Automating Instructional Design

Concepts and Issues

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Chapter Three

Functions of an Automated Instructional Design System

Charles M. Reigeluth

To state the obvious, the purpose of an automated instructional design system is to automate the instructional design process. *Automating* could entail anything from providing a few tools for an instructional designer to use, to entirely replacing the instructional designer. It generally does not refer to replacing the subject-matter expert. The *instructional design process* could entail anything from the instructional strategy selection process (the design phase of the instructional systems development process) to the entire spectrum of phases, including analysis, design, development, implementation, and evaluation. Where an automated instructional design (AID) system falls on these two continua will determine how powerful a tool it is for course development.

Regardless of where an AID system falls, it must incorporate knowledge about both process and product. *Product* knowledge includes knowledge about what the instruction should be like when the design process has been completed. This knowledge is referred to as principles and theories of instruction, which prescribe different instructional strategies for different situations. *Process* knowledge includes knowledge about how to create the product. It is a set of procedures and heuristics as to how to analyze the learners' needs, how to select appropriate content for the instruction, how to use principles and theories of instruction, how to develop or produce any learning resources or instructors' guides, how to conduct a formative evaluation, and so forth. Although an AID system must incorporate knowledge about both process and product, the scope of this chapter is limited to a discussion of product knowledge: instructional theories and principles.

Instructional theories and principles are very different from learning theories and principles. They are concerned with prescribing what the instruction should be like—what instructional strategies should be used when—and therefore are prescriptive. Learning theories and principles, on the other hand, are concerned with describing what goes on in a learner's head—what learning processes a learner uses—and therefore are descriptive. John Dewey (1900) characterized instructional theory as a "linking science" between learning theory and educational practice.[1] There is a strong relationship between these two disciplines. Instructional theory provides concrete guidance for how to facilitate the occurrence of certain learning processes. And learning theory provides a rationale as to why certain instructional prescriptions are useful. Learning theory can provide a basis for the (deductive) development of instructional theory, but instructional theory can just as readily be developed (inductively) through trial and error. And instructional theory can just as readily provide the impetus for development of learning theory (for example, to explain why an instructional strategy is so effective under certain conditions).

Regardless of the scope of the AID system, its most important function is to specify what the instruction should be like for a particular situation (particular goals, content, learners, and learning environment). In other words, it must prescribe the most appropriate instructional strategies and tactics.

Organizational Strategies

In the process of designing instruction, an instructional designer or an AID system must address macro-organizational strategies first, for they include prescriptions for selecting, structuring (grouping), and sequencing the course content, which must be done before mid-level and micro-organizational strategies can be selected.

Macro-Organizational Strategies

In addition to strategies for selecting, structuring, and sequencing the course content, macro-organizational strategies include ones for synthesizing (explicitly teaching interrelationships) and summarizing (systematically reviewing) the content.

[1]Editor's note: It is just this concept of instructional theory as a linking science that inspired the choice of AIDA as an acronym—AIDA (Verdi's opera) was commissioned to celebrate the opening of the Suez Canal, which links two bodies of water.

Selecting content

The selection of content is based on needs analysis and task or content analysis. Needs analysis entails identifying the goals (the desired expertise for the learners) and identifying the learners' current knowledge (the existing expertise of the learners). The need is the gap between the two. To figure out how to fill the gap, one must perform a task analysis that identifies the specific knowledge and skills that are missing. This includes identifying procedures, causal models, and other knowledge structures that distinguish the desired expertise from the existing expertise. Selecting content is not an instructional strategy. It is concerned with deciding what to teach rather than how to teach it. However, it is included here because of its great importance in the design process.

Structuring and sequencing content

In research on structuring and sequencing a course or training program, it emerged that every pattern of sequencing is based on a single type of relationship within the content (Reigeluth, 1989). For example, the chronological sequence is based on the time relationship among events; Gagné's hierarchical sequence is based on the learning prerequisite relationship among skills; the forward-chaining procedural sequence is based on the order relationship among activities; the Reigeluth-Merrill elaboration theory's conceptual elaboration sequence is based on the parts or kinds taxonomic relationships among concepts; Scandura's shortest-path sequence (further developed and popularized by P. Merrill, 1987) is based on the simple-to-complex relationship among paths of procedures, and so forth.

