AUTOMATED AND AMPLIFIED: ACTIVE LEARNING WITH COMPUTERS AND RADIO (1965-1979)

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Two combined design cases examine historically significant projects in technology-assisted instruction developed at Stanford in the 1960's and 1970's: Computer Assisted Instruction (CAI) for elementary school students, and the Nicaraguan Radio Mathematics Project (NRMP). The combination of the cases allows for the exploration of the commonalities in instructional design, use of technology, and methodology of each project, and reveals the practical and theoretical forces which positioned the highly experimental CAI as the genesis of NRMP, which became the model for Interactive Radio Instruction (IRI) which itself fulfilled the initial projects' vision of active learning at scale. Today, as we pursue these same goals of student engagement and global access, these two integrated cases offer the successes and failures of the early experiments as considerations for our present designs while establishing a clearer intellectual heritage of technology-enhanced instruction.

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INTRODUCTION

In 2012, Massive Open Online Courses (MOOCs) captured the attention and imagination of the public as a new educational technology that could promote learning on a massive scale. Yet the design for engaged learning using technology, including computer-mediated, individualized instruction and even the flipped classroom, can be found in two Stanford projects implemented in the early 1960's and 1970s. The first, Computer Assisted Instruction (CAI) in elementary mathematical logic began with a pilot in Palo Alto in 1965; its achievements and limitations led to the creation and implementation of the Nicaragua Radio Mathematics Project (NRMP), 1975 - 1979, which has become the model for Interactive Radio Instruction (IRI), a scalable methodology for active learning and the standardization of instruction. To date, over 20 million students worldwide have participated in IRI's active learning methodologies in a diverse set of subjects (Ho & Thukral, 2009). Like MOOCs, the goals of both CAI and NRMP were to improve educational quality, provide effective, low-cost access to education, and to deploy available technologies to enhance teaching and learning at scale.

HISTORICAL AND INTELLECTUAL LOCATION OF CAI AND NRMP

The US Department of Education (then the Office of Education) began funding research projects which explored the uses of computers in educational contexts in the late 1950's. By 1969, over 210 projects had been funded across the U.S. across a variety of use cases including programming, computer models, informational retrieval systems, administration, curriculum development, training, and computer-assisted and computer-managed instruction. Perhaps because the available technology was bulky, expensive, and not easily obtained, the most common use of the computer across these projects was for the organization, administration, and analysis of data.

Yet, despite limitations of access, a handful of researchers at institutions such as the University of Illinois at Urbana-Champaign, Penn State University and Stanford University

FIGURE 1. Computer-Assisted Instruction. An elementary school student interacts with the artificial tutor (Suppes, 1966).

were pioneering efforts in computer-assisted instruction, where the student actively engaged with the computer to receive lessons and immediate response based on performance. Their efforts actualized a long-held vision of using technology to construct an “artificial tutor” to scale personalized and accurate instruction on demand. Although the technology was generally inaccessible, it was capable of interacting with the user; the early experiments focused on the expansion and adaptation of these capabilities.

One experiment notable for the boldness of its design and its demonstrated effectiveness was Computer Assisted Instruction in Elementary Mathematics by Prof. Patrick Suppes at Stanford University. I worked at Stanford for Dr. Suppes from 2004-2012, and details about these projects came from conversations between us in 2014.

The project began in 1965 with elementary school students in Palo Alto (Figure 1), and was designed to see if computers could help very young students learn mathematical reasoning. The initial school sites and the students were chosen based on proximity to the campus and the willingness of their teachers to participate in the experiment. Proximity was necessary to provide adaptive instruction: the machines the students used were connected by telephone lines to a central computer on the Stanford campus.

Each day, students listened to a recorded lesson and answered drill and practice questions to assess their understanding of the material. Their performance data was delivered to the central computer where it was analyzed each night, so that the student received a lesson tailored to their level of understanding the following day.

Some students were given these lessons as pre-work to prepare them for their teacher’s instruction; other teachers used them as drill and practice for lessons already taught. In each case, the teacher determined how to best use the

technology to blend the classroom so that it served student learning objectives.

