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Billy Vaughn Koen and the Personalized System of Instruction in Engineering Education

Dr. Atsushi Akera, Rensselaer Polytechnic Institute

Atsushi Akera is Associate Professor in the Department of Science and Technology Studies at Rensselaer Polytechnic Institute (Troy, NY). He received his M.A. and Ph.D. in the History and Sociology of Science, University of Pennsylvania, and currently serves as the Chair Elect of ASEE's Liberal Education / Engineering and Society Division; an elected member of Society for the History of Technology's Executive Council; as Associate Editor of the international journal, Engineering Studies; and a member of the Editorial Board of the IEEE Annals of the History of Computing. the United States (1945-present). Publications include Calculating a Natural World: Scientists, Engineers and Computers during the Rise of U.S. Cold War Research (MIT Press, 2006).

Billy Vaughn Koen and the Personalized System of Instruction in Engineering Education

This paper offers a historical account of a radical pedagogic experiment called the Personalized System of Instruction (PSI) that earned considerable attention in our society during the late 1960s and early 1970s.[1] For those currently interested in MOOCs, the Kahn Academy and all that, this is a history well worth revisiting. PSI was an early example of an inverted classroom, a programmed system of instruction rooted in behaviorist psychology with an explicit focus on learning outcomes. Those familiar with PSI, and with behaviorist approaches to education have all noted the relevance of these earlier approaches to current online and distance learning environments.[2] Going beyond what we typically see today, PSI was a method that, when properly implemented, could guarantee that upwards of 70% of the students in a class would earn an 'A' with knowledge retention exceeding that of students enrolled a course taught using traditional methods. This history of PSI is designed to provide us with insights about the institutional contexts that promote—and suppress—pedagogic innovation. As it turns out, the focus on historical context will also take us into some fantastic territory, from Brazilian revolutionary history, to the subtleties of Skinnerian behaviorism, to high-tech opportunism in the State of Texas during an era of "national competitiveness."

I also note at the outset that many people in ASEE's Liberal Education / Engineering & Society Division will also recognize the main protagonist of this story. Billy Vaughn Koen was an active member of our division, and his work on the philosophy of engineering that grew out of his commitment to broadening the education of engineers earned him the Olmsted Award in 1987, the top prize of our division.[3] Today, we focus on the pedagogic reform that he pursued two decades earlier at the University of Texas at Austin.

Koen and the Emphasis on Teaching at UT Austin

Koen was born in Graham, Texas, the child of two educators. When Koen was still a young boy, his father changed his career from teaching to photojournalism and moved to Austin where he became the staff photographer for the University of Texas at Austin. Through his father's work, Koen came to know John J. McKetta, the chair of the Chemical Engineering Department and later Dean of the College of Engineering.[4]

Koen enrolled at the University of Texas, studying Chemical Engineering under McKetta's influence. Excelling in his studies, he then moved on to a doctoral program in Nuclear Engineering at MIT. (Chemical engineering remained an important component of the early work in nuclear engineering.) There he pursued cutting edge work on reactor kinetics using advanced computational modeling techniques. His MIT doctorate, which he received in 1968, provided Koen with three options for a career: A position at Los Alamos, an offer to join General Atomics, or a teaching position back at UT Austin. Koen enthusiastically embraced the role of teacher.[5]

It was also no accident that Koen returned to Texas. In 1963, McKetta had stepped up to become the Dean of the College of Engineering, where he began pursuing a two-prong strategy for improving the college's standing. On the one hand, conversations about the future of oil production—peak oil in Texas would occur in 1972[6]— brought the state to set its sights on nuclear energy. Austin was one of the schools that won support for a teaching and demonstration reactor, and McKetta needed a faculty that could leverage this support into a strong research program. But in the wake of Sputnik, there were also broad concerns about engineering education and an engineering "manpower(*sic*)" crisis, especially in a state that had placed only limited emphasis on engineering education. With the support of General Dynamics, a defense contractor located near Dallas, McKetta assembled a Bureau of Engineering Teaching, a colloquium series on effective teaching, and an annual prize awarded to the best engineering teacher. Koen was someone McKetta could entrust to pursue both of his major initiatives.[7]

