

COMPUTER ASSISTED INSTRUCTION: OPTIMIZING THE LEARNING PROCESS  
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I was asked by the organizers of this symposium to describe the research done on computer assisted instruction (CAI) at Stanford University in the early 1960s. The work was done under the auspices of the Institute for Mathematical Studies in the Social Sciences and was a collaborative effort between Patrick Suppes and myself. However, Bill Estes played an important role in shaping and guiding the research program. This symposium is in honor of Bill Estes and his contributions to the psychological and cognitive sciences; the work I will describe is part of that legacy. My talk will be informal but is based on some two dozen papers that are available on my website [www.rca.ucsd.edu](http://www.rca.ucsd.edu) under “Selected Scientific Papers”. Those who are interested in technical details should visit the website.

Let me begin by describing the relationships among Pat Suppes, Bill Estes and myself. I was an undergraduate at the University of Chicago in the late 1940s and worked as a part-time student assistant for physicist Nicolas Rashevsky who became famous in later years for mathematical models of biological phenomena. One day he suggested that I attend a lecture by Bill Estes, a psychologist who was developing stochastic models to describe learning, both humans and animal learning. I attended the lecture, talked with Bill afterwards and was blown away by what he was doing. So in the fall of 1950, I found myself as a graduate student in the psychology department at Indiana University working with Bill Estes.

The military draft was still in effect at the time and my draft board was very tough. They gave me a strict limit of four years to complete the Ph.D. degree. I finished my degree in 1954 and went off to military service in the U.S. Army. To my surprise, I ended up in Monterey, California spending most of my time at the Naval Postgraduate School (NPS) working in the computer science laboratory. It was a remarkable opportunity. In those days there were only a handful of computers in American universities and they were not for general use.

In the fall of 1955 Bill Estes was on sabbatical leave from Indiana University, spending the year as a fellow at the Center for Advanced Studies in the Behavioral Sciences in Palo Alto. One Saturday, I drove from Monterey to Palo Alto to meet with Bill at the Center. It was a tranquil sunny morning, and, as was Bill's custom, our conversation was hushed and moved along at a very slow pace. Graduate students in those days often called him "long latency Bill" because he would take an interminable amount of time before answering a question. Suddenly, there was a pounding on his study door and I rushed a young man. With hardly a word of introduction he was at the blackboard, chalk chips flying in all directions, as he expounded on a mathematical problem. Estes leapt to his feet and the two began writing equations on the blackboard, jabbering back and forth and bouncing up and down. I had never witnessed anything quite like it. Who was this person who had such an energizing effect on Bill? It was Patrick Suppes, also a fellow at the Center, who was a full professor of philosophy at Stanford University at the age of 32. His areas of expertise were mathematical logic and the philosophy of science, particularly the role of formal models in scientific theory. During the course of their year at the Center, Bill taught Pat Suppes about psychology, mainly from the viewpoint of Bill's theory of stimulus sampling. They became close friends and devoted colleagues.

Pat was a very influential member of the Stanford faculty and arranged for me to go to Stanford in the fall of 1956 and for Bill Estes to join the faculty a few years later. I should add that Pat also played a key role in recruiting Gordon Bower, Roger Shepard and Ewart Thomas to Stanford.

In 1962, Suppes and I received a grant from the Carnegie Foundation of New York to support the use of a computer to conduct psychological experiments. Of special interest was the idea of teaching reading and mathematics to young children under computer controls with the capability of individualizing the instruction. We purchased a PDP-1 computer manufactured by Digital Equipment Corporation; it was one of the first transistorized computers. We quickly had six terminals running on a time-sharing system and were busing kindergarten and first grade students to our laboratory at Stanford. Encouraged by our initial success, we applied and received a one million dollar grant from the U.S. Office of Education; this was before the U.S. Department of Education existed. In those days million dollar grants were rare; even the physics community took note.

