Instructional Design Theory for Automated Instructional Development

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Abstract

- An instructional template separates resources from a format strategy, but retains a one-to-one relationship between resources and the use of these resources in the strategy.
- An expanded instructional template enables the user to use the same knowledge in more than one strategy.
- An instructional transaction defines a knowledge structure appropriate to most knowledge of a particular type. This knowledge structure makes a general transaction possible.
- At a system level an instructional transaction is a set of enactment rules for displaying knowledge elements and resources and interpreting student input.
- A transaction can perform its responsibilities in a number of different ways depending on the values of its parameters. Changing the parameter values of a transaction changes the way it interacts with the student. A transaction configuration is a given set of parameter values.
- Rules relating student characteristics and parameters can enable an instructional transaction to be automatically reconfigured.
- Making parameters explicit to the user enables the user to override the automatic configuration of a transaction and to define custom configurations.

Introduction

For the past 6 years the Second Generation Instructional Design (ID_2) Research Group of the Department of Instructional Technology of Utah State University has been exploring theory and techniques necessary to develop intelligent instructional design tools. Two major goals of this effort are:

- **A significant reduction in time for developing effective interactive multi-media instruction.**

- **More effective instructional design for interactive multi-media instruction.**

ID Expert™ version 1.0 represents significant progress toward these goals. A subject matter expert can now develop effective interactive multi-media instruction in a few hours instead of many weeks.

ID Expert™ includes the following unique features:

- The user can simultaneously use a single knowledge base for several different courses.
- The user can develop multi-media resources once and then reuse them in different lessons or courses.
- The user can replace multi-media resources without doing any redevelopment.
- The user supplies only the knowledge to be taught since the instructional strategies are built-in.
- At a touch of a button the user can easily modify the built-in strategies.
- At a touch of a button the user can change the instructional strategies from learner control to system control.
- At a touch of a button the user can enable or disable presentation, exploration, practice or assessment interactions.
- At a touch of a button the user can enable or disable a variety of different built-in practice exercises.
- At a touch of a button the user can reconfigure a course based on changes in audience characteristics (motivation, experience).
- At a touch of a button the user can modify a single course to serve different audiences.

We have described the operation of ID Expert ™ in a previous paper (Merrill, et al, in press). In this paper we will try to explain some of the architecture and theory underlying ID Expert™.

Architecture of ID Expert™

Multi-media computer-assisted instruction is too often an extension of programmed instruction. CBI authoring systems based on this model have a frame-based architecture. These systems display a frame of information consisting of graphics, text, audio or video. They then ask the learner a question, usually consisting of one of the standard question forms of multiple-choice, short answer, true false, or matching. Depending on the learner answer, they present another frame of information. This architecture requires the user to author each frame individually. These systems then store these frames in a data base that resembles a file cabinet of displays that these systems can access in various orders depending on the branching structure (Merrill, 1985).

Many noninstructional computer applications have a different architecture that consists of an algorithm plus data. An algorithm is a sequence of computations that it repeats over and over with different data. *Instructional transactions* are algorithms for interacting with the learner. The subject matter content is data that instructional algorithms use. Different kinds of knowledge require different kinds of transactions. We design and program the necessary set of

these instructional transactions only once. We can then use them over and over with different content topics.

Authoring by way of an instructional transaction approach requires the user or system to select those transactions that are appropriate for a given topic. The user merely supplies the subject matter content in a form that can be used by the transaction. There is no need to determine every display; to determine a branching structure, to select what kind of questions to use, and to specify answer processing. This algorithm plus data approach to the development of courseware is many times more efficient than a frame-based approach. Using a frame-based approach a designer requires 200 or more hours to develop a one hour lesson; while using an instructional transaction approach a designer can develop the same lesson in 20 hours or less. Furthermore, the frame-based approach may limit the interactions to answering questions, whereas an instructional transaction can involve interactive environments that enable the learner to explore the subject matter, manipulate simulations of devices, and other more complex interactions.

Figure 1 indicates that ID Expert™ consists of the following components: a family of transactions each consisting of several interaction modes (present, practice, assess) with an interaction manager; a knowledge base containing the knowledge or skill to be taught; a resource data base containing multi-media representations of the knowledge; a set of parameters that customize the transaction for a given task, learner population, and learning environment; a transaction configuration system; a knowledge acquisition system; and multi-media resource editors.