By his own recollection, Koen made three promises to the senior faculty members on the search committee who interviewed him. The first was that he would make an internationally known contribution to the field of nuclear engineering. The second was that he would make an equally important contribution to engineering education that would bring credit to his department and to his university. For the third, he assured the committee that he would make an even broader contribution that would "change the way the world sees the human species," work that would become the basis of his Olmsted Award.[8] We focus today on the productive tension between his interest in teaching and research.[9]

In this respect, probably the most important thing to note in this necessarily abbreviated paper is that, having promised the moon, Koen, like so many PhD students, received no real training as a teacher while in graduate school. Undaunted, Koen applied the same heuristic he used during his studies in nuclear engineering, which was to canvass the state of the art in the discipline within which he wished to claim expertise. It was through this process, and through information provided by a classmate, that Koen discovered the Personalized System of Instruction.[10]

PSI's Origin in Revolutionary Brazil

PSI was developed by the head of the Psychology Department at Columbia University, Fred S. Keller. Keller was a close friend and colleague of the renowned behaviorist, B. F. Skinner. Between 1928 and 1931, Skinner and Keller were part of a group of young Turks in Harvard's Psychology Department who, as PhD students, dared to challenge the dominant introspective approach in American psychology. Influenced by Freudian psychoanalysis, but keeping an arms-length from it, American academic psychologists embraced an introspective approach that stood at one end of the spectrum of the mind-body dualism defined by Descartes. Riding on the crest of the historic rise of the experimental sciences, the behaviorists—Pavlov, Thorndike, Watson, and the like—came to occupy the other extreme in their assertion that the mind, and even the construction of "self," was the exclusive product of each individual's encounters with the environment. It was Skinner who had given full articulation to this position through his 1938 seminal text, *The Behavior of Organisms: An Experimental Analysis*, published a half-dozen years after his dissertation.[11]

This was, however, work that was completed two to three decades earlier. By 1960 Keller was approaching retirement after successfully building up one of the country's most acknowledged shops for behaviorist research. (Skinner was back at Harvard.)[12]

But then Keller received a rather unusual invitation. During the 1950s and 60s, Brazil was experiencing considerable revolutionary unrest, fueled by the pressures of modernization and accelerated development. Following the suicide of President Getúilo Vargas in 1954, Brazil was thrown into a period of political turmoil marked by the quick succession of presidents. However, there was a period of relative calm between 1956 and 1960 when the progressive vision put forward by Juscelino Kubitschek—the promise to deliver "fifty years of progress in five"—ignited the country's imagination, bringing economic prosperity, and hope. This hope was based on a uniting the nation, which was symbolized by Kubitzchek's commitment to a new capital city, Brasilia, and its shining new university.[13]

This vision was largely upheld by Kubitschek's more conservative successor, Jânio Quadros. On the other hand, higher education remained an elite institution in Brazil. While more broadly progressive ideals animated the vision for the University of Brasilia, at other Brazilian universities the governing vision remained that of changes designed to add to Brazil's reputation and national identity. Keller first received an invitation from the Dean of the Faculty (equivalent to Provost) at one of the established national universities, the University of Sao Paulo, to help modernize the university's Psychology Department and curriculum. Unfortunately for Keller, by the time he arrived the dean had been ousted as a result of a political miscalculation—after just seven months in office, Quadros tendered a resignation, apparently hoping that this would instead bring him broader powers. Instead, it produced a distinctly leftist turn in the government. But this was also the era during which the United States was struggling with Fidel Castro, and was found meddling in Brazilian politics. Keller found himself at the mercy of a skeptical if not hostile faculty that remained unconvinced that an outsider, and an American at that, could or should transform their academic programs.[14]

Unwilling to return to Columbia having made the journey, Keller began working with Dr. Carolina Martuscelli Bori, one of the younger, more sympathetic faculty members. After having also enlisted a graduate student, Rudolpho Azzi, who happened to be an experienced teacher, the group worked to assemble a research program and teaching laboratory in behaviorism at the University.[15]