In the cognitive domain, the Reigeluth-Merrill elaboration theory (Reigeluth and Stein, 1983) prescribes a holistic approach to structuring and sequencing that may enhance such goals as building stable cognitive structures, facilitating creative thought, and allowing for maximum appropriate learner control. The elaboration theory's simplifying conditions method (Reigeluth, 1987) calls for beginning the instruction with the simplest kind of typical task an expert would perform, and teaching it on the application (skill) level. The conditions which make that kind of task so simple are identified, and subsequent lessons in the course gradually relax those conditions so that ever more complex tasks are learned. These tasks can be primarily domain-dependent skills, generic skills, or understandings.

There is still relatively little known about the kinds of relationships that are most important for facilitating learning. New approaches to sequencing will probably be developed as new kinds of relationships are identified, especially for the affective domain. It seems likely that optimal sequencing strands will be developed for each of a variety of types of learning, then interwoven with each other to form a complete course or curriculum sequence.

Synthesizing and summarizing content

Synthesis is the process of explicitly teaching important relationships among ideas. Summarizing entails providing systematic review, perhaps by having the learners periodically use what they have learned. Very little attention has been paid to developing useful strategies and tactics for synthesis and summarizing (see Van Patten *et al.*, 1987). This is particularly unfortunate since they can have such a powerful impact on learners.

Mid-level Organizational Strategies

Some instructional planning is done on a level which is broader than micro-strategies (for a single idea) but considerably narrower than macro-strategies (for an entire course). Bruner's notion of a "learning episode" is a good example. A learning episode has a problem-solving character, it has a clear beginning and a clear end, it builds up to a climax of understanding, and its length should be proportional to the payoff—the magnitude of the climax of understanding (Bruner, 1960). Romiszowski's (1984) overall instruction strategies is another example, and they include such alternatives as an expositive strategy and an experiential strategy.

Merrill has also developed some mid-level organizational strategies he calls transactions (or instructional interactions), each of which is designed for a specific purpose or situation (Li & Merrill, 1990; Merrill, Li, & Jones, 1991); see especially Merrill's chapter in this volume. A transaction is a set of micro-organizational tactics and a strategy for sequencing those tactics. Transactions are configured according to several "parameters" (tactics), including:

- transaction mode (expository or inquisitory)
- instructional control (learner- or system-controlled)
- display
  - representation form
  - location of information
  - duration
- practice
  - format
  - amount
  - criteria
- feedback
  - conditions
  - types
  - durations
- guidance
  - conditions
  - types
  - amount
  - duration

Merrill has identified four major kinds of transactions: component, abstraction, association, and enterprise. A **component transaction** teaches all or part of one kind of cognitive structure, or "frame" as he calls it. An **abstraction transaction** teaches all or part of an abstraction hierarchy (ranging from instances on the lowest level of abstraction to progressively more general levels of a cognitive structure). An **association transaction** teaches two or more cognitive structures linked by an association relation. And an **enterprise transaction** teaches all cognitive structures (and their interrelations) for a given "enterprise" (task).

At present, there is very little in the way of tested prescriptions in this area. It seems likely that prescriptions will be developed for the use of such strategies as: apprenticeship, debate, field trip, game, ancient symposium, laboratory, lecture, project, simulation, role play, brainstorm, tutorial, and others (Dorsey *et al.*, 1989).

Micro-Organizational Strategies

Many instructional theorists, including Gagné, Merrill, and Gropper, have proposed that the selection of micro-organizational strategies and tactics should depend primarily on the nature of what is to be learned (see Reigeluth, 1983). Different theorists have offered different taxonomies of what is to be learned, but there is a surprising degree of similarity among those taxonomies.

