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AUTHOR Tennyson, Robert D.; Christensen, Dean L.
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ABSTRACT

This paper defines the next generation of intelligent computer-assisted instructional systems (ICAI) by depicting the elaborations and extensions offered by educational research and theory perspectives to enhance the ICAI environment. The first section describes conventional ICAI systems, which use expert systems methods and have three modules: a knowledge base, a student model, and a tutor model. The second section discusses the ICAI system of the future--a system that elaborates and extends the three basic modules of the conventional ICAI system--and explains how the future system will integrate artificial intelligence (AI) tools and methods with instructional variables and conditions empirically tested and shown to improve learning. It is concluded that the next generation ICAI will use a comprehensive meta-learning model which would take individual differences into account in the assessment and diagnosis processes, and make reference to both the learner's acquisition (i.e., storage) and retrieval of knowledge; it will select the strategies of instruction from a rich base of instructional variables according to learning objectives and the structure of the information to be learned; and it will use the concepts of artificial intelligence in the form of heuristics that have the capacity to learn and to adjust according to given situations. Some examples of major advantages that may result from the use of the next generation ICAI system conclude the paper. (18 references) (CGD)

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Authors:

Robert D. Tennyson
Dean L. Christensen

Educational Research and Theory Perspectives on Intelligent Computer-assisted Instruction

Robert D. Tennyson
University of Minnesota
178 Pillsbury Dr. S.E.
Minneapolis, MN 55455

and

Dean L. Christensen
Control Data Corporation
Box 1249
Minneapolis, MN 55440

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Educational Research and Theory Perspectives on Intelligent Computer-Assisted Instruction

Robert D. Tennyson
University of Minnesota

Dean L. Christensen
Control Data Corporation

Conventional intelligent computer-assisted instructional systems (ICAI) have a theoretical foundation which is based in computer science (Dreyfus & Dreyfus, 1986). Current ICAI programs are basically prototype systems whose aim is to enhance instruction through the employment of computer-based software tools. Most of these tools are directly associated with the expert systems methods of the artificial intelligence (AI) field. Given the computer science focus of these conventional ICAI programs, the attention given to learning and instructional theories has been minimal. As such, there is no direct empirical verification to show how the specific software tools may result in improved learning. The assumption of the conventional ICAI proponents is that the tools themselves will improve learning. However, learning and instruction are much more complex processes than are exhibited in the prototype ICAI systems and, when viewed from an educational perspective, these systems have a rather novice approach to both learning and instruction (Tennyson & Park, 1987).

With this perspective in mind, we would like to suggest that the next generation of ICAI will differ from the current software tool-based models, to instructional systems that have their theoretical foundations in educational and psychological theories of learning and instruction. The aim of the educationally-based ICAI systems will be to improve the acquisition, storage, and connections between instructional variables and learning. The next generation ICAI systems will employ the AI/expert systems tools but with variables and conditions directly related to the fields of psychology and education. This paper will define the next generation of ICAI by showing the elaborations and extensions offered by educational research and theory perspectives to enhance the ICAI environment.

Conventional ICAI

Conventional ICAI systems, using expert systems methods, have three major modules (or models) (Fletcher, 1984); a knowledge base, a student model, and a tutor model. Each of these modules can be summarized as follows (Figure 1):

- Knowledge base. A data base which represents knowledge of a specific topic that an expert may have in memory. The information in a knowledge base is usually obtained by an interview conducted between an individual labelled as a knowledge engineer and a subject matter expert. The goal of this process is to query the expert so as to obtain both declarative knowledge and procedural knowledge. The idea is to have a knowledge base module that can both generate solutions to previously unencountered situations and make inferences from incomplete measures or data.

-Student Model. A mechanism for assessing the student's current knowledge state of the information in the knowledge base. The student's prior knowledge state is generally represented as either a subset of an expert's knowledge (e.g., overlay model, Goldstein, 1982) or the student's misconceptions of the expert's knowledge base (e.g., the buggy model, Brown & Burton, 1978).

-Tutor Model. The purpose of this module is to manage the instruction. This is done by a management system (termed an inference engine) that makes decisions such as selecting problems to be solved, critiquing performances, providing assistance upon request, and selecting remedial materials.