Each instructional transaction shell is able to support different types of *interaction modes*. It is able to present knowledge or demonstrate a skill, provide practice for the learner in using the knowledge or skill, and assess the learner's acquisition of the knowledge or skill. An instructional transaction shell includes an *interaction manager*. It supports both learner selection of interaction mode and is able to prescribe which interaction mode is appropriate for a given learner at a given moment in the instructional process.

In ID Expert™ subject matter content (knowledge) is decoupled from the instructional strategies necessary to teach this knowledge. When knowledge is decoupled from strategy, then this knowledge must have a specified structure in order for a pre-stored instructional strategy to be able to present this knowledge to the learner, to enable the learner to practice the knowledge, or to assess the learner's acquisition of this knowledge. In version 1.0 of ID Expert™ a knowledge base consisting of three types of knowledge objects: entities (objects), activities (procedures), and processes, supports the instructional transactions. The representation system used in this knowledge base elaborates each of these knowledge objects (that is, links them to other knowledge objects) by component relationships (parts, steps, and events), property relationships, abstraction relationships (classes, subclasses, and instances), and association relationships. Some important association relationships include: an entity owns processes and/or activities; a process changes the properties of one or more entities; and an activity changes the property values of its entity owner. ID Expert™ links a particular kind of knowledge structure or set of associated knowledge structures with a given class of instructional transaction.

ID Expert™ decouples knowledge objects from the resources used to represent this knowledge. The multi-media resource data base represents knowledge objects by text descriptions, auditory messages, graphics, animation, and/or video. The multi-media resource

data base may represent the same knowledge object one way in one lesson, but a different way in a subsequent lesson.