The plan was to develop a CAI system to teach reading and mathematics to culturally disadvantaged children (K-3). Our group at Stanford, in collaboration with IBM, undertook the design and implementation of what became known as the IBM 1500 Instructional System. The 1500 system was set up at a school in East Palo Alto and went into operation in the fall of 1967. The system was housed in two trailers on the school parking lot. One trailer housed the computer system; in the other trailer were 16 student terminals. Each student terminal had a cathode-ray tube (CRT), a typewriter keyboard, a light pen to touch a point on the face of the CRT, a projector with a capacity of 1,000 color images, a set of earphones with a microphone, and pre-recorded audio messages that could be “randomly” accessed (this was before digital audio was commercially available). Pat Suppes had responsibility for developing the mathematics curriculum, and I had responsibility for reading.

By the end of two years, some 400 students had received a major part of their daily instruction in reading and mathematics under computer control. As the first installation of its kind, it received considerable national attention; over 3,000 visitors a year had observed students at work on the system. More importantly, significant gains in student achievement had been demonstrated. A description of our work with the 1500 system is available in an article published in the *American Psychologist* entitled “Computerized Instruction and the Learning Process”<sup>1</sup>.

The 1500 system permitted us to individualize the learning process but not to the extent we desired. The computer that drove the system was the IBM 650, the first computer to be widely adopted by American universities; today’s iPhone has ten thousand times the computing power of the IBM 650. Further, the cost of the system was prohibitive and locating the computer at the school site had major disadvantages. Fortunately, while working with the 1500 system, we continued to expand the PDP-1 system housed at Stanford. The student terminals were simpler: a low cost display device, a typewriter keyboard and a headset supported by digital audio that was truly random access. We soon had about 40 terminals in several Stanford buildings connected to the computer by phone lines. It was not a big step to connect to schools at remote sites. We restructured the reading and math programs for the Stanford system and by 1967 had about 3,000 students receiving daily instruction in seven nearby elementary schools and in locations as distant as McComb Mississippi, Morehead Kentucky and

Washington, DC. The system and its effectiveness are summarized in an article in the *American Psychologist* entitled “Teaching Children to Read Using a Computer”<sup>2</sup>.

As the Stanford system was upgraded and enhanced, it was possible to experiment with a wider range of courses. For example, Pat Suppes developed a program in logic that he used to supplement his regular Stanford lecture course in introductory logic. My group developed a course in computer programming using the computer language BASIC. It was widely used by Stanford graduate and undergraduates and at two local community colleges<sup>3</sup>. These courses were adaptive in two ways: (1) the sequence of instruction varied as a function of a student’s performance history and (2) the CAI program could self-modify as more students completed the course and their data were used to update estimates of parameters that specified problem difficulty<sup>4</sup>.

Bill Estes, although not directly involved in developing CAI programs, served as a test subject for many of our programs and was particularly helpful in providing advice on optimizing student performance. At the time, Bill was learning Russian and used a Russian CAI vocabulary program that we had developed to supplement classroom instruction. He became somewhat proficient and at the 1966 International Congress of Psychology in Moscow gave his speech in Russian. He discussed research on animal conditioning and his experience using CAI to learn a second language. There was only one complication. The person who helped him prepare his remarks translated the word “conditioning” into the Russian word for “air conditioning”. It puzzled the audience for a moment, but they quickly understood the error. His speech was a great success and much appreciated by his Russian hosts.

A principal goal of our CAI research was to experiment with different approaches to optimizing student performance. For some topics, we were able to formulate mathematical models of the learning process and then use methods of control theory to make moment-by-moment decisions about what should be learned next to optimize the student’s performance. Several parts of the K-3 reading program and of the foreign language vocabulary programs provided elegant examples of this approach. In other cases, the optimal schemes were not optimal in a well-defined sense, but were based on our intuitions about learning and relevant laboratory

experiments. Elsewhere, I have used the term “theory of instruction” to describe the issues involved in using a theory of learning, formal or not, to develop an optimal program of instruction<sup>5</sup>.

In 1968 Bill Estes left Stanford to join the newly established psychology group at Rockefeller University in New York. He invited me to be a visiting scholar at Rockefeller for the academic year 1975-76 and I readily agreed. Part of my plan for the year was to write a book reviewing the work that I had done on CAI. The title of the book was to be “Theory of Instruction”. But at the last minute the world changed for me. I was recruited to the National Science Foundation expecting to spend my sabbatical year in Washington, DC. I should note that I never made it back to Stanford. My career as an active researcher ended at that point<sup>6</sup>.