This work was deemed a success, and Bori and Keller were invited to take their work to the University of Brasilia, Bori to create a new department of psychology, and Keller to continue on as advisor. With the university's doors yet to open, they had the time and space to plan. It was in the course of designing from scratch an introductory course in experimental psychology that the group came up with PSI. Pressed to be experimental in form as well as content, the group began considering how their knowledge of behaviorist principles could be applied to the classroom itself. Keller had in fact already done something similar amidst the crucible of war, where he used reinforcement theory to speed up the training of Morse code to Signal Corps officers during World War II. Reasoning that the method could be applied to an entire course, and not just a short-term training situation, Keller and his Brazilian colleagues began working out an overall pedagogic system designed around behavioral reinforcement.[16]

The political context of Brazil, and the institutional environment of the University of Brasilia, created a space conducive to pedagogic thinking and experimentation. It also placed an indelible imprint on the choice of pedagogic strategy, for under Quadros' successor, João Goulart, the democratizing potential of a behaviorist approach to education, in which every youth could be given the support they needed to learn and advance, became a desirable goal.[17] And to emphasize, PSI was initially developed for a laboratory based course in experimental psychology, where the successful replication of a known experiment, such as a rat learning to press a lever, could be as reinforcing to the student as it was for the rat. However, as subsequently reformulated to work for text-based courses, the basic principles of PSI were as follows:

> "1. 'The go-at-your-own-pace feature, which permits a student to move through the course at a speed commensurate with his ability and other demands upon his time.'
> "2. 'The unit-perfection requirement for advance, which lets the student go ahead to new material only after demonstrating mastery of that which preceded [it].'
> "3. 'The use of lectures and demonstrations as vehicles of motivation rather than sources of critical information.'
> "4. 'The related stress upon the written word in teacher-student communication.'
> "5. 'The use of proctors, which permits repeated testing, immediate scoring, almost unavoidable tutoring, and a marked enhancement of the personal-social aspect of the educational process.'"[18]

Those engaged in online and distance education today my wish to pause to think about which of these methods are in use today, or could be adapted to the current distance learning environment through new social or technological arrangements.

At the heart of the "Keller Plan" was a self-paced system of instruction built around concise teaching modules with specified learning outcomes, and an inverted system of instruction that focused, generally, on written study guides and tutoring, as opposed to lectures. There was also a "readiness test" that required students to score 100% before they could advance on to the next unit. Like mice on a treadmill, or rats in a maze, students would strive to learn the right answers, retaking the test as often as they needed to complete all of the units for which they would earn an 'A'. The method worked well. In fact it worked all too well, for as many as 80% of the students earned an 'A' after having spent as much as twice the amount of time on this class as compared to their other classes (this during an era prior to rampant grade inflation). Outside of Brasilia, this did generate suspicion and envy on the part of other faculty. Long operating in Skinner's shadow, Keller nevertheless felt that, quite late in his career, he had finally contributed something truly original to the world of teaching and scholarship.[19]

Transporting PSI into Engineering Education

Koen came across published accounts of Keller's methods, including his famous Presidential address, "Good-bye-teacher…," delivered before the American Psychological Association in 1967. Never one to be constrained by disciplinary boundaries, Koen decided immediately to apply Keller's method to his senior-year nuclear engineering course. On the other hand, neither one to do anything haphazardly, Koen taught the course using traditional lectures during his first year at UT Austin, while he prepared the course for PSI in the second. This gave him a clear point of comparison. As the method promised, PSI generated astounding results. 72% of the students preferred his course to a traditional lecture course. 88% reported putting in more effort into this course than any of their other courses, and the same number of students reported that they looked forward to this course more than anything else they were taking that semester. And whereas only 20% of the students earned an A in the earlier non-PSI version of the course (28% earned 'B's and 35% earned 'C's), 70% of the students earned 'A's in the PSI version of the course.[20]

The College's Bureau of Engineering Teaching took an immediate interest in Koen's success, and other instructors, especially in Mechanical Engineering, began making use of the method. PSI, with its reported successes, also began to garner national attention, as it was described broadly in ASEE's flagship journal, *Engineering Education,* and other publications. Soon there were national conferences and at least one ASEE summer teaching institute dedicated to PSI and other forms of individualized instruction.[21]