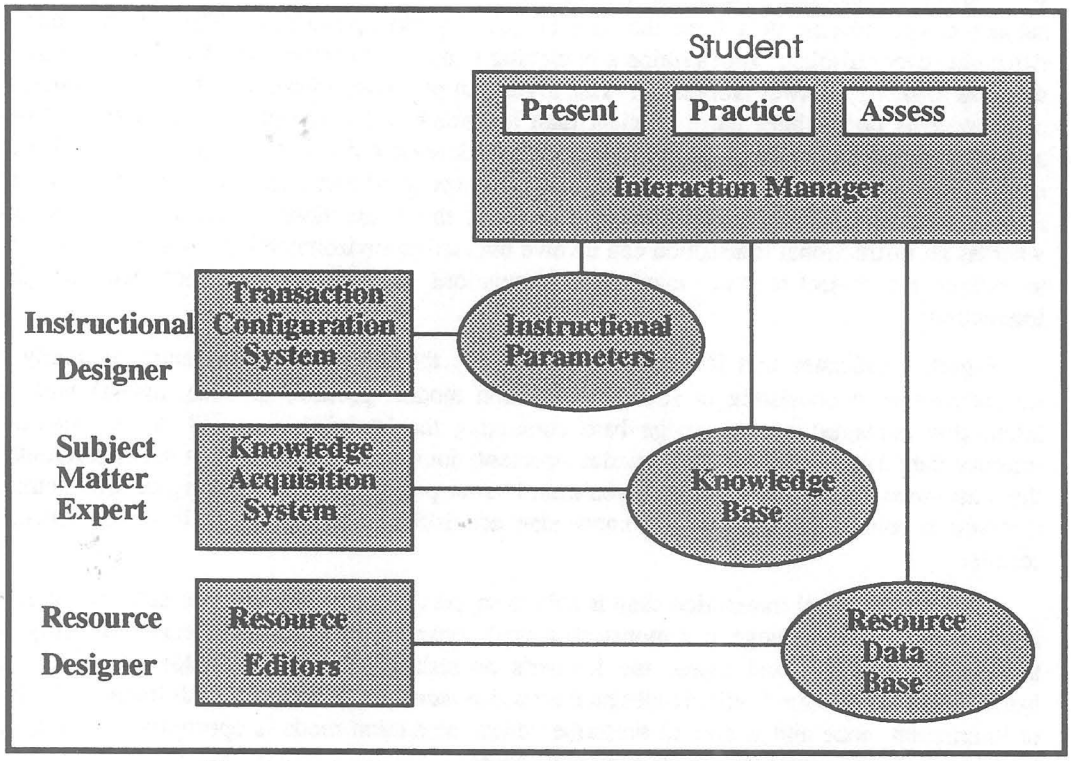

Figure 1 Architecture of an instructional transaction shell

ID Expert™ consists of an instructional development environment as well as an instructional delivery environment. Unlike other authoring systems, the knowledge acquisition system enables a subject matter expert to specify the knowledge and resources without concern for how this knowledge will be taught to the learner. The knowledge acquisition system translates knowledge obtained from the subject matter expert into the components of its unique knowledge representation system. This translation is necessary in order for the knowledge to used by the transactions.

Most authoring systems require the user to do some form of programming either with commands, icons, or menus. This instructional programming is usually easier than using a programming language, but it still requires the user to construct the displays and interactions with the student. The interactions of ID Expert™ are built-in and do not require the user to construct them. However, each instructional transaction has a set of parameters that enables the user to customize the transaction for particular learner populations, tasks, and learning environments. Parameters determine which interactions the system activates and how each instructional function carries out its responsibilities. The user can modify (usually with the click of a button) the parameters that activate or control these interactions. If the built-in rules for configuring the instructional interactions do not provide appropriate instruction for a given

subject matter, instructional environment, or group of learners, then the user can modify the interactions by changing the value of the parameters that control these interactions.

ID Expert™ can store several different parameter configurations for different audiences or instructional situations. The system can be reconfigured by merely selecting a previously stored configuration that consists of different parameter settings.

Knowledge decoupled from strategy

A computer program is an algorithm plus data. An algorithm is a procedure for performing some symbol manipulation task. Data are the symbols that the algorithm manipulates. Computer algorithms gain their power by being reusable; the program uses the same algorithm over and over with different data.

An instructional transaction shell is a computer program that encapsulates the conditions for a given type of knowledge. We assume that an instructional transaction shell is an algorithm. We assume that we can decouple the subject matter (knowledge) to be taught from the strategy required to teach this knowledge. We assume that the subject matter to be taught is the symbols manipulated by the algorithm and represents the data part of the computer program. Therefore, we can use a given instructional transaction shell (computer algorithm) over and over to teach different knowledge (data).

The decoupling of knowledge and strategy is one of the fundamental assumptions underlying the design of ID Expert™. However, we have implemented this assumption at a number of levels. At one end of the continuum, instructional transactions are templates for which there is a one-to-one association of knowledge elements with strategy components. At the other end are more general instructional transactions for which there is a many-to-many relationship of knowledge elements with strategy components.

Instructional design templates

An instructional template is an instructional format containing windows into which the system places different knowledge resources. Using a template enables the instructional designer to decouple knowledge from instructional strategy. The user can link different sets of knowledge resources to the template, but it still retains its same basic form. An instructional template is the most direct application of the separation of subject matter and strategy assumption. Figure 2 is from an electronic text book transaction. Mark Lacy, an instructional designer from the ID_2 research group at USU, developed the electronic multi-media text book transaction. The sample lesson is from a social studies text book and illustrates a unit on transportation. However, a designer can use the text book transaction for any subject matter.

The learner has considerable learner control. The buttons at the bottom of the screen allow the student to engage different types of interaction: an overview, summary, practice, and events. The buttons on the right allow the learner to select a number of different types of information within a given learning interaction. Selecting the text-overview button causes the transaction to display a scrolling window that contains the text as given in the text book. Selecting the read-aloud button on the text screen causes the system to read the text aloud. Selecting the slide-overview button causes the system to open a window on the screen and to present a series of pictures and captions illustrating the main points of the unit being taught. Selecting the video-overview button causes the system to open a window where it presents a short video, complete with sound, to illustrate the main points of the unit. Selecting the audio-overview button causes

the system to play a short narrative introduction to the unit. Selecting the map-overview button causes the system to present a map showing the early canals and railroad routes. The goal of this transaction is to provide a variety of multi-media resources all of which present the ideas to be learned.