Both students and teachers enjoyed working with the technology, and while the program was successful, expanding to schools in Mississippi, Kentucky, and Iowa in addition to the California schools over the next two to three years, it was ultimately too expensive and impractical to scale. Each participating location had access to a Programmed Data Processor (the PDP-8 mini-computer) which transmitted student data via telephone line to the PDP-1 computer at Stanford for nightly analysis. Most schools did not have access to these larger computers, and the PDP-8 was capable of being connected to only 60 teletype terminals (TTY) on which the instruction was primarily delivered. The high cost and limited availability of the hardware meant the reach of computer-assisted instruction exceeded the grasp of easily available technologies by too wide a margin.

But the relative ease of implementation for schools who had access to the hardware, the improvement in learning outcomes, the standardization of high quality interactive instruction, and the enthusiastic response from both teachers and students appealed to the US government as a method of providing access to effective educational content and practices to underdeveloped regions and/or underserved students around the world. The most significant hurdle to widespread implementation was the cost and availability of the technology.

The United States Agency for International Development (USAID) contacted Suppes and his team and asked if principal design elements of CAI’s of adaptivity, interactivity, and effectiveness could be replicated using radio to help scale active learning practices globally. “We worked on computers, but then USAID asked if we could use radio, because it was cheaper,” says Suppes (personal communication, June 12, 2014). Historically, one of the cheapest and most widely available technologies used for education was radio, yet education delivered via radio was broadcast-only, with none of the interactivity of CAI.

After an initial survey of several potential sites, Nicaragua was chosen because the government provided both facilities and local staff for the project, students would be taught in their native language, and there was no pre-existing radio instruction. Most importantly, the math curriculum developed by the Nicaraguan Ministry of Education closely resembled those of other developing countries; therefore, it was an ideal test case for which to pilot a mathematics curriculum developed for radio broadcast supported by teacher-directed activities. If proven successful, USAID hoped this model could then be easily localized to other regions around the world.

FIGURE 2. Elementary school students in Managua respond to a radio lesson in mathematics. Credit: Tom Tilson

And so in 1975, ten years after fourth-grade students in Palo Alto area schools completed daily drill-and-practice arithmetic lessons in their classroom on a teletype machine connected by telephone lines to a computer on the Stanford campus, first grade students in sixteen classrooms in the [District] of Masaya, outside Managua, Nicaragua, listened to a 20-minute mathematics lesson on the radio while responding verbally, physically and by writing answers on a worksheet to questions posed during the broadcast (Figure 2).

Those worksheets were brought to a central location in Managua where they were entered into a computer by punch cards. Those cards were fed into the computer and their data stored on magnetic tape; those tapes were sent by international mail to Stanford where the data was analyzed on the computer there. This data was used to refine the lessons to be more effective. The data transfer Nicaraguan schoolroom to Stanford campus took approximately one week; curriculum changes could be made during the course of the school year. It is interesting to note that in the years of operation no data was ever lost in the mail.

Growing political instability in Nicaragua in 1978 precipitated the withdrawal of US government funding for the project, and Stanford funding followed suit. Yet while the project lay dormant in Nicaragua, the principles and methodologies of NRMP were adapted and expanded over the next 40 years

to include Interactive Radio Instruction (IRI) across a range of topics including mathematics, language, science, and reading among others. To date, over 20 million learners in primarily poorer and/or densely populated countries including Sudan, Mali, Indonesia, Haiti, and India have used IRI in the classroom, and IRI continues to be a viable approach to reaching the estimated 72 million children worldwide who are not in school (Ho & Thukral, 2009).

Online, the design model of scalable, active learning introduced in CAI and developed in IRI is now seen in a number of popular educational technologies, especially, adaptive learning programs, and MOOCs themselves. Just as importantly, these early projects helped pioneer the practice of collecting student data to measure effectiveness of instruction and allow for curricular changes during the instruction period as well as to individualize instruction based on performance. Most significantly, both CAI and NRMP identified the potential of technology to enhance teaching and learning by making them more effective and affordable. Fifty years later, we are using similar design principles of interactivity, engagement-based strategies, evidence-based design, and adaptive instruction and methods to achieve those same goals.

DESCRIBING THE DESIGNS OF CAI AND NRMP

The designs of CAI and NRMP answered two separate but related questions: is it possible for technology to provide interactive and individualized instruction, and if so, can that instruction be scaled effectively to those who need it most?