The experimental dimension of PSI also contributed to its uptake by engineering educators. The very fact that student progress was measured using unit tests that occurred with high frequency meant that PSI generated gobs of data. Students were tested often because of Thorndike's "Theory of Effect." The theory stipulated that enhancements to behavior occurred more reliably as a result of regular reinforcement (although this was modified by Skinner's own work, which focused more on intermittent schedules of reinforcement). The unit tests therefore made it possible to document student progress on a quantitative basis, and furthermore, it made possible experiments with course design that aimed to optimize learning outcomes. ASEE's Engineering Research and Methods Division (ERM) had already been established several years earlier. Nevertheless, ERM provided fertile soil for PSI's reception. After all, the learning outcomes data generated by PSI helped to establish that there could indeed be a scientific and statistical foundation for educational research, complete with standard deviations. PSI was also backed by what, to engineering educators, was the incontrovertibly rigorous theories of behaviorist research. PSI was a haven for those who were beginning to seek recognition for research in engineering education as well as the discipline in which they were trained. Despite being separated by more than a generation, Koen and Keller became fast friends.[22]

To be fair, PSI was not always successful. One of Koen's colleagues in Mechanical Engineering, Lawrence Hoberock, applied PSI to a more traditional course on kinetics and dynamics. His students did demonstrate accelerated learning during the first part of the semester. However, Hoberock, who remained a bit too wedded to course content, made the units too difficult and the tests too long to ensure continued success. Students began losing wind, with only 18% of the students actually making it to the end. This made it necessary, in turn, to modify the grading structure on an ad hoc basis so that this cohort of students could continue on with their studies. Hoberock had, in fact, cheated.[23] He offered supplemental lectures to cover ground that he didn't think the students were all able to get from the readings, and this was based in turn on the fact that he had tried to cram too much into the course. Like so many other engineering educators, Hoberock regarded this as a necessary evil, where a highly over-compacted curriculum resulted from the unreasonable effort to offer a professional degree in just four or at best five undergraduate years (even if leading educators said that it was merely the underlying preparation for professional training). Here, Thorndike's Theory of Effect operated as a governing law in that once you went outside of the envelope of the speedup that reinforcement made possible, students, like rats, could become discouraged and give up, thus negating the desirable effects of reinforcement.[24]

The Behaviorist Foundations of PSI

There are important subtleties to the psychological basis for PSI that I will unfortunately be unable to address adequately in this compressed version the story.[25] However, we can at least begin by taking note of some of the paradoxes inherent to PSI. The method was cast as a form of liberative pedagogy, and yet it relied on what many would regard to be one of the harshest branches of psychology. One only needs to read Rebecca Lemov's account of some of the other major strands in American behaviorism—its use in everything from suggestive advertising to military interrogation and brainwashing—to realize just how far this line of thinking could go.[26] PSI was also born in the context of the radical social vision of Brazil. The idea, if tainted with a twinge of social Darwinist thought, was that anyone who put in the time and effort could master any subject, regardless of social background or innate ability. But in the U.S. context, the method was appropriated to serve the workforce development objectives of a Cold War state, albeit within a field—engineering—that did serve as a vehicle for upward social mobility even during the 1960s and 70s. The PSI classroom also inverted, at least on the surface, the traditional authority between students and faculty, as student proctors who were often just a year or two ahead of the students they tutored, ran the entire course. Yet, the instructor-qua-experimentalist remained in firm control of the entire learning situation, much like the military junta that manipulated Brazilian politics from the shadows.

Besides which, what, exactly, was being reinforced with PSI?

A close look at the data generated by PSI courses point to an important fissure in this set of paradoxes. Using Koen's own course as an example, we note again that 88%, of the students put more effort into this course than any other course. And while still a high figure, only 72% of the students indicated that they liked the course better than a lecture course, even as the same, higher percentage of students (88%) said they looked forward to this course more than any other course. In other words, Koen, Keller and their cohort were conditioning their students to love the course at least as much, if not more so, than the engineering knowledge they acquired.