Figure 3 is a portion of an authoring screen for the electronic textbook. The authoring is very straight forward. The authoring screen presents each of the buttons that appear as options for the student followed by a text field where the author enters either the text to be presented or the path to a multi-media resource file that is to be presented. In the illustration we show the overview button. The author either types or pastes the text to be presented into the scrolling text field. The system presents this information to the student when the student selects the text-overview button. The slide-button is followed by a series of fields. In the first field the author types the path to the graphic resource the system will present as each slide. The following field is the text caption that the system will present beneath the slide. The complete authoring system has similar fields for each of the options available in the system. The author provides the resource information requested. If no information is available the system automatically eliminates the button from the student menu.

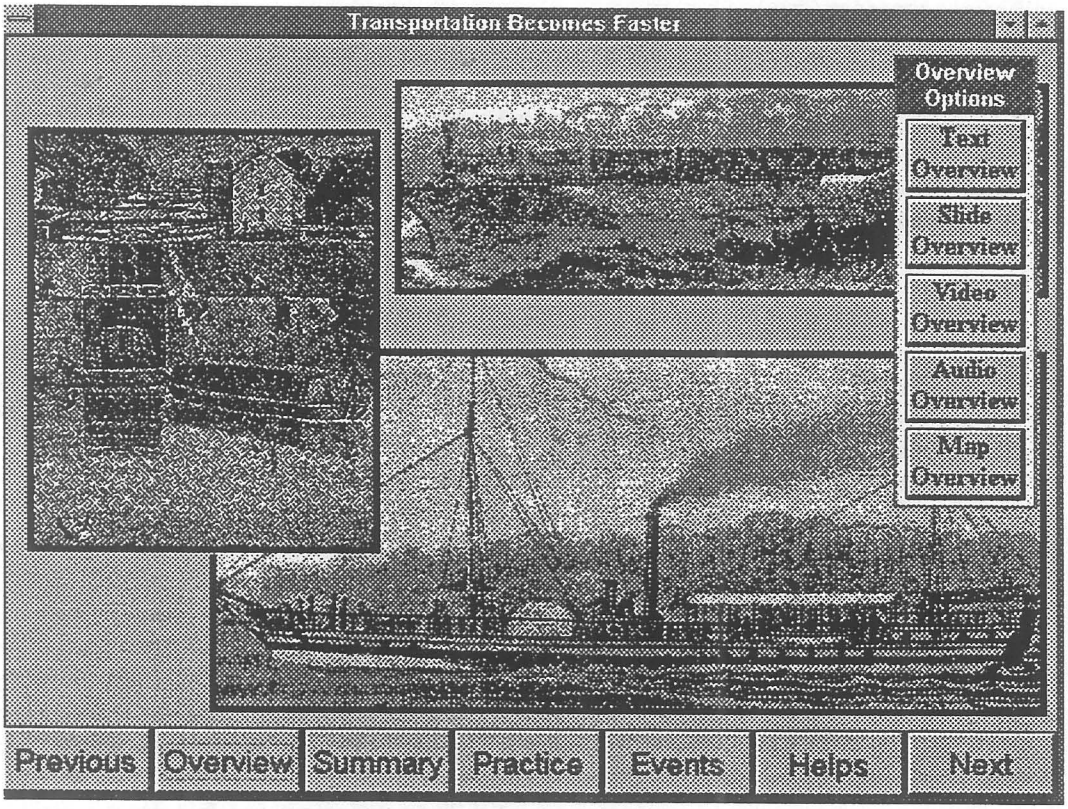

Figure 2. The student interface from the electronic multi-media text book transaction.

In the electronic text book transaction the author does not need to be concerned with the presentation. That is already programmed. The author merely supplies the text or paths to the resources to be presented and the system configures the presentation for the student, determines which options are available based on the whether or not information has been provided by the author, and presents the option buttons to the student.

