not difficult to imagine situations in which discovery is inappropriate and inefficient: for example, a learner experienced in a related domain may be best served by a simple presentation of the similarities and differences on critical aspects; while a learner with no knowledge of a subject may benefit from an organization of the knowledge to be learned so that a mental model into which further knowledge can be related can begin to be built.

We contend that the most appropriate instructional strategy is a function of the domain to be instructed, a given learner's knowledge of that domain, and the instructional setting. Discovery learning is one strategy among many; the key from an instructional design point of view is having a basis for knowing when to prescribe discovery, and when to prescribe another method.

Note however that an ITS or a micro-world simulation, or another means of discovery learning, can be used as a transaction in ID_2. It is necessary to describe the ITS or micro-world in terms of the types of domain knowledge instructed, the strategy implemented, and the specific elaborated frames instructed (as these simulations are typically not domain-independent).

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