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TICCIT TO THE FUTURE: ADVANCES IN INSTRUCTIONAL THEORY FOR CAI

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The TICCIT system represents a considerable technological advance over previous CAI systems primarily because of its unprecedented foundation in instructional theory. This paper briefly describes the theory-base of the TICCIT system; it summarizes some recent advances in instructional theory for sequencing and synthesizing related parts of a subject matter; and it describes three major implications of those advances for the design of future theory-based CAI systems. Those implications concern (1) the selection of content, (2) the use of strategies for sequencing, synthesizing, and summarizing, and (3) the provision of knowledge necessary for the learner to make good strategy decisions.

The TICCIT system (Time-shared Interactive Computer-Controlled Information Television, jointly developed by The MITRE Corporation and Brigham Young University) represents a considerable technological advance over previous CAI (computer-assisted instruction) systems for several reasons, the most important of which is its unprecedented foundation in instructional theory. However, TICCIT represents what will soon appear to be only a primitive first step in the development of instructional-theory-based CAI systems.

The future of CAI lies in *instructional-theory-based* systems because of their greater effectiveness and efficiency. The major problem in the development of such systems is that instructional theory has been insufficiently developed for theory-based systems to make much difference. But recent advances have changed this situation, and continued progress in the development of instructional theory holds even more promise for the future.

First, this paper briefly describes *TICCIT's theory base*. Then it summarizes some recent advances in instructional theory regarding the sequencing and synthesizing of subject matter. And finally, it discusses three major *implications* of those advances for the design of future theory-based CAI systems.

TICCIT'S THEORY BASE

At the time that TICCIT's software was being designed at Brigham Young University, M. David Merrill was developing a theory of instruction (Merrill and Boutwell, 1973; Merrill, Richards, Schmidt, and Wood, 1977; Merrill and Wood, 1974, 1975a, 1975b). This theory was concerned with strategies for teaching a *single* topic (e.g., a single concept or a single principle). Such strategies have come to be called *micro strategies* (in contrast to macro strategies which are strategies that relate to teaching many related topics—e.g., sequencing strategies). Micro strategies include such strategy components as generalities, examples, practice, and "helps". Helps are instructional displays that make it easier to understand each of the other strategy components (a) by relating the generality to an example, point by point, or (b) by relating an example or a practice item to the generality, point by point. Each of these strategy components can in turn be broken down into its components. For instance, examples (1) should be "divergent" (i.e., widely different from each other), (2) should have nonexamples that are "matched" (i.e., as similar as possible) to the examples, (3) should have "attribute isolation" (i.e., devices which focus a student's attention on important things), and (4) should use a variety of "representation forms" (e.g., visual as well as verbal representations). For an overview of Merrill's instructional theory, see Merrill, Reigeluth, and Faust (1979).

The result of these simultaneous activities was the design and development of the first extensively theory-based CAI system. The instructional displays were divided into different types based on Merrill's theory—generalities, examples of each generality, practice on the use of each generality, helps on each of those three types of displays, and three categories of difficulty on the examples and practice. The system was designed with a special keyboard that enables the learner to select any one of the types of displays (i.e., strategy components) whenever s/he wants. In this

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way, the learner is given control over the timing and quantity of each of these important strategy components. This not only gives the learner access to the kind of instructional display that s/he needs at any moment, but it also teaches the learner some good learning strategies that s/he can use to great advantage off line. For a more in-depth description of TICCIT and its theory base, see Merrill, Schneider, and Fletcher (1979).

ADVANCES IN INSTRUCTIONAL THEORY

Through funding from Brigham Young University and the Navy Personnel Research and Development Center, Reigeluth and Merrill were recently able to work intensively on further developing their *macro theory* of instruction. A macro theory is concerned with strategies that relate to teaching many related topics. It includes four major design considerations, called the "four S's": selecting, sequencing, summarizing (i.e., previewing and reviewing), and synthesizing (i.e., showing interrelationships among) the related topics in a subject matter. Their *elaboration theory of instruction* was developed as an alternative to the heirarchical task analysis methodology for designing instruction on the macro level.