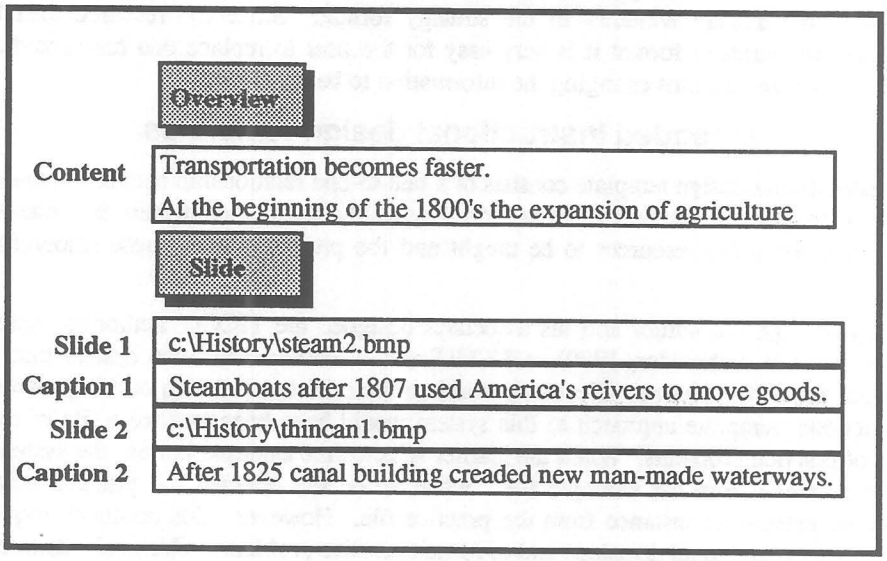

Figure 3 A small piece of the authoring interface for the electronic multi-media text book transaction.

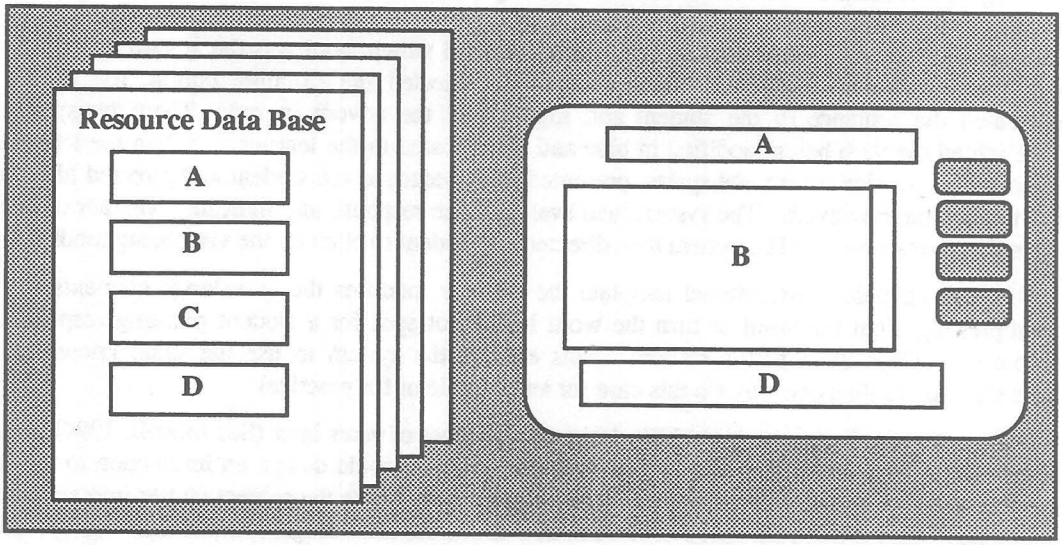

Figure 4 Instructional template -- one-to-one relationship between knowledge elements and strategy.

The portion of the electronic multi-media text book transaction illustrated here is an instructional template. In an instructional template there is a one-to-one relationship between

resources and the use of these resources in the interaction with the student. The strategy is a format with controls and windows for presenting these resources. When the student selects a given control, the system creates the appropriate window, and presents the resource that corresponds to this window to the student. Figure 4 illustrates a resource data base and a strategy format for an instructional template. Each record in the resource data base contains slots that correspond to the display windows in the strategy format. Since the resource data base is separate from the strategy format it is very easy for the user to replace one resource data base record with a new record thus changing the information to be taught.