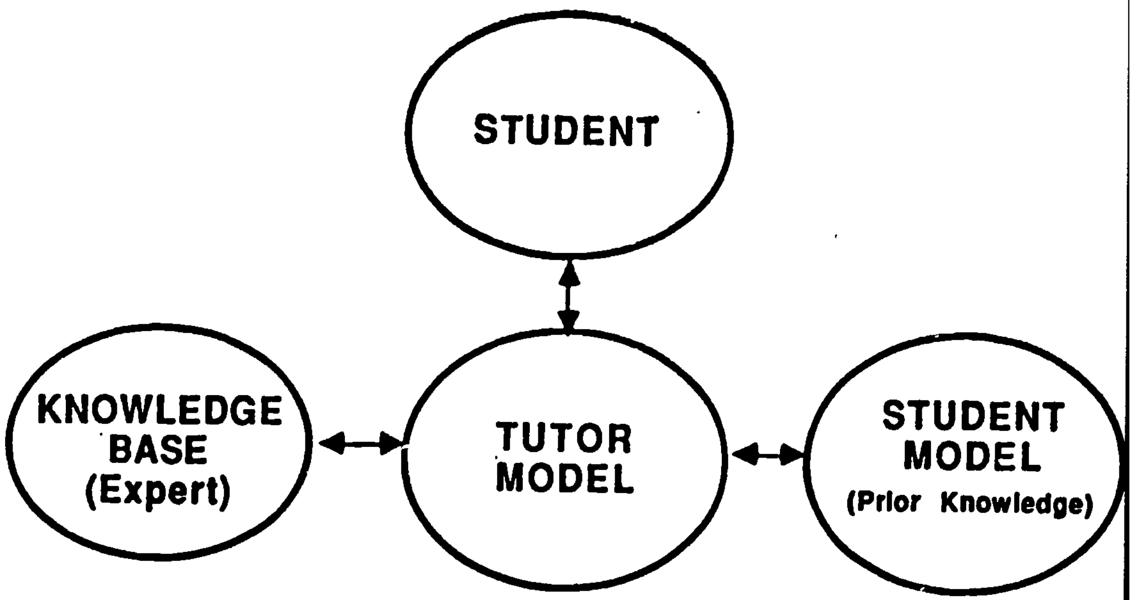
In conventional form, the tutor model employs basically a single instructional strategy embedded in the system for all students and situations. For example, the most commonly used strategy is a Socratic method of teaching which requires the student to response to a given stimulus. As such, the strategy borrows heavily from the early programmed instruction (PI) format of intrinsic programming developed by Crowder in the late 1950s.

Insert Figure 1 about here

Educational Research and Theory Perspectives

Because of the powerful programming tools offered by the developments in AI software intelligence methods, we feel that computers can now offer educators a means to more fully utilize the capabilities of the computer to enhance instruction and, thus, improve learning. To fully accomplish this goal, the AI tools need to be employed within the conditions of the educational environment. Proposed for the next generation of ICAI, is a system that elaborates and extends the three basic modules of the conventional ICAI system (see Figure 1). The proposed additions are taken directly from a rich base of cognitive psychological and educational theory and research on learning and instruction. The educational perspective offers ICAI, in contrast to the contemporary computer science

Conventional ICAI Components



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Educational Elaborations

- Developmental Knowledge
- Different Perspectives
- Creative Search Strategies

- Informal Heuristics
- Meta-Learning Theory
- Meta-Instructional Strategies

- Individual Differences
- Necessary Knowledge
  - Prerequisite
  - Associative
  - Background

Elaborations to ICAI from an Educational Perspective.

perspective with its limited and narrow understanding of learning and instruction, an integration of AI tools and methods with instructional variables and conditions empirically tested and shown to improve learning. The basic educational elaborations and extensions can be summarized as follows (see Figure 1):

-To extend the knowledge base to include, in addition to the expert's knowledge, developmental knowledge used by the learner to acquire expert knowledge (i.e., Dreyfus & Dreyfus, 1986).

-Develop knowledge bases in ways that represent different perspectives on problem solving and problem formation.

-Employ inference engines within tutor models that use informal and fuzzy logic methods in addition to the structured formality offered by the current methods of IF THEN rule statements. This would allow for much broader applications of ICAI in less structured domains of information (e.g., the humanities).

-Extend the forms of knowledge representation to include, in addition to the usual tree structures, heuristic systems that create search strategies.

-Design tutor models that more fully exhibit the characteristics of an expert teacher by increasing the potential of the instructional strategy. That is, a tutor model that prescribes, instead of a given single strategy, a meta-instructional strategy formed from a rich pool of instructional variables.

-Expand the student diagnosis to include individual differences. Rather than the simple assessment of prior knowledge to prescribe instruction, additionally evaluate students in reference to cognitive and affective variables.