The following are among the many deficiencies of the hierarchical task analysis methodology that the elaboration theory is intended to overcome: (1) it provides no prescriptions as to summarizing strategies, (2) it provides no prescriptions as to synthesizing strategies, (3) it usually results in a high degree of fragmentation, which hinders motivation and meaningful understanding, (4) it provides an incomplete basis for selection of topics, (5) its parts-to-whole sequencing strategy is inconsistent with much knowledge about how learning occurs most effectively (such as schema theory and its predecessor, subsumption theory), and (6) it is a very incomplete basis upon which to make decisions about sequencing the instruction, mostly because learning prerequisites are only one aspect of the structure of subject-matter content.

It is beyond the scope of this paper to provide more than a brief summary of the elaboration theory of instruction. For a more in-depth description, the reader is referred to Reigeluth (1979), Reigeluth, Merrill, Wilson, and Spiller (in press), and Reigeluth, Merrill, Wilson, and Spiller (Note 1). As part of their elaboration theory of instruction, Reigeluth and Merrill have developed a *model* for sequencing, summarizing and synthesizing the related topics in a subject matter. First, the instruction presents a special kind of overview which epitomizes the instructional content rather than summarizing it. Because it is an epitomizing overview, it is called an *epitome* (ē•pĭt′ō•mē) to distinguish it from other kinds of overviews.

Second, the instruction proceeds to *elaborate* on that epitome by providing detail or complexity on each aspect of the epitome. This process of elaboration occurs in "layers", one layer at a time, until the desired level of detail or complexity is reached. The first layer, called the *first level of elaboration*, is made up of a number of discrete elaborations. Each of these elaborations adds some detail or complexity to a single aspect of the epitome.

Third, at the end of each elaboration, the instruction provides a summarizer and an expanded epitome. The *summarizer* provides a concise generality for each topic presented in that elaboration, and the *expanded epitome* (a) shows the important relationships among the topics comprising the elaboration and (b) shows the context of the elaboration within the epitome. Fourth, the instruction provides more detailed elaborations (called level-2 elaborations), if they are necessary to bring the student to the depth of understanding specified by the objectives of the instruction. Level-2 elaborations elaborate on each aspect of a level-1 elaboration. Each of the level-2 elaborations is also followed by a summarizer and an expanded epitome. This pattern of elaboration followed by summarizer and expanded epitome is continued for additional levels of detail until the level of detail specified by the objectives is reached. Finally, there is a *terminal epitome* at the end of the instruction. Figure 1 is a diagramatic representation of the elaboration model of instruction.

There are four major kinds of relationships among topics within any subject-matter. When applied to specific subject-matter content, the identification of each kind of relationship yields what we refer to as a *subject-matter structure*—the representation of a single type of relationship with a subject-matter. The following are the four major kinds of subject-matter structures (see Reigeluth, Merrill & Bunderson, 1978 for an in-depth explanation and examples).

Conceptual structures show superordinate/coordinate/subordinate relationships among concepts. There are three important types of such structures: *parts taxonomies*, which show the concepts that are components of other concepts; *kinds taxonomies*, which show the concepts that are varieties of other concepts; and *matrices*, which are the crossing of two (or more) taxonomies.

Theoretical structures show change relationships among concepts. They are integrated sets of principles, and they are often called models.