Perhaps the first type of learning to be analyzed and investigated (because it is the simplest, most superficial type of learning) is what Bloom calls "knowledge" (Bloom 1956). Merrill refers to this type of learning as "remember verbatim" (Merrill *et al.*, 1979), and Ausubel calls it "rote learning" (Ausubel *et al.*, 1978). It is also one aspect of Gagné's "verbal information" (Gagné, 1985) and Anderson's "declarative knowledge" (Anderson, 1985).

A more complex type of learning is what Bloom calls "application." Merrill refers to it as "use-a-generality," Gagné calls it "intellectual skill," and Anderson uses the term "procedural knowledge." Certainly, learning to apply a rule requires very different methods of instruction from just memorizing it.

An even more complex type of learning has only recently begun to receive widespread investigation under the rubrics of thinking skills and learning strategies. It includes Bloom's higher levels ("analysis," "synthesis," and "evaluation"), Merrill's "find-a-generality," Gagné's "cognitive strategies," and Anderson's "domain-independent knowledge."

Interestingly, several of these taxonomies of learning have identified another type of learning which has been largely ignored by instructional theorists until now, and in fact was even largely ignored by learning theorists until recently. It is similar to (though somewhat more complex than) what Bloom calls "comprehension" and what Merrill refers to as "remember paraphrased," and comes closest to what Ausubel identifies as "meaningful verbal learning." It is also the other aspect of Gagné's "verbal information" and Anderson's "declarative knowledge." When students have to learn what an atom is, one hardly has concept classification (applying the concept) in mind. The learners are not expected to be in a situation where they need to say, "Oh! Look at that! That's an atom!" And their teachers certainly don't want them just to recite by rote what an atom is. There is clearly another type of learning, which is perhaps best characterized by the word "understanding." It seems to arise through the construction of meaningful (nonarbitrary) linkages or relationships between the new idea and what the learner already knows.

In sum, there are in the cognitive domain four major types of learning which require very different methods of instruction. The most intuitive labels may be: (a) memorizing information, (b) understanding relationships, (c) applying skills, and (d) applying generic skills. The various types of "domain dependent" content (content in the subject areas), such as concepts, procedures, and principles, can be acquired as any one of the first three types of learning. A concept can be memorized (either its definition or an example of it), or it can be understood (its relationships with other knowledge), or it can be applied (instances can be classified as examples or nonexamples of it). The fourth kind of learning is "domain independent" and generally requires more time to acquire. There is strong evidence that these four types of learning dictate different choices of strategies and tactics more than any other consideration or factor.

It is important to note that these types of learning are not levels of learning in the sense that one level must be acquired before another level can be acquired. People often acquire rules on an application level without being able to verbalize or state the rules. This happens to all ages, from children (e.g., linguistic rules) to experts in complex domains (e.g., problem solvers and strategists). Also, many procedures are learned on the application level without any understanding of what is happening or why it works. Math and statistics are often learned (taught) this way (unfortunately). And students clearly do not need to memorize a passage in order to be able to understand it.

Facilitating memorization

The field of instructional theory has grown out of a behavioral orientation which focused most efforts on prescriptions for memorizing information (association tasks). Research has shown that there are three tactics which should universally be used to facilitate this type of learning (called "routine tactics"): presentation, practice, and feedback. First, present the information that is to be memorized. Second, provide the learner with opportunities to practice remembering it under conditions typical of the post-instructional requirements. Finally, provide immediate feedback on each practice, by confirming correct answers or giving the correct answer on wrong answers.

Additional tactics include: repetition, chunking, prompting, and mnemonics. Practice opportunities should be repeated until the learner has mastered the information. If more than about seven items of information are to be memorized, then the items should be chunked into groups of no more than about seven items each; and the presentation, practice, and feedback should focus exclusively on one chunk until it is mastered. Prompting is a way of helping learners when they cannot remember the information. Prompts are designed to help the learner establish retrieval cues. Mnemonics, which are based primarily on cognitive theory, can greatly decrease the amount of time and effort students need to memorize information. They include first-letter mnemonics (acronyms), phrases, visual images, rhymes,and songs.