-Elaborate the student model by assessing in addition to prior knowledge other forms of necessary knowledge. These other forms include: (a) prerequisite knowledge, information directly needed to understand the information to be learned; (b) associative knowledge, information within the domain being learned but not directly connected or linked to the information being learned; and (c) background knowledge, information that provides a context to fully understanding the information to be learned.

In planning a learning environment, it is convenient to consider the division of the educational variables and conditions into curricular and instructional components (Tennyson &

Christensen, 1988). The curricular component includes those elements of education not directly linked to student interaction. The instructional component on the other hand deals with those elements directly involved with student interaction in learning. Using this paradigm, we will discuss the above defined educational elaborations for ICAI within these two components. Our assumption is that in an ICAI environment, these two components would operate in an iterative fashion such that the conditions of instruction established in the curricular component would adjust according to learner progress and needs while in the instructional component. And that learner outcomes from the instructional component would feed back to the curricular component to update the decision making mechanism at that macro level (Seidel & Stolurow, 1980).

Thus, in addition to the above defined elaborations, we propose that ICAI be extended into an educationally-based learning environment that includes both curricular and instructional variables and conditions. Also, that the ICAI system provide for adaptive instruction based on cummulative knowledge and moment-to-moment learning need. Within a curricular component, the system would diagnose the student from initial assessment information and then from continuous information coming back from the instructional component. The curricular component would prescribe the necessary instruction from normative parameters, while with the instructional component, the system would adapt the prescription according to individual student needs during actual learning. In this sense, assessment and learning would be occurring simultaneously. The next two sections will describe my proposed extension of the current ICAI model to more fully meet the educational situation as contrasted to the tool design paradigm offered by conventional ICAI.

Curricular component. The primary purpose of the curricular component would be to establish the initial conditions of instruction by considering the interaction of individual difference variables with the specifications of the content domain of a given curriculum. Conventional ICAI has no methodology which can deal with the considerable effect which individual differences have on learning achievement. The curricular component would encompass both the cognitive and affective measures of individual differences.

Cognitive measures would include such constructs as intelligence, aptitude, ability, and cognitive style. For example, a learner may have a high intelligence level but little aptitude or ability for a given curriculum. Thus, to maximize learning, instruction should be adjusted to take the learner's strengths and weaknesses in these areas into account.

Affective measures would deal with constructs such as (a) personality (e.g., introverted and extroverted learners need different optimal learning environments [Eysenck & Eysenck, 1975]; learners with a Type A personality tend to differ in drive from Type B [Friedman & Rosenman, 1974]); (b) motivation (a profile of the learner's initial motivation can be adjusted and have influence as the learner moves through the curriculum [Tennyson & Breuer, 1984]); and, (c) anxiety (instructional strategies can be employed to lessen anxiety where it interferes with learning [Tennyson & Boutwell, 1973]).

In conventional ICAI programs the student model is basically represented as a subset of an expert's knowledge base. This error model focuses on the student's prior knowledge and the ability for information recall, while ignoring the acquisition of the information. In this conventional ICAI model, learners can easily form misconceptions (even though such programs are actually trying to correct misconceptions), particularly in higher order and more complex information structures (Scandura, 1984).

The educational perspective offers to improve on this conventional student model by expanding it to include, in addition to prior knowledge assessment, achievement measures on three other types of necessary knowledge: prerequisite, associative, and background knowledge (Tennyson & Cocchiarella, 1986). Prerequisite knowledge refers to supportive knowledge that is (a) directly related to the information to be learned and (b) the student already has in memory. Associative knowledge refers to information that is in the same domain but is only indirectly connected with the to-be-learned information. Background knowledge refers to information that is generally outside the domain but provides necessary context for fully understanding the information to be learned. Prior knowledge, in contrast, refers to that specific information to be learned that the student already has in memory.

The addition of these other three knowledge achievement measures would influence the conditions of instruction in terms of remediation and the amount of instruction for the to-be-learned information. They would also establish a richer learner diagnostic profile for instructional prescriptions than one based solely on a single variable of prior knowledge as in the case of conventional ICAI.

Each of the above mentioned individual difference variables has differing effects on learning and needs constant adjustment based on the structure of the to-be-learned information. While each of these constructs has implications at the instructional level, because of their trait nature, putting them at the curricular level can definitely expand the capabilities of the conventional knowledge base (expert module) to better deal with the structural conditions of the information to be learned. In other words, curriculum issues can be dealt with in such a way that if learners found that they are either lacking or unsure of specific knowledge, that the system would be able to diagnose the specific knowledge lack and to appropriately adjust the curriculum.