Procedural structures show procedural relationships among event concepts. There are two important types

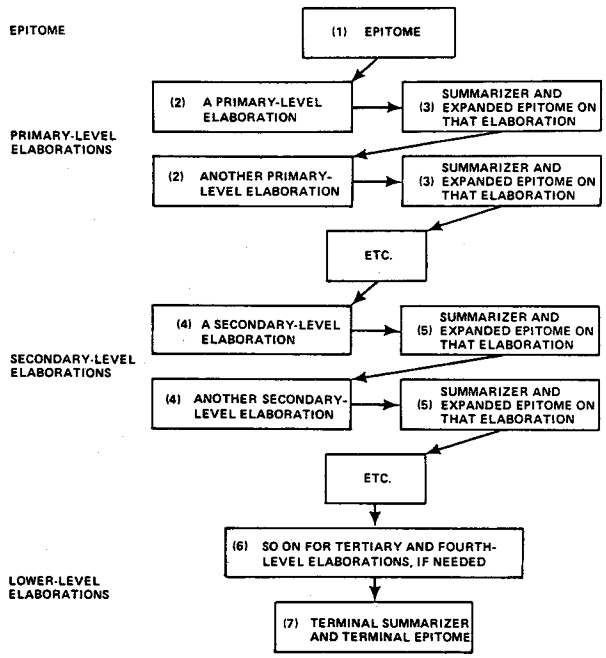

Figure 1. A diagrammatic representation of the elaboration model of instruction.

of such structures: those which show *procedural-order relationships*, which specify the order(s) for performing the steps of a single procedure; and those which show *procedural-decision relationships*, which describe the factors necessary for deciding which alternative procedure or sub-procedure to use in a given situation.

Learning structures show the learning prerequisite relations among concepts and principles.

This knowledge about subject-matter structures is important to the elaboration theory for two reasons: they are used for designing the instruction, and they are presented to the student as synthesizers. With respect to *designing the instruction*, the way in which the epitome is created and elaborated on is dictated by the choice of a single type of structure for "orienting" the elaboration. This "orientation structure" may be conceptual, procedural, or theoretical. And that orientation structure alone provides the basis for deciding what topics should be presented in the epitome and in each successive level of elaboration.

The second reason why subject-matter structures are important to the elaboration theory is that they can be presented to the student to *show the important relationships within the subject matter*. We believe this is highly facilitative of forming stable cognitive structures and thereby increasing long-term retention. This is done in the epitome and in the expanded epitomes.

IMPLICATIONS FOR CAI

One of the greatest deficiencies that has been encountered with both the TICCIT system and the PLATO system, as well as in other types of modular instruction, is the problem of "splintering" or lack of synthesis and integration of the modules or segments of instruction. The recent advances in instructional theory outlined above hold much promise for solving this problem.

A radically different function for subject-matter structure is described above. Instructional designers for CAI, like those for other media of instruction, have traditionally thought of subject-matter structure as a framework for guiding the design of instructional sequences. But the above-described theory views it as that plus a lot more. Structure should itself be *taught*. It should be a part of the instruction in order to teach the important interrelationships within a subject matter. Including such interrelationships in the instruction should solve the problem of splintering and should help increase the student's long-term retention, transfer, and motivation.

Accordingly, future CAI systems should teach structure along with the modules in a manner similar to that described above: begin with a general epitome, continue with alternating elaborations and synthesizers, and end with a complex epitome. But the implications of this instructional model go beyond considerations for the design of the instruction on CAI; they call for a different design of the CAI system itself.

The remainder of this paper discusses three important implications for the design of future theory-based CAI systems: (1) the CAI system should provide a larger degree of learner control over the selection of content; (2) it should provide learner control over components of the other kinds of structural strategies (i.e., sequencing, summarizing, and synthesizing strategies); and (3) it should provide the learner with the kinds of knowledge and information necessary for him/her to make good learner-control decisions.

Learner Control Over Selection of Content

As CAI systems start entering homes and adult-education contexts as well as schools, learners are going to demand increasing capabilities of CAI to provide learner control over the selection of content without cumbersome and demotivating "bottom-up" sequences being forced on them. It will also become increasingly important that the instruction be designed in ways that are more motivational and enjoyable for the learner. The above-mentioned advances in instructional theory for synthesizing and sequencing hold much promise for meeting these needs.