The design objective for CAI was to create an automated tutor-student relationship using the computer, an emerging and somewhat experimental technology in education in the 1960s. The computer played the role of the tutor, providing instant feedback to the student and adapting instruction based on the student's understanding. Individualized instruction in the form of the student-tutor relationships has been considered an ideal method of learning in every aspect except for efficiency; the promise of combining the instructional effectiveness of the tutor with the cost-effectiveness of automating him or her served as the ideal for this project's design (Suppes, 1966), just as it continues to serve as the purpose of many educational technologies of today.

The design of the tutor was comprised of three technologies: recorded lessons provided aural instruction, a cathode-ray screen displayed questions or problems, and a keyboard or stylus (light pen) enabled the student to respond to the machine by entering answers or solutions. Students were engaged aurally as they listened to lessons, visually as they read questions or problems, and physically as they typed on a keyboard or tapped the screen. In turn, the machine

FIGURE 3. Components of the artificial tutor (Suppes, 1966).

provided visual feedback to the students' physical responses to create an interactive learning experience (Figure 3).

The first technology used was audio instruction: students listened to recorded lessons delivered through headphones while seated at the terminal. These lessons were created to develop understanding of mathematical logic and reasoning and to fulfill explicit learning objectives created by teachers. Because the rich lessons could then be repeated as often as needed, their effect could be amplified to many students across classrooms and school locations.

Audio messages were felt to be preferable to solely visual ones because evidence showed that student understanding at elementary levels clearly increased when instruction was verbal and not written. Young children respond better to the spoken word than the written one, and when math instruction is presented verbally, comprehension of mathematical concepts is not dependent upon literacy or reading skills. Aural delivery in CAI was proven to be especially useful for underserved learners whose reading skills were not commensurate with their mathematical reasoning ability. And even adept readers at a young age are able to understand spoken directions at a far greater degree of complexity than written ones. (Suppes, 1966). The effectiveness of audio instruction was expanded and examined more closely in the design and delivery of mathematics lesson via radio as realized in the Nicaraguan Radio Mathematics project.

The second technology used in the design was the cathode-ray tube employed to display questions and problem sets. At the time, this technology was very new and was seen as desirable because of its resemblance to the popular television screen. Younger students who could not yet read (or whose skills were emergent) could point to correct answers and see spatial relationships among figures as they listened to an explanation.

The third technology was either a light pen used to tap the cathode-ray tube, or a modified keyboard: both allowed the students to communicate with the machine. The keyboard was the easiest and cheapest way for the student to transmit her response to the computer; one-keystroke responses were designed to lower the barrier for those unfamiliar with typing or the keyboard itself.

When students put on headphones and communicated with the machine, they created a closed circuit of learning between themselves and the technology. This closed loop allowed space for deliberate practice and for individualized instruction, but it separated the students physically from the learning community inside the classroom. The isolation had beneficial effects; it enabled students to focus exclusively on their own learning. Although this design of CAI with recorded lessons, cathode-ray tube and keyboard or stylus was the most expensive implementation of the artificial tutor, it was also the most desirable for the most practical of reasons – it was quiet and did not disturb other students in the classroom. (A more widely available implementation, the teletype machine, was noisy and could be a distraction.)

CAI was first envisioned in three possible forms, dependent upon available technology. The least expensive and most widely available implementation employed teletype machines. Students read arithmetic problems, typed their answers, and received instant feedback from the machine. This model was used primarily for drill and practice sessions to test and reinforce understanding. The second implementation more fully realized human student-tutor interaction through recorded lessons, visual prompts and problems on a cathode-ray tube or teletype, and visual feedback to the student's physical response of typing or tapping an answer. While this approach required more sophisticated hardware, it was more suitable for younger children and others whose reading skills were not yet fully developed. The third model of interaction was designed to encourage verbal dialogue between the student and the machine: the student would listen to recorded lesson and respond verbally to questions, and the computer would interpret the response as correct or incorrect. This vision was too advanced for the technological capabilities of 1965. But its potential would be realized and ultimately expanded in the Nicaragua Radio Mathematics Project ten years later.