A second important piece of the puzzle relates back to the subtleties of Skinnerian behaviorism. The very notion of "operant conditioning" upon which Skinner based his reputation represented a partial move away from the earlier stimulus-response theory in that it assumed that reinforcement could produce a knowing entity that could act upon the world. This was still a "knowing self" produced through a long history of encounters with their environment, not the autonomous individual born out of a doctrine of free will. And while agency, in this sense, remained limited in the animals Skinner used in his experiments, the construction of self could become quite complex for humans as a result of the complex social interactions that occurred outside of the laboratory walls. In his later, more speculative work on topics such as "verbal behaviors," Skinner did in fact distance himself from his early experimental work, representing it as but a scientific window into what remained a complex array of human behaviors, not all of which would easily yield themselves to experimental analysis.[27]

This is not to say that Skinner was able to extract himself from the reductive habits of the experimental sciences. Skinner himself published a book on the subject of teaching in 1968, with the title, *The Technology of Teaching.* Estimating that some 25,000 reinforcements would be required to cover a basic subject such as arithmetic, Skinner found mechanical aids to be the best option for trying to repair the U.S. public education system.[28] By contrast, it was Keller, and by extension, Koen, who recognized that the reinforcements that PSI delivered were not about reinforcing discrete learning events. With PSI, their focus was really on higher order learning behaviors—how to read a technical text, learning not to procrastinate, knowing when to ask for help—that the "good" students had already acquired during their grade school years, and which could be reinforced, accentuated, modeled, and shared in a carefully designed classroom environment. As a nuclear engineer, Koen no doubt remained partially wedded to course content like his mechanical engineering colleague. Nevertheless, both for he and Keller, the true goal of PSI was to cultivate sound learning habits and strategies conducive to lifelong learning. This was something engineering educators had long insisted was essential to engineering professional identities, but could rarely find a way to reduce to practice. As expressed through their occasional references to "generalized reinforcement," this was the behavior that PSI was designed to reinforce.

The Challenge of Sustaining Educational Reform

As the implementation spread to faculty members unfamiliar with the psychological foundations of PSI, reports from the field began to grow more mixed. In 1974, the University of Texas' El Paso campus and New Mexico State University held a joint symposium on PSI. The symposium was set up to help promote the method, but the organizers had to admit that the general tenor of the meeting was "not one of enthusiastic optimism, but mild disappointment and discouragement."[29] The principal organizer came to the conclusion that existing articles about PSI were too positive, and that they were setting up false expectations. Instructors who were hoping for a miracle found the intensive work required to set up a PSI course to be a real "eye opener." And those who launched their course without having carefully prepared their course in advance set themselves up for disaster, as they struggled to produce study guides, chock full of errors, which impinged negatively on the student's learning experience—and hence reinforcement. Also misunderstanding the fifth principle of PSI about student-teacher interaction, which was really meant to applied only to the proctor, many instructors embraced PSI expecting more rewarding interactions, only to find that they were spending too much time "writing study guides and exams to work closely with [the] students."[30]

Compounding the difficulties was the habit many engineering educators had of trying to engineer a better solution. For instance, John T. Sears from West Virginia University tried to apply PSI to his junior-level thermodynamics course, despite having no proctor. Also wedded to the idea of a grade distribution, Sears only guaranteed the students a C for finishing all of the units. Additional work, evaluated using traditional methods, was used to assign students a higher grade. Sears also felt it necessary to give students "careful criticism" of their homework, which meant that the students received this feedback later, at the next class at best. This ran against the principle of providing instant feedback, which was considered essential from the point of view of operant conditioning. Because there were no lectures and no proctors, Sears also repurposed class time, during which they were supposed to be studying and preparing for the unit tests, with a set of design exercises, which added an additional learning objective to an already overburdened course. When students began falling behind, Sears instituted specified deadlines for every two weeks of the semester.[31] This was a clear instance of what Koen and Keller worried about, a compromised, "SLI" (Something-Like-It) implementation of PSI that could only discredit the method.[32]

This example also points, if indirectly, to the broader circumstances surrounding engineering education that constrained and ultimately limited PSI's circulation. Even at UT Austin, Koen struggled with the difficulties associated with working within the constraints of an academic calendar. The fact that all courses started and ended at a specified date made it impossible to operate with what one proponent labeled, "learning as a constant and time [spent on a course] as the variable." PSI's proponents regarded this to be the ideal way to run a PSI course, given the different backgrounds, innate abilities, and intrinsic interests of the students.[33] Meanwhile, the "incompletes" that Koen and his colleagues often assigned to students as a way of getting around this problem drew unwanted attention from the registrar, who eventually prohibited the practice. In addition to the envy that the PSI grade distribution generated, having other faculty within a department who were not committed to the method meant that the opportunity for integration, which was especially important for a mastery-based educational method, remained limited.[34] Soon, other vocal critics joined the fray, including those troubled by the significant effort students placed in a PSI course at the expense of their other courses. All this cast additional doubt on PSI as a potential solution to the broader challenges of engineering education.[35]