Some aspects of the elaboration theory of instruction facilitate learner control over content, while others impede it. There is a good analogy for showing the implications of the elaboration theory for learner control over the selection of content. It is the use of a *zoom lens* to take a look at a picture. A person should start with a wide-angle view, which shows the major parts of the picture and the major relationships among those parts (e.g., the composition or balance of the picture). The person can then zoom in on whichever part of the picture that interests him/her. Assume that the zoom operates in levels or discrete steps rather than on a continuous basis. Zooming in one "level" allows the person to see the major subparts of that part and the major relationships among those subparts. This again provides a basis for the viewer to select whichever subpart most interests him/her for zooming in for more detail. If s/he reaches a point where s/he is no longer interested in more detail on a part, the person could zoom back out to a point where s/he is interested in more detail on one of the parts.

In a similar way, the elaboration model starts on a very broad, general level with the epitome and gradually elaborates on aspects of the epitome. This approach gives the learner sufficient knowledge to provide a basis for selecting subsequent content; and the general-to-detailed organization allows the learner to learn what s/he wants to learn without having to go through a series of learning prerequisites that are on too low a level of detail to interest him/her much at this point anyway. As s/he becomes interested in more detail, s/he will want to learn those detailed prerequisites because s/he will see and understand their importance for learning the detail that interests him/her.

But how should this potential for selection of content influence the design of future CAI systems? *First*, it requires software and a keyboard that will allow the learner to select any part of a lesson for further elaboration. Something like the TICCIT map structure should work fairly well if instruction were provided at all map levels instead of just at the bottom level. (But the nature of the contents of the maps would often be very different from the way they are at present on the TICCIT system—each level of boxes would be elaborations on the boxes on the next higher level.) *Second*, the advances in instructional theory call for software that will provide expanded epitomes that are expanded only on the parts that the learner has selected for elaboration.

Both of these characteristics are more complex than they may at first seem. When a person looks at one part of a picture in detail (through a zoom lens), this is likely to influence what s/he "sees" in the subsequent parts of the picture. Such *elaborative dependence* is an extremely important factor for instruction. In order for instruction on an aspect of the epitome to be most effective, the related aspects that a learner has already studied should usually be taken into account in the design of the new aspect. This somewhat impedes the design and implementation of instruction for learner control over the selection of content, which is why the special capabilities of CAI are important. CAI can keep track of what the student has studied, and it can modify each subsequent elaboration, and even the synthesizers, accordingly.

You have probably noticed that learner control over the *selection* of content implies a certain amount of learner control over the *sequencing* of content. Since these two types of macro strategies are so interrelated, it would be helpful now to discuss the implications of the advances in instructional theory for sequencing, summarizing, and synthesizing strategies.

Learner Control Over Other Kinds of Macro Strategies

To continue the zoom-lens analogy, the viewer could be given control over the *order* in which s/he looks at parts of the picture, regardless of whether or not s/he has control over entirely skipping certain parts. The viewer could zoom in first on those parts of the picture that interest him/her most. The viewer may choose to zoom in very little before zooming back out to the wide-angle view to see the context of this slightly more detailed part of the picture. (This is equivalent to learner control over frequency of synthesis as well as over type of sequence.) Or the viewer may continue to zoom in for even greater detail on that same part of the picture. And, if the viewer chooses to zoom back out right away, s/he could continue to take short zoom-ins on all the parts of the whole picture before taking longer zoom-ins on any single part.

One can readily see that the possibilities for the learner, as for the viewer, are almost infinite as to different patterns that could be followed. Unfortunately, up to now the zoom has hardly been used at all in instruction. Most instructional sequences begin with the "lens" zoomed all the way in at one corner of the "picture" and proceed—with the "lens" locked on that level of detail—to systematically cover the entire scene. This has had unfortunate consequences both for synthesis and for motivation.