NRMP amplified the possibilities of the interactive audio instruction piloted in CAI. The objective of this design was to "use the voice transmitted by modern methods of radio rather than the classroom teacher," says Suppes (personal communication, 2014). The design goal for this project was to enhance teaching and learning by standardizing instructional delivery and expanding its reach at low cost, and its purpose was to improve education globally by providing access to effective educational materials to remote and/or

underserved students and to correct for divergent levels of teacher preparation.

Due to the goals of cost efficiency and scale, the bulk of the design work for the NRMP was not performed with technology but with curriculum. Because the curriculum itself had been recently redesigned and the teachers retrained, the redesign work focused on delivery rather than content. The design team from Stanford felt that teachers would be less resistant to changes in how lessons were delivered rather than in what the lessons covered. Therefore, the key objectives of the design of these radio lessons were to implement the strategies of effective teachers: encouraging active response from children, distributing practice, reinforcing knowledge of results, and providing different pathways for children who learn at different rates.

Working with the official mathematics curriculum developed by the Nicaraguan Ministry of Education, curriculum designers worked with local expert and script writers to create 20 minute interactive lessons (Figure 4) where students engaged with the radio 40-50 times by responding verbally, making a physical motion, or writing on their worksheet.

FIGURE 4. An artist in Nicaragua creates a worksheet for students to use during radio lessons. Credit: Tom Tilson

First, the curriculum designers broke the existing curriculum into smaller units on specific topics which could be reassembled into a lesson to provide distributed practice in several areas over a series of lessons. Then the scriptwriter created a draft of a radio script from these specifications which encouraged students to respond. This draft was then read to staff involved in classroom observation and teacher training to gain feedback on clarity, level of difficulty in language, and overall student interest in the characters and stories in the lesson. Third, an artist created a worksheet on which students could record their responses. The data from these worksheets was then analyzed by computer. When the data indicated a lesson was not effective, it was rewritten and rerecorded and then rebroadcast to the students weeks later. Testing and analysis showed significant improvement after lesson revision and continued practice on the topic by students.

Each radio lesson script was written to implement the following effective teaching strategies: to give students multiple opportunities to actively engage with the lesson, to provide knowledge of correct results to increase the rate of learning, to encourage practice with concrete materials to make abstract concepts real, to distribute practice over multiple sessions, and to tailor instruction to individual learning rates when possible.

This last strategy proved difficult to implement using synchronous broadcast as the delivery method for instruction. “We recognized in designing NRMP that we could not individualize the radio responses to the individual responses of the students. The point of the project was to send a very high level of exposition, and the advantage was in the curriculum,” says Suppes (personal communication, 2014). The other active learning strategies were realized through having the students respond to questions and prompts in the broadcast at a rate of 2-3 times a minute. A key finding of initial pilot projects was that students remained engaged with the lesson as long as they were asked to respond frequently; students were even more engaged than if the mathematical questions were embedded in an entertaining story.

These 20 minute lessons, followed by 20 minutes of instructor-led activities provided all of the mathematical instruction for first grade students. Each day, the lesson was broadcast to classrooms on the radio, during which students interacted with the radio; afterwards, the teacher directed additional activities designed to reinforce and deepen the students’ understanding of the material. These activities were provided to teachers in a written guidebook, developed alongside the curriculum. This shift in instructor role from content delivery to learning facilitator is enjoying a resurgence through use of filmed content in “flipped classrooms” across a range of schools and institutions in the U.S. Nearly 40 years ago, NRMP pioneered the design of blending the classroom with

interactive technology so that the instructor could devote more time to instruction and less to content delivery.

EXPERIENCING THE DESIGNS

Computer Aided Instruction

By 1968, CAI had spread to schools in four states, selected for their willingness to experiment and their access to a master computer such as the PDP-8. Most students participated in drill-and-practice with the teletype machine. Schools in California had direct phone lines connecting the terminals or teletype machines to a PDP-1 (Figure 5) on the Stanford campus or an IBM 1500 system located nearby. In Kentucky and Mississippi, terminals and teletypes at the school were

connected to a PDP-8 which was itself connected to the PDP-1 at Stanford.