Let me conclude with a few remarks about CAI since I left the field more than three decades ago. Over these years, research on CAI continues at a number of universities and there are some beautiful examples using psychological theory to individualize learning. A variety of commercial entities, both large and small, have promoted the use of CAI in schools, universities, and for training personnel in the military and corporate sectors. The deployment of CAI has not been as rapid as I predicted in a 1969 article in the *Proceedings of the National Academy of Sciences*, but it has been substantial.<sup>7</sup> The most persistent and long-term contributor to the field is Pat Suppes. His efforts have been truly remarkable, both in the development of new programs and in detailed experimental evaluations of student performance. The *Stanford University Online High School* is an example of what he has accomplished. It is an online, fully accredited, diploma granting program for grades 7-12 that serves students from around the world. It has been in operation for over a decade with excellent results.

The world of CAI underwent a total transformation in 1994 with the advent of the internet. The internet offers a platform for instruction with a rich, multi-sensory student surround and a virtually unlimited computing capacity. It is not just the internet, but also wireless communication—not being tied to the internet by a cable makes a big difference. Others at this symposium will discuss MOOCs and related efforts. That work is promising, but the key to success is individualizing instruction, and necessarily that requires a psychological theory of the learning process.

I retired from the University of California in 2003 and, shortly after my retirement was announced, Bill Estes wrote me a letter. The essence of the letter was: “Dick, it’s time to get back to serious work. Your book on a theory of instruction is long overdue.” His commitment to psychological research was unwavering throughout his life.

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<sup>1</sup> Atkinson, R.C. Computerized Instruction and the Learning Process. *American Psychologist*, 1968, 23, 225-239.

<sup>2</sup> Atkinson, R.C. Teaching Children to Read Using a Computer. *American Psychologist*, 1974, 29, 169-178. See also Fletcher, J.D. and Atkinson, R.C. Evaluation of the Stanford CAI program in Initial Reading. *Journal of Educational Psychology*, 1972, 63, 597-602.

<sup>3</sup> Barr, A., Beard, M. and Atkinson, R.C. A Rationale and Description of a CAI Program to Teach the BASIC Programming Language. *Instructional Science*, 1975, 4, 1-31.

<sup>4</sup> Atkinson, R.C. Adaptive Instructional Systems: Some Attempts to Optimize the Learning Process. In D. Klahr (Ed.), *Cognition and Instruction*. New Jersey: Erlbaum Associates, 1976.

<sup>5</sup> Atkinson, R.C. Ingredients for a Theory of Instruction. *American Psychologist*, 1972, 27, 921-931. See also Groen, G.J. and Atkinson, R.C. Models for Optimizing the Learning Process. *Psychological Bulletin*, 1966, 66, 309-320; Atkinson, R.C. Optimizing the Learning of a Second-Language Vocabulary. *Journal of Experimental Psychology*, 1972, 96, 124-129; Atkinson, R.C. and Paulson, J.A. An Approach to the Psychology of Instruction. *Psychological Bulletin* 1972, 78, 49-61; and Chant, V.G. and Atkinson, R.C. Application of Learning Models and Optimization Theory to Problems of Instruction. In W.K. Estes (Ed.), *Handbook of Learning and Cognitive Processes* (Vol. 5). Hillsdale, New Jersey: Erlbaum Associates, 1978.

<sup>6</sup> Atkinson, R.C. The Golden Fleece, Science Education, and U.S. Science Policy. *Proceedings of the American Philosophical Society*, 1999, 143 (No. 3), 407-417. See also Pelfrey, P. *Entrepreneurial President: Richard Atkinson and the University of California*. Berkeley and Los Angeles, California: University of California Press, 2012.

<sup>7</sup> Atkinson, R.C. Computer-Assisted Learning in Action. *Proceedings of the National Academy of Sciences*, 1969, 63, 588-594.