Again the question arises as to how these notions of sequencing, summarizing, and synthesizing should influence the design of future CAI systems. *First*, experience on the TICCIT system (Merrill, Schneider, and Fletcher, 1979) shows that on higher cognitive learning tasks, learner control over the above-mentioned micro strategy components (generalities, examples, practice, and helps) is beneficial—for affect and motivation, as well as for effectiveness and efficiency. Therefore, a *strategy keyboard*, similar to the one for learner control over micro strategies, should be created to give the learner some control over the macro strategy components for these three types of strategies. For instance, this keyboard could allow the learner to refer back to the epitome at any time, it could allow him/her to see a summarizer at any time (i.e., a concise statement of all the generalities s/he has studied in that elaboration up to that time), and it could allow him/her to select any part of the epitome—or of an elaboration—for further elaboration. *Second,* to handle variations in sequencing, software must be created to solve the problem of elaborative dependence. The computer should vary many elaborations somewhat, depending on which elaborations the student has and has not already studied.

However, even with this ability to overcome the problem of elaborative dependence, there are certain facets of sequencing content that should not be open to learner control. If the purpose of the instruction is the efficient performance of a *procedure*, there is a certain sequence that will optimize learning (see Reigeluth, et. al., Note 1). And to a lesser extent, if the purpose of the instruction is the attainment of a certain depth and breadth of understanding of related *principles*, there is also a specific sequence that will optimize learning (see also Reigeluth, et. al., Note 1). But if the purpose of the instruction is an understanding of the basic *concepts* in a field, then the sequence is not nearly as important as long as it follows some kind of a top-down pattern (i.e., general-to-detailed sequence). Elaborative dependence is also minimal for such a conceptual approach.

In other words, if a procedural or a theoretical orientation structure is used, then learner control over both content and strategy components may have detrimental effects; whereas if a conceptual orientation structure is used, then learner control over both content and strategy components is strongly advisable. The conceptual orientation structure is basically a "general education" approach to a subject matter and is the approach for which learner control over content would be most important. Procedural and theoretical structures could be nested within that conceptual orientation structure, such that the learner could decide whether and when to study each such nested type of content; but once s/he decided to study one of these nested components, his/her selection and sequence of content within that component would be fixed, although it would still follow the elaboration model pattern.

However, even in cases in which there is an optimal sequence for all learners to follow (i.e., for procedural and theoretical structures), there still may be many circumstances in which the benefits from learner control over content would outweigh the costs of a non-optimal sequence, particularly if the learner were given information about optimal sequences so that s/he would not vary too far from the optimal. This leads us to the *third* implication of the elaboration theory for CAI: the CAI system should provide the learner with the kinds of knowledge and information necessary for him/her to make good learner-control decisions.

Knowledge for Effective Learner Control

For accommodating individual differences, we have just advocated giving the learner *control over the selection of different strategy components* rather than having different "tracks" for different types of students. We advocate this, even if research shows that a certain strategy is always best for a certain type of student, for the following reasons: (1) if the student characteristics cannot be changed—such as certain kinds of aptitude—it is important for the student to learn which strategies are best for him/her and (2) if the student characteristics can be changed—such as a poor learning strategy—it is much more important to improve that shortcoming than to provide an instructional strategy (or method) that minimizes it. CAI systems, like all instructional systems, should have built-in programs for improving such student characteristics.

We mentioned above that experience on the TICCIT system shows that on higher cognitive tasks, learner control over micro strategy components is beneficial—for affect and motivation, as well as for effectiveness and efficiency. But in order to be maximally beneficial, the learner must know (1) the nature of the contents of each strategy option (e.g., a help, some more practice, a harder example) and (2) the nature of the effects on learning of each of those options. Without such *knowledge*, learner control may actually be detrimental. With such knowledge, the student makes far better decisions than any "program" ever could about whether s/he, upon doing a practice problem wrong, should rework that practice problem, should look at the practice help, should look at an example, or should just go on to another practice item.

We anticipate that the same will be just as true for learner control over macro strategies: that the learner must know (1) the nature of the contents of each strategy option and (2) the nature of the effects on learning of each of those options. (This notion is not unique to learner control. Students would also learn better from textbooks if they were given instruction about optimal learning strategies for learning from texts.)