The location of the instructional terminals varied by school. Schools that had multiple machines available for instruction, a separate room to house them, and teaching staff available to help with any technological difficulties, grouped the machines in one room. Other schools distributed the machines one to a classroom, and the teacher provided support if necessary. Teachers in the project had the opportunity to participate in a workshop where they created learning objectives which incorporated practice with the computer, and also received training in trouble-shooting technical difficulties, such as the ribbon breaking in a teletype machine.

Students were assigned to work with the machine once a day for 5-10 minutes. This work consisted of practice exercises, and/or a recorded lesson and practice exercises

chosen to fulfill learning objectives developed by the teacher. The content delivered to the student reflected what the teacher had previously introduced in the classroom and what the students had already practiced there: CAI lessons and drill-and-practice work primarily served to support and enhance the teacher's instruction.

Students took turns and sat at the machine one by one. They first typed in their name, which was often the most typing they had to do at any one time. The teletype whirled, the keys clacked, and the first question of a lesson chosen on the basis of the students' performance the previous day was presented for the student to answer. Students had 10-15 seconds to answer these questions such as "L.C.M is Least Common Multiple. ____ is the L.C.M of 4 and 9." If the student did not answer in time, the machine responded with the message TIME IS UP. If the student answered

FIGURE 5. A PDP-1 powered CAI elementary math instruction. Terminals at the school locations were connected by phone lines to a local PDP-8 which was connected via phone line to the PDP-1 at Stanford. Credit: Marcin Wichary (<http://www.flickr.com/photos/8399025@N07/2635003339>)

PLEASE TYPE YOUR NAME

ROBERT VALENTINE

DRILL NUMBER 604032

L.C.M. MEANS LEAST COMMON MULTIPLE

___ IS THE L.C.M. OF 4 AND 9

TIME IS UP

36 IS THE L.C.M. OF 4 AND 9

23 IS THE L.C.M. OF 12 AND 8

WRONG

24 IS THE L.C.M. OF 12 AND 8

1 IS THE L.C.M. OF 15 AND 10

WRONG

___ IS THE L.C.M. OF 15 AND 10

TIME IS UP, ANSWER IS 30

30 IS THE L.C.M. OF 15 AND 10

60 IS THE L.C.M. OF 12 AND 30

12 IS THE L.C.M. OF 2, 4, AND 6.

FIGURE 6. A record of a student-computer interaction on a teletype machine.

40 IS THE L.C.M. OF 8, 10, AND 5

S. FOR SUMMARY S.

	NUMBER	PERCENT
CORRECT	14	70
WRONG	5	25
TIMEOUT	1	5

70% CORRECT IN BLOCK, 70% OVERALL TO DATE

GOOD BYE, O FEARLESS DRILL TESTER.

TEAR OFF ON DOTTED LINE

.....

FIGURE 7. Student feedback complete with summative score and personalized response given by the teletype machine.

incorrectly, the machine typed WRONG. If the student answered incorrectly or failed to answer two times in a row, the answer was shown, and the student was given a chance to enter this correct answer to reinforce the experience of entering the correct answer. Figure 6 shows how CAI these were communicated these to the learners via teletype. After the third attempt, the next question was shown, whether or not the student submitted the correct answer. Because a certain number of exercises were expected to be completed within a certain time, students were limited to three attempts per question.

At the end of the lesson, the student received a paper printout of the session, including a summative grade and a cheery message (GOOD BYE O FEARLESS DRILL TESTER). Figure 7 shows feedback to learners at the end of their session. The immediate feedback on performance and supportive, personalized message motivated students, made their progress visible, and personalized the interaction with the machine through acknowledgement of work completed and examined. The student then rejoined class or, if the machines were in a separate room, returned to the classroom.

The idea of individualized instruction was further reinforced by the student leaving the class or the classroom to interact with a machine. Students who listened to an audio lesson and responded to recorded prompts on either the teletype or by touching a light pen on a cathode-ray screen could have this isolating effect intensified. Wearing headphones separated them from the class aurally, and what they saw visually and responded to was individualized and not part of the classroom as a whole.

Nicaragua Mathematics Radio Project

Students in the NMRP, on the other hand, received their instruction collectively since a primary goal of this program was low cost quality instruction at scale. This proved potentially problematic to classrooms with a broad range of achievement. Collective instruction was individualized to some extent by distributing worksheets tailored to different levels of ability so that students followed the same instructions but were able to practice with materials suited to their individual level. Post-lesson materials to reinforce themes at differing levels were also considered, although ultimately worksheets

were determined to be too expensive to provide to every student, and blackboards were used instead.