Extended Instructional design templates

An instructional design template consists of a one-to-one relationship between resources and the presentation of these resources. Even more reusability takes place if there is a one-to-many relationship between the resources to be taught and the presentation of these resources to the student.

Some years ago the author and his associates designed the TICCIT authoring system (See Merrill, Fletcher, & Schneider, 1980). TICCIT was a learner controlled system that, among other things, allowed the user to select an example or practice by the touch of a keyboard button. The instructional template approach to this system would have been to have a file of examples and a file of practice problems. When the learner selected the example button, the system would present an instance from the example file; when he or she selected the practice button, the system would present an instance from the practice file. However, this approach requires the author to make instructional decisions and to format practice problems. Our goal was to have the author merely supply subject matter and have the system decide how to use this subject matter.

Figure 5 illustrates our solution to this challenge. An instance data base contained a list of instances (in Figure 5 these instances are sentences containing adverbs, the topic being taught). The author merely provided each sentence and indicated which word was the adverb and which was the verb being modified. When the learner selected the example button, the system presented the sentence to the student and highlighted the adverb in red. Then the system highlighted the verb being modified in blue and so indicated to the learner. When the learner selected the practice button, the system presented the sentence to the student and directed him or her to click on the adverb. The system then evaluated the response and indicated whether or not the student was correct. The system then directed the student to click on the verb being modified.

In this extended instructional template the strategy modifies the knowledge elements (for example, highlight the word or turn the word into a hot spot for a student pointing response) before it displays them to the student. This enables the system to use the same knowledge element in more than one way (in this case for an example or for practice).

In another project on writing skills designed a number of years later (See Merrill, 1994), we realized that we could extend this notion even further. We could design an interaction to teach not just adverbs, but any part of speech. The author merely broke the subject matter into smaller components and provided additional information about the knowledge. In this case the system can use the same sentence in a number of ways. For example, the sentence could illustrate sentence structure showing the noun phrase and the verb phrase; or the sentence could be an example of a statement or an imperative. The system was able to take this information and modify the presentation so that it now uses the same knowledge elements in a number of different ways without requiring the author to recopy and reformat the knowledge.

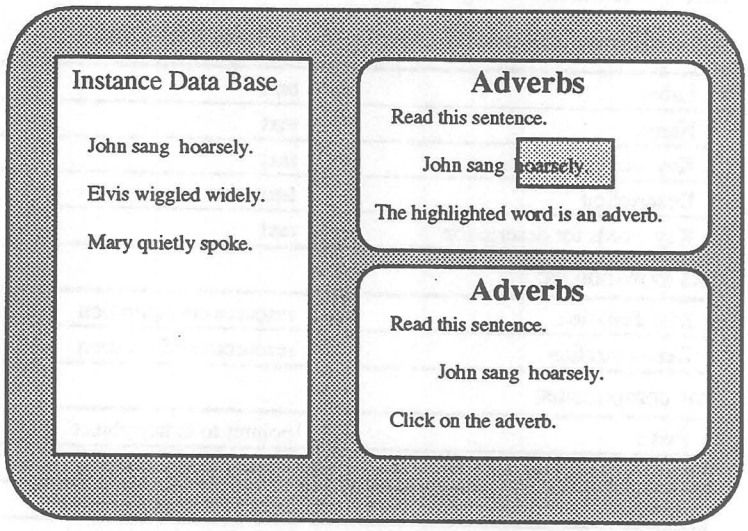

Figure 5 An extended instructional template reuse of knowledge for different interactions.

It was these projects that eventually led us to the idea of making a completely general interaction (a transaction) which could use any knowledge of a particular type and create a wide variety of interactions ranging from various types of presentation to a wide variety of practice. The challenge for such a system was to determine what are the knowledge elements that are appropriate for most knowledge, and what are the rules for manipulating this knowledge to cause different types of interactions for the students.

Instructional Transactions

From a system point of view a transaction is a set of rules for displaying knowledge objects and elements to a student, and rules for interpreting input from the student. One key to a transaction, that can teach any kind of knowledge, is to identify an appropriate knowledge structure that we can use with a wide variety of subject matters. The second key is to determine a general set of rules for manipulating these knowledge objects and learner input so as to provide a variety of interactions ranging from presentation to assessment.