But how can this be applied to CAI? The *knowledge* that the learner needs for effective learner control has two components, which should be provided in two different ways. First, the *nature of the contents of each strategy option* should be taught in an introductory module (or modules) on the CAI system. This is a concept-classification task that should be taught with generalities, examples, practice, summarizers, etc. Second, the learner needs to learn *when to use each of those strategy options*—i.e., what each contributes to learning and what kinds of learning problems each can solve. This can be implemented in two ways: (1) teach some *rules* for the use and effects of each option in a second introductory module (complete with generalities, examples, practice, summarizers, etc.) and (2) provide an *"advisor"* program to give advice to the learner.

The advisor program should provide advice under two conditions: (1) whenever the student requests it with a special learner control button (as on the TICCIT system) and (2) whenever both a) the student's strategy is found to be ineffective and b) the student is varying from the rules for effective use of the strategy options. The advisor program must keep track of the pattern of use of strategy options and compare it against an "ideal" created from the rules. Deviations from the ideal should be analyzed as to which rules are violated, and corresponding recommendations should be made to the student. Some parts of error analyses on a student's practice items and tests could also be used as a basis for advice to learners.

But perhaps the "ideal" pattern for use of strategy options will vary from one learner to another. CAI has a unique capability for accomodating this probability. The error analyses on a student's practice items and tests could be used as a *basis* for changing the "ideal" pattern for different learners and for different conditions for each learner. Also, some student "aptitudes" (see Cronbach and Snow, 1977) may provide a reliable basis for modifying the advice for each learner; but care must be taken to periodically monitor changes in those aptitudes and to update their inputs to the advisor for each student.

SUMMARY

The future of CAI lies in instructional theory-based systems because of their greater effectiveness and efficiency. The major problem in the development of such systems is that instructional theory has been insufficiently developed for theory-based systems to make much difference. But recent advances have changed this situation, and continued progress in the development of instructional theory holds even more promise for the future.

First, we briefly described *the theory base of the TICCIT system*, which is the first important theory-based CAI system. Its theory base is in the area of micro strategies, and it was implemented with a special keyboard providing learner control over the timing and quantity of certain micro strategy components: generalities, examples, practice, and helps.

Then we summarized some *recent advances in instructional theory* for macro strategies: sequencing, synthesizing, and summarizing related topics in a subject matter. The elaboration theory of instruction (see Note 2) includes the use of such strategy components as an epitome, elaborations on that epitome, internal and external synthesizers on those elaborations, second-level elaborations, synthesizers for those second-level elaborations, and a terminal epitome. The nature of the synthesizers and epitomes depends upon the type of orientation structure that was selected (on the basis of goals): conceptual, theoretical, or procedural. These strategy components can be used in ways similar to the use of a zoom lens for viewing a picture.

Finally, we described three major *implications* of those advances in instructional theory *for the design of future theory-based CAI systems*. First, the CAI system should provide a large degree of learner control over the selection of content. Second, the system should provide learner control over strategy components for sequencing, summarizing, and synthesizing the content. And third, it should provide the learner with the kinds of knowledge and information necessary for him/her to make good decisions. This knowledge and information could be provided in two ways: (1) by introductory modules which teach the learners a) the nature of the contents of each strategy option and b) some rules about the effects and use of each of those options, and (2) by an advisor program which gives both solicited and unsolicited advice to the learner.

NOTES

1. Reigeluth, C.M., Merrill, M.D., Wilson, B.G., and Spiller, R.T. *Final Report on the Structural Strategy Diagnostic Profile Project*. Submitted to the Navy Personnel Research and Development Center, San Diego, California, July 1978.

2. For a description on how to design instruction according to the elaboration theory, see: Reigeluth, C.M., and Rodgers, C.A. The Elaboration Theory of Instruction: Prescriptions for task analysis and design. *NSPI Journal*, (Special issue on task analysis; P. Merrill, Ed.), in press.

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