Instructional component. The tutor module in conventional ICAI is basically limited to one instructional strategy; for example, the Socratic and coaching methods. With only one instructional strategy, the system can run into a number of limitations such as: assuming too much or too little student knowledge, producing instructional material at the wrong level of detail, and not being able to work with the student's own conceptualizations of the information which they are learning.

An educationally-based ICAI system would expand the tutor module by not limiting itself to only one instructional strategy. By assessing individual difference variables and curricular issues during instruction, the system can have the flexibility to prescribe appropriate integrated-instructional strategies (Tennyson, 1988).

This flexibility would be allowed by the use of informal heuristic methods in the inference engine of the tutor model. The use of these heuristic methods is built around a direct connection to cognitive science theories of learning (Ploya, 1945). A heuristic can be defined as a "rule of thumb" search strategy that is composed of variables that can be manipulated to provide increasingly better decisions as more knowledge is acquired. This ability allows the heuristics to adjust to new data and experiences and to add new variables and even heuristics without necessarily influencing the operations of the system.

Frequently, program designers refer to informal heuristics as "fuzzy " logic statements because, unlike the production rule statements needed in conventional ICAI programs (i.e., IF THEN statements), informal heuristics can be written as abstract flexible statements which acquire assumptions with experience. Therefore, an informal heuristic can start to understand a situation and "think" about possible outcomes that do not exhibit correct or incorrect solutions. Also, informal heuristic methods differ dramatically from the algorithm or tree-structure methodology of AI programming in that they are usually written as conditional probability statement codes. In educational terms, an informal heuristic may be thought of as a higher order rule statement rather than a depository of domain-specific information

(Dorner, 1933).

We propose the employment of the informal heuristic approach because the flexibility offered by such programming techniques allows the integration of various theory-based learning variables to a given programmatic method (e.g., few learning variables fit a tree-structure format). These heuristics would be used in the sense of leading to discovery by considering many different learning variables, abstraction levels (shifts from one level to another), and unique combination which establish the conditions for learning and the conditions of instruction.

Selection of the integrated-instructional strategies would be based upon four different sources of information (Tennyson & Rasch, 1988). First, the direct connection to a learning theory which explains learning, memory, and cognition. Typically, from an educational perspective, this would be in the form a meta-learning theory developed because of the educational need to explain both learning and cognition. Second, an understanding of the learning outcomes related to the objectives of the curriculum and instruction. Although, there are many taxonomies by which to specify learning objectives, we employ the well-developed approach offered by Gagne's (1985) conditions of learning (verbal information, intellectual skills, and cognitive strategies). Third, the structure of the information to be learned needs to be analyzed for both learning effectiveness and storage in the data base. Conventional expert system tools and shells provide assistance in the latter development of the knowledge base. However, the presentation structure needs additional manipulation to improve learning. Much of the recent research findings in human knowledge representation (as constrasted to machine representation as in AI/expert systems programs) clearly indicates that the overt structure of the information directly affects learner acquisition. That is, presenting the information in reference to its schematic structure significantly improves acquisition because the learner is storing both semantic knowledge and schematic knowledge simultaneously. Conventional ICAI knowledge base structures are only focusing on semantic understanding. And, fourth, the instructional variables which can be prescribed into specific and adaptable integrated-instructional strategies. Most of these instructional variables are derived directly from educational research findings. For example, some of these variables that can be prescribed based on individual student need and progess are sequence, amount of information, instructional control, time on task, use of text and visuals, cooperative learning, simulations, and others that an expert teacher may employ to facilitate learning.

Summary

In summary, the next generation of ICAI will differ from conventional ICAI on several important variables. First, with foundations in learning and instructional theory, ICAI wll use a comprehensive meta-learning model which would take individual differences into account in the assessment and diagnosis processes, and make reference to both the learner's acquisition (i.e. storage) and the retrieval of knowledge. Conventional ICAI programs follow, for the most part (if any), learning models based on the assumptions of a discovery form of learning. Second, ICAI will make no assumption for a given strategy of instruction; rather, the strategies of instruction will be selected from a rich base of instructional variables according to learning objectives and the structure of information to be learned. Third, ICAI will employ the concepts of artificial intelligence in the form of informal heuristics (as well as formal heuristics) that have the capacity to learn and, therefore, to adjust according to given situations.

The proposed educationally-based ICAI systems can be characterized as decision-making systems that are iterative in nature such that with experience, they can continuously improve the learning of each learner. This would be done by an adaptive management system which concurrently diagnoses learning while prescribing instruction. By monitoring learner progress during the actual acquisition of information, the educationally-based system will improve learning in terms of both the effectiveness of amount and quality of knowledge acquired and the efficiency in time required to learn.