Facilitating application of skills

The behavioral orientation of learning theory and instructional theory also yielded some valuable prescriptions for teaching skill application (especially concept classification and procedure using). For routine tactics Merrill's (1983) component display theory extends the notion of presentation-practice-feedback to generality-examples-practice-feedback. The generality is a definition of the concept or statement of the procedure or principle. The examples are instances of the concept or demonstrations of the procedure or principle. The practice is an opportunity for the learner to classify new instances of the concept; to perform the procedure in a new situation; or to use the principle to predict effects, explain causes, or implement solutions (achieve desired effects) in new situations (Merrill, 1983; Reigeluth & Schwartz, 1989). The feedback confirms a correct answer or corrects the learner's cognitive processing on wrong answers.

Additional tactics include consistency, divergence, progression of difficulty, attention focusing, and alternative representation, among others. Consistency entails making the examples, practice, and test items as similar as possible to the postinstructional requirements. Divergence entails making the examples as different as possible from each other, making the practice items as different as possible from each other, and making the test items as different as possible from each other. The examples and practice should also be arranged in an easy-to-difficult order. The learner's attention should be focused on important aspects of the generality, examples, and feedback, through use of color, comments, shading, zooming, animation, loudness, and so forth. And the generality, examples, and practice items should often be represented in a different form, such as realia, iconic, and abstract (symbolic) forms. For a review of research on each of these tactics, see Merrill *et al.* (1976).

Facilitating understanding

Behavioral theory has little to say about how to facilitate understanding. Hence, there is relatively little in the way of validated prescriptions for facilitating the acquisition of understanding (meaningful learning). What work has been done has largely been on the development of descriptive learning theory (cognitive theory), rather than prescriptive instructional theory, with the exception of Ausubel's work (see Ausubel *et al.*, 1978).

There appear to be two different kinds of understanding, which require very different instructional strategies and tactics. One is what might be called conceptual understanding, for it entails understanding an idea by relating it to other knowledge in a semantic network or schema. Crucial to this form of understanding is identifying the kinds of relationships which represent important dimensions of understanding for the new idea (Lindsay & Norman, 1977). They may include superordinate, coordinate, and subordinate relationships, as well as analogical, experiential, functional, and others. Once the important relationships have been identified, it is possible to select a tactic appropriate for teaching each. Superordinate relationships are built by relating the new knowledge to a meaningful context or advance organizer. Coordinate relationships are built through comparison and contrast, subordinate through analysis of varieties and/or components, analogical through comparison and contrast with an analogy, and experiential through description of concrete examples or case studies. It is important to select familiar "objects" for teaching these relationships. A relationship can only be taught by relating the new idea to another idea ("object") that the learner has acquired. The more familiar the learner is with the object, the easier it will be to learn the relationship.

The other kind of understanding is what might be called causal understanding, or mental model, for it entails understanding an interrelated set of causal relationships and interdependencies. Since causal models are usually quite complex, one important instructional strategy is to use an elaboration sequence based on simplifying conditions (Reigeluth, 1987; see "Micro-Organizational Strategies" above). For example, White and Frederiksen (1987) designed a progression of microworlds (computer-based simulations) for teaching the laws of motion. The first microworld was the simplest because it stipulated many simplifying conditions, such as that an object could move in one-dimensional space only and there was no friction. The conditions simplified the causal model to the point where it could be relatively easily acquired by experimenting in the microworld. Then those simplifying conditions were gradually relaxed, one or two at a time, requiring the causal model to gradually grow in complexity. Other important tactics appear to be: labeled illustrations (Mayer, 1989), demonstrations, exploration, and practice in predicting, explaining (or inferring), and solving problems (Reigeluth & Schwartz, 1989).

Facilitating application of generic skills

Behavioral theory has not contributed much to knowledge about how to teach generic skills. However, instructional theorists and cognitive scientists have recently begun to devote greater attention to generic skills: thinking skills, problem-solving skills, learning strategies, and metacognition. Of the work that has been done here, most of it has been on deciding what to teach, rather than how to teach it. It seems likely that the most important methods will be a good simple-to-complex sequencing strategy for teaching any given generic skill, and prescriptions for integrating such single-skill sequences with each other and with a range of domain-dependent content sequences (both are macro-organizational strategies). Other than this, it seems likely that a generic skill will have to be analyzed as to its skill (primarily procedure-using) components and its understanding components, and that those components will be taught using the micro-organizational strategies and tactics appropriate to each.