Knowledge representation for Entity Knowledge Object

Table 1 is a formal knowledge structure for an entity knowledge object. The left column lists each of the knowledge elements or slots. The right column is a resource or is a pointer to a resource that represents the knowledge element.

Table 1 Formal knowledge representation for entity knowledge object.

Element or slot	Resource or pointer
Label	text
Name	text
Key words for name	text
Description	text
Key words for description	text
Links to resources:	
Manifestation	resource configuration
Demonstration	resource configuration
Owns components:	
Part 1	pointer to entity object
Part 2	pointer to entity object
Part n	pointer to entity object

Transaction enactment rules

Table 2a and 2b illustrate some of the rules for enacting an identify transaction. The rules as presented here are psuedo code and must obviously be programmed into a formal programming language to be used in ID Expert. The parameters (column 1) and parameter values (column 2) are conditions for the command in the right column to be enacted. If the parameter listed in column 1 has the value listed in column 2 then the transaction carries out the instructions in column 3. Each event element can be selected or deselected independent of other elements. Table 2a are the enactment rules for the presentation interaction of the transaction. Table 2b are the enactment rules for the practice interaction of the transaction. This is not a complete set of rules. We have designed other types of presentations including explore and assess.

Table 2a Identify transaction presentation mode enactment rules for ID Expert™

Parameter	Value	Tx Enactment
entity elements		
	manifestation	display resource configuration for entity
	location	display location indicator
	name	display name of entity
	description	display description of entity
	demonstration	display resource configuration for entity
part display	random	display parts in random order
	remove after each	display elements for one part then remove prior to displaying elements for the next part
	simultaneous	display elements for all parts when the learner enters the interaction
presentation order	list of elements	determines the order of presentation for entity elements
element display time*	wait for user input	display element and wait for mouse click before proceeding to the next element
	wait until event ends	display each element and retain until all elements for a given part have been displayed. On mouse click after part remove previous part's elements.
	wait for [ ] secs	display each element for the number of seconds specified
abort presentation	yes	allows the learner to interrupt and stop the presentation

* Applies to each element of the presentation: name text, manifestation, description text, demonstration

Table 2b Identify transaction practice mode enactment rules for ID Expert™

Parameter	Value	Tx Enactment
presentation elements[2]		IDX displays selected presentation elements.
	manifestation	display resource configuration for entity
	location	display location indicator
	name	display name of entity
	description	display description of entity
	demonstration	display demonstration for entity
response elements*		IDX requires the learner to respond by supplying the selected response elements.
	location	learner clicks on the location of the part
	name	learner selects name or types key word for name of part
	description	learner selects description or types key words for description of part

* Each part element can be selected or deselected independent of other elements. Each element can appear on only on the presentation list or the response list.

Table 2b continued Identify transaction practice mode enactment rules for ID Expert™

Parameter	Value	Tx Enactment
practice sequencing	simultaneous	requires the learner to complete all of the selected response modes for one part before going on the next part.
	sequential	requires the learner to complete one response mode for all of the parts before going to the next response mode.
	learner control	display a response menu to the learner listing all the selected practice modes.
part order	random	requires the learner to practice parts in random order
	fixed	requires the learner to practice parts in a fixed order
abort practice	yes	allows the learner to abort practice before finishing
mastery	criterion %	the minimum score (% correct) accepted for passing the transaction
	# tries to criterion	number of tries to reach criterion. In standard and remedial segment sequences IDX automatically returns the learner to present or explore if the learner does not reach criterion within this number of tries.
Feedback time	no feedback	no feedback is provided after learner response
	immediate	feedback is provided after each response
	delayed	The system withholds feedback until the learner has completed all the practice interaction for all the parts within the transaction. The system delayed feedback is a final score.
feedback source	system	display IDX messages
	designer	display user generated feedback messages
feedback type	R/W correct answer	display "right" message followed by correct answer or "wrong" message followed by correct answer
	R/W	display "right" or "wrong" message only
	W only	display "wrong" message only
	CA	display correct answer after right or wrong responses
# tries		number of tries required before displaying a feedback message. Prior to reaching this number IDX displays "try again" message and repeats the practice.
Response timing*	Wait for user input	allows the learner to take as long as necessary to complete the response
	Wait [ ] seconds	display a "time is up" message if the learner does not respond within [ ] seconds
Response mode	recall	requires learner to type key words for name or description
	recognize	requires learner to select name or description from a list

* Separate timing parameters for each of the response elements.