The day's lesson was broadcast to all participating classrooms, and students participated as a group. In each classroom, the teacher turned on the radio, music began, and a nationally-known singer introduced the program with a song. (This song became a hit, and some objected that it made the study of math too popular.) Immediately, students were asked questions and expected to respond. The questions were posed in multiple forms to increase learning; for instance, an abstract question, "What is 5 plus 10?" was followed by the same question in concrete terms, "Juan earned five centavos yesterday, and ten centavos today. How much did he earn altogether?" Students were also asked to respond physically—tapping their knees a certain number of times, or holding up a number of fingers. Because many of the interactions were verbal or physical, students could learn from each other's responses; at other times during the first year (1975), they answered questions posed on the broadcast on worksheets, until these were deemed to be too expensive to supply daily. In subsequent years, they wrote on their answers on the board (Figure 8) and used paper only once a week to take a test. The results of these tests were put on punch cards and transferred to magnetic tape in Nicaragua; the tape itself was sent to Stanford where the data was analyzed on the PDP-1.

The longevity of this curriculum design is notable; a 2009 report on IRI states "Most of the principles of interactive instruction identified by the original Nicaragua project have proved durable, appropriate and relevant." Over 20 million students in over 37 countries have participated in IRI, and the principal elements of frequent opportunities for student response to recorded material are present in educational computer games, instructional videos with

FIGURE 8. NRMP: An instructor fills in answers called out by students during a radio lesson. Credit: Tom Tilson

embedded quizzes, polling, and even the use of clickers in a live classroom. At the time that NRMP was designed, the idea that active learning promoted deeper learning was still in its infancy. In fact, Suppes published some of the first papers testing this hypothesis (Suppes & Ginsberg, 1962). The widespread adoption of the design of NRMP for IRI has proven to be a critical inflection point for active learning principles to be accepted and adopted broadly.

FAILURE ANALYSIS

Both project designs were pedagogically innovative in promoting active learning techniques, and successful in improving student engagement and learning outcomes. And both ultimately succumbed to financial pressures, although of different types. CAI was always intended as an experimental project as access to the technology necessary to implement it was both expensive and scarce. Conversely, NRMP was developed to be cost-effective and broadly available, yet the sustainability of the project came under attack from political, financial and organizational forces.

Pedagogically, both CAI and NRMP were successes. Students in NRMP classrooms reported learning gains approximately 20% higher in learning outcomes than their peers in traditional classrooms. Gains in oral topics such as oral addition, subtraction, and word problems were especially high. The most effective response was the delayed oral response: students were asked to think of an answer but not say it aloud until prompted. Because the majority of the NRMP students lived in rural areas where most business or marketplace transactions were conducted orally, these learning gains reinforced the usefulness of interactive, oral mathematics education.

Initially, NRMP's lessons were well-received by students and teachers; all the instructors who participated in the 1975 program asked to be included the following year. As the program continued, however, resentment developed among some teachers who felt they were being displaced as content experts by the radio lessons. Ultimately, the internal bureaucracy in Nicaragua, combined with lack of governmental control over teacher development eroded support for the program.

Politically, the civil unrest and governmental instability of the late 1970's forced withdrawal; these events coincided with the financial pressure applied by USAID, who initially subsidized the project, insisting the Nicaraguan ministries assume half the cost of the program. When the ministries balked, both Stanford and USAID withdrew financial support for the project.

CONCLUSION

Just as the design and implementation of the computer assisted instruction (CAI) in elementary mathematical logic

directly influenced and informed the design of Nicaraguan Radio Mathematics Project (NRMP), so have both endeavors fundamentally expanded ideas of computer-mediated instruction to include providing multiple opportunities for active learning at scale. The commonalities of the instructional models of these projects are reflected in the design of many current educational technologies where students interact individually with a centralized curriculum. Each also identified the effectiveness and affordability of active learning practices enabled through technology. And while both projects explored the possibilities of technology to assume some of the work of instruction, both ultimately enhanced the role of teachers in the classroom by creating the conditions for new teaching practices to emerge.

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