Affective learning

These four types of cognitive learning (memorizing, applying, understanding, and generic skills) represent important aspects of instructional theory. Martin and Briggs (1986) identify several different dimensions of affective learning, each of which seems likely to require different methods of instruction. They include: attitudes/ values, morals/ethics, self-development, emotions/feelings, and several other dimensions. Within each, they conduct a comprehensive review of literature (theory and research), and formulate some instructional strategies and tactics.

Perhaps the most commonly taught of the dimensions of affective learning is attitudes/values. The major theories that offer instructional prescriptions include:

- The Yale Program (Hovland, Janis, & Kelley, 1953), which offers prescriptions for the use of persuasive communications;
- Dissonance Theory (Festinger, 1957), which prescribes techniques for increasing or decreasing dissonance among the learner's attitude, behavior, and/or environment,
- Social Learning Theory (Bandura, 1977), which prescribes a variety of techniques for changing attitudes by influencing conse-

quences of those attitude, such as direct reinforcement, vicarious reinforcement through modeling, and verbal persuasion.

Martin and Briggs then propose three major strategies for effecting attitude change based on the review of literature: persuasion, dissonance, and modeling. And they propose specific tactics for implementing each strategy. For example, a few of the tactics proposed for persuasion include:

- Use a credible source.
- Present both sides of the attitude if the audience is hostile or when the other side will be presented also.
- Provide an opportunity for overt verbalization or action.
- Delineate the reason for accepting an attitude, as well as providing the attitude itself.
- Attempt to lower the ego-involvement of the attitude object (pp. 137-138).

Although Martin and Briggs have considerably advanced our knowledge about how to design good instruction for affective learning, much more work is needed in this area.

Other conditions for selecting tactics

However, the selection of micro-organizational strategies and tactics should not just depend on the nature of the content. The nature of the learner is important, as well as the capabilities of the media that are selected. There is growing evidence that the nature of the learner has the greatest influence on decisions about what to teach, rather than how to teach it (Jonassen, 1982). It is not desirable to teach things which the learner has already mastered, for that would be a waste of time and money, and it would demotivate the learner. On the opposite extreme, it is undesirable to teach things which are too far beyond the learner's current knowledge, for lack of important prior knowledge (including prerequisite skills—Gagné, 1985) would make learning very difficult, if not impossible.

Perhaps the second most important way that the nature of the learner influences the selection of micro-organizational strategies and tactics is in making decisions about the amount of instructional support provided to the learner, that is, how rich the the instruction should be. It is important to assess the difficulty of the content based on the learner's ability and prior familiarity with it. The more difficult it is, the richer the instruction needs to be, including the use of more examples and practice, alternative representations (especially hands-on and visuals), attention-focusing devices, hints, and shaping (or successive approximations).

A third way that the nature of the learner is important is in the selection of motivational strategies. A motivational profile of the learner is very important for selecting appropriate motivational strategies (Keller, 1983, 1987).

With respect to the nature of learning environments, significant strides in information technologies are providing educators and trainers with tools of a magnitude of power previously undreamed of. Most current micro-organizational strategies were developed with a "page" mentality for paper delivery. To take full advantage of the capabilities of new mediational systems, educational thinking must advance beyond such a static, confining level. Strategies and tactics need to be developed which take advantage of the dynamic, interactive, and artificial intelligence capabilities of computers and interactive video. When such media are available, strategies and tactics that take full advantage of them should be selected.

Computer-based simulation possesses great potential for taking advantage of advanced technologies. But most simulations fall miserably short of their potential. Prescriptions for improving their quality are under development. Alessi and Trollip (1985) and Reigeluth and Schwartz (1989) have developed some prescriptions, but much more work remains to be done to test, refine, and further develop such prescriptions.