Tx strategy selection rules

Once we have identified parameters we can define rules that enable the system to automatically configure these parameters. ID Expert™ includes rules for automatically configuring transactions given certain student characteristics. Table 3 illustrates a rule for selecting interaction mode based on learner learning level and motivation. Table 4 illustrates a rule for determining transaction sequence and interaction sequence based on learner experience and motivation. These are merely sample rules and do not represent all of the rules in ID Expert ™.

Table 3 ID Expert™ configuration rule for selecting interaction mode.

Interaction Mode Selection								
learning level	Overview		Familiar		Basic		Mastery	
motivation	High	Low	High	Low	High	Low	High	Low
present:		selected		selected	selected	selected	selected	selected
explore:	selected		selected		selected		selected	
practice:			selected	selected	selected	selected	selected	selected
assess:							selected	selected

Note: Experience and job aid have no affect on interaction mode selection.

Table 4 ID Expert™ configuration rule for determining transaction and interaction sequence.

Segment Strategy				
Experience	High		Low	
Motivation	High	Low	High	Low
Tx sequence:	learner control	integrated	learner control	integrated
Interaction sequence:	learner control	remedial	learner control	standard

Note: Learning level and job aid have no affect on segment strategy

In ID Expert™ version 1.0 the system uses these rules when the instruction is being designed to automatically configure the interactions. The rules define a variable set of default values for the parameters.

In future versions of ID Expert™ we plan to enact these rules in real time. That is, the system will monitor the students for motivation. If the monitor function determines that the motivation level has changed, then the system will modify the values of the parameters that are affected by motivation according to rules like those indicated above. In this way ID Expert™ becomes an adaptive system.

Bibliography

The following sources describe the work of ID_2 research group in more detail. Not all of these sources were cited in this paper.

Merrill, M. D., Fletcher, K. A. & Schneider, E. W. (1980). TICCIT. Educational Technology Publications.

Jones, M. K., Li, Z., & Merrill, M. D. (1990). Domain knowledge representation for instructional analysis. *Educational Technology.* 30(10), 7-32.

Li, Z., & Merrill, M. D. (1990). Transaction shells: a new approach to courseware authoring. *Journal of Research on Computing in Education.* 23(1), 72-86.

Merrill, M. D. (1985) Where is the authoring in authoring systems. *Journal of Computer-Based Instruction.* 12(4), 90-96.

Merrill, M. D. (1987). Prescriptions for an authoring system. *Journal of Computer-Based Instruction.* 14(1), 1-8.

Merrill, M. D., Li, Z., & Jones, M. K. (1990a). Limitations of first generation instructional design (ID_1). *Educational Technology*, 30(1), 7-11.

Merrill, M. D., Li, Z., & Jones, M. K. (1990b). Second generation instructional design (ID_2). *Educational Technology*, 30(2), 7-14.

Merrill, M. D., Li, Z. & Jones, M. K. (1991). Instructional Transaction Theory: an introduction. *Educational Technology*, 31(6), 7-12.

Merrill, M. D., Li, Z. & Jones, M. K. (1992). Instructional Transaction Theory: responsibilities, methods, and parameters. *Educational Technology*, 32(2), 5-27.

Merrill, M. D., Jones, M. K. & Li, Z. (1992). Instructional Transaction Theory: classes of transactions. *Educational Technology*, 32(6), 12-26.

Merrill, M. D. & ID2 Research Team. (1993). Instructional Transaction Theory: knowledge relationships among processes, entities, and activities. *Educational Technology*, 33(4), 5-16.

Merrill, M. D. (1994) David G. Twitchel (Ed.) *Instructional Design Theory*. Educational Technology Publications.

Merrill, M. D. & ID2 Research Team. (1994). Automated instructional design and development. In Press.