At both the curricular and the instructional levels, the variables defined in this paper would interact in an almost infinite number of instructional conditions and events. Of special note will be the ability of the entire system to adjust decision making parameters both with group experience and by individual learner experiences. That is, as experience is gained from both sources, the heuristics which are formed with currently available information and data, would adjust accordingly. Because the heuristics would be independent of both hardware and software conditions, they would be easily transferred and generalized to other systems as well as accomodating new development in both hardware and software.

A number of major advantages can be implied by the use of the proposed educational elaborations and extensions of the current generation ICAI systems. For example, the next generation ICAI systems would be designed to improve learning by integrating learning theory with instructional design. Also, the systems would employ a holistic approach of pre-information and continuing information processing about the learner, rather than diagnosing and remediating specific problems as seen in conventional AI programs. Furthermore, the systems would be active rather than passive in nature, and would be able to recognize the totality of the individual and the complexities involved in creating favorable learning environments to improve learning.

In conclusion, we are proposing that the next generation of ICAI be based on educational and psychological theory and research findings. That it employ where appropriate the tools and shells of AI and expert systems methods, but that such tools do not dictate or control the design and implementation of the learning environment. Much like educators have for decades used the research tools from the field of statistics for help in experimentation, we can use the tools offered by computer science in the design of learning enviornments. In both situations, however the educator most control the tools as a means to the end, not as the end in themselves as in the current prototype applications of ICAI.

References

Brown, J. S., & Burton, R. R. (1978). A paradiagrammatic example of an artificially intelligent instructional system. International Journal of Man-Machine Studies, 1?, 323.

Dorner, D. (1983). Heuristics and cognition in complex systems. In R. Groner, M. Groner, & W. F. Bishof (Eds.), Methods of heuristics. Hillsdale, NJ: Erlbaum.

Dreyfus, H. L., & Dreyfus, S. E. (1986). Mind over machine. New York: Freeman Press.

Eysenck, H. J., & Eysenck, B. G. (1975). Eysenck personality questionnaire. San Diego, CA: Educational and Industrial Testing Service.

Fletcher, J. D. (1984). Intelligent instructional systems in training. In S. A. Andriole (Ed.), Applications in artificial intelligence. Princeton, NJ: Petrocelli.

Friedman, M., & Rosenman, R. H. (1974). Type A behavior and your heart. New York: Knopf.

Gagne, R. M. (1985). Conditions of learning. 4th Ed. New York: Holt, Rinehart, & Winston.

Goldstein, I. P. (1982). The genetic graph: A representation for the evolution of procedural knowledge. In D. Sleeman and J. S. Brown (Eds.), Intelligent tutoring systems. New York: Academic Press.

Ploya G. (1945). How to solve it. Princeton, NJ: Princeton University Press.

Scandura, J. M. (1984). Cognitive instructional psychology: System requirements and research methodology. Journal of Computer-based Instruction. 11, 14-21.

Seidel, R. J., & Stolurow, L. (1980). An heuristic meta-model for computer-managed instruction. Journal of Research and and Development in Education, 14(1), 16-32.

Tennyson, R. D. (1988). An instructional strategy planning model to improve learning and cognition. Computers in Human Behavior, 4, 3545.

Tennyson, R. D., & Boutwell, R. C. (1973). Pretask versus within-task anxiety measures in predicting performance on a concept acquisition task. Journal of Educational Psychology, 65, 88-92.

Tennyson, R. D., & Breuer, K. (1984). Cognitive-based design guidelines for using video and computer technology in higher education. In O. Zuber-Skeritt (Ed), Video in higher education. London, England: Kogan Page Ltd.

Tennyson, R. D., & Christensen, D. C. (1988). MAIS: An intelligent learning system. In D. H. Jonassen (Ed.), Instructional designs for microcomputer courseware (pp. 247-274). Hillsdale, NJ: Erlbaum.

Tennyson, R. D., & Cocchiarella, M. J. (1986). An empirically based instructional design theory for teaching concepts. Review of Educational Research, 56, 40-71.

Tennyson, R. D., & Park, O. (1987). Artificial intellegence and computerbased learning. In R. Gagne (Ed.), Instructional technology: Foundations (pp. 319342). Hillsdale, NJ: Erlbaum.

Tennyson, R. D., & Rasch, M. (1988). Linking cognitive learning theory to instructional prescriptions. Instructional Science, 17, 369385.