Advances in information technologies have also made possible the design of intelligent tutorial systems which can be used alone or in combination with simulations or other instructional approaches. The major deficiency to date for such systems is an inadequate set of instructional rules for an expert tutor so it will optimally facilitate learning. There is much room for improvement in the area of operationalizing prescriptions to the level of specificity necessary for expert tutors. Merrill (1989) has made some important advances in this area, but much more work is needed.

Motivational Strategies

Another important issue that has been too little explored in research and theory is that of motivating learners. All of the above-mentioned kinds of strategies and tactics can be used to enhance motivation to learn: organizational, mediational, and management. Motivational strategies were largely ignored by instructional theorists until very recently. Keller (1983, 1987) has done much to integrate the current knowledge about motivation into a set of prescriptions for instructional designers, but more work is needed in this area, particularly regarding motivational strategies which are uniquely possible with advanced technologies.

Mediational Strategies

Given that instructional technology has strong roots in media, instructional designers have a tendency to constrain their instructional designs to certain mediational systems, particularly to such resources as print, computers, and video. However, many other types of mediational systems can be used. The source of instruction can be human or nonhuman; a human source can be a professional or an amateur; a nonhuman source can be instructionally designed or not created specifically for purposes of instruction; and the intended receiver can be an individual or a group. These characteristics yield the typology of mediational systems shown in Table 3.1. Note that the labels in the boxes are familiar concepts that do not overlap 100 percent with the concept as defined by the characteristics of the source and receiver. They are included here merely to be illustrative—the sort of approach one might think of first for each category. There is also considerable overlap between these categories and the mid-level strategies mentioned earlier. Furthermore, it is important to keep in mind that almost any medium (or combination of media) can be used within each of these categories.

Instructional designers have had a tendency to use self-instructional modules without considering that another mediational system might be better. Cost-benefit analysis is likely to be very important in making informed decisions. For practical guidelines in this area, see Romiszowski (1988). It is important to think of the instruction in terms of interactions between the mediational system and the learner, rather than to just think in terms of delivery of content by the system (Merrill, 1988).

Management Strategies

As instructional tools become more powerful and more varied, the task of managing the instruction becomes more formidable and more important. It is not just a matter of coordinating diagnosis-and-revision activities, although that is certainly very important. It is also a matter of deciding which kind of resource is important for whom and when, and which strategies and tactics are important for whom and when on each resource. A wide variety of considerations comes into play, including individual differences, mastery learning, record keeping, learner control, scheduling, incentives, and much more. With the development of expert systems, it is possible to think of designing an advisor into computer-based instruction. Such an advisor could monitor the learner's activities, intervene with advice when appropriate, answer questions about instructional management, and serve other instructional management functions. But what are the rules which should govern such an advisor? And what instructional management activities are best left to a human? Much more work is needed to develop useful prescriptions regarding such management issues.

Conclusion

To be successful, an AID system must specify what the instruction should be like for a particular situation (particular goals, content, learners, and learning environment). Instructional theory, as a "linking science" between learning theory and educational practice, provides the growing but

SOURCE		RECEIVER: Individual	RECEIVER: Group
Human	Professional	*Tutoring*	*Lecture*
Human	Amateur	*Peer Tutoring*	*Discussion*
Nonhuman	Designed	*Self-instruction Module*	*Group Activities*
Nonhuman	Natural	*Individual Projects*	*Group Projects*

Table 3.1. Typology of Mediational Systems.

still incomplete knowledge base for prescribing the most appropriate instructional strategies and tactics. An AID system can only be as good as the knowledge about instructional design that we put into it. While we already know much about how to facilitate memorization-level and skill-level learning, we know much less about how to facilitate understanding, generic skills, and affective learning of various kinds.

But advancing our knowledge about "product" (what good instruction is like for different situations) is only half of the story. We then must figure out efficient processes for applying that knowledge to particular situations, including analysis, design, development, implementation, and evaluation. The quality of these two kinds of knowledge that is built into an automated instructional design (AID) system will determine how powerful a tool it is for course development.

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