All in all, PSI flashed across the horizon during a brief time between the late 1960s and early 1970s when student demands, faculty interest, and administrative expectations in the United States aligned to create an institutional context conducive to a real emphasis on teaching and learning—at least at a certain range of institutions. But the two oil crises and the resulting decade of economic "stagflation" during the rest of the 70s brought engineering educators to shift their attention to a perceived crisis in U.S. industrial productivity. Given the intensive work required to set up a PSI course, few faculty members from research universities (and from universities with high teaching loads) were willing (or able) to give PSI a try. The situation only grew worse during the 1980s, as the concern about productivity transformed into a broader discourse about "national competitiveness," and the way that engineering research was touted as a way for the necessary transition to a "high tech" economy. Even at UT Austin, it became less fashionable for any faculty to express a strong interest in teaching.

PSI did continue to be employed at UT Austin, having found a solid institutional home there.[36] Nevertheless, the fate of the method there remains indicative of the broader, national trends. Given the inflated OPEC oil prices, Texas actually weathered the recessionary period of the 1970s quite well, and the state had made major investments in higher education amidst significant economic and demographic growth.[37] However, the collapse of the OPEC cartel and the resulting drop in oil prices between 1981 and 1983 had a devastating effect on the Texas economy as well as its higher education system. A 26% cut in the state's higher education budget was seriously considered for the 1986-1987 fiscal biennium.[38] A shift towards research had already occurred during the retrenchment during the second half of the 1970s (in no small part because Texas had reached peak oil in 1972), but this latest economic turn prompted the state to place even greater emphasis on research, and a "high tech" economy modeled after Silicon Valley and Route 128. It was said that educated minds would become "the oil and gas" of Texas' future economy.[39]

The state's most concerted bid to enter into the high tech era occurred through its successful bid to bring the Microelectronics and Computer Technology Corporation (MCC) to Austin. MCC was the nation's first research consortium, said to be the U.S. response to the Japanese "Fifth Generation Project" in artificial intelligence. The firm was headed up by none other than a former director of the National Security Agency, Admiral Bobby Ray Inman (Ret.). The proposal affected the University of Texas directly, since a key commitment that won the bid, beyond the $20 million building erected to house this private corporation, was the promise to upgrade UT Austin's faculty and research capabilities by opening up 30 new faculty lines, especially in fields such as electrical engineering and microelectronics.[40]

Koen's own career reflected this turn of events at UT Austin. While Koen was tenured early, in just three years, it took him longer to attain the rank of Full Professor. This was partly because of time spent away from UT Austin—Koen spent several years at the French Atomic Energy Commission's main research laboratory in Saclay, France, where he pursued the work on reactor safety that also earned him international recognition.[41] However, the tenure standards at Austin were such that he needed to rebuild his vitae through work performed at the university. It is also worth noting that Koen's vitae also contains a mixture of research publications in nuclear engineering and those pertaining to PSI and educational research. In the end, it was probably his teaching that earned Koen his promotion. McKetta's successor, Ernest F. Gloyna, placed him on the list of candidates for promotion to Full Professor in 1982, the year Koen won a prestigious state-wide teaching award. Moreover, amidst some backlash generated by the university's heavy emphasis on research, UT Austin's Vice President for Academic Affairs placed Koen at the top of the list of candidates for promotion from the College of Engineering that year. While PSI continues to be used to this day at UT Austin in somewhat modified form (to Koen's chagrin), even Koen came to think carefully about how to advise young, untenured faculty who were interested in teaching, but had to meet the university's evolving tenure bar.[42]

Implications for Engineering Educators

First and foremost, this is a story about the rise and fall of an educational method, and how its development, reception, and ultimate decline were influenced, even animated by the various contexts that either favored or worked against an emphasis on teaching. However, given that this version of the paper is not being presented to a historical journal, allow me to shift modes and think more directly about the practical (and policy) implications of this story for an engineering education audience.[43]

It is probably helpful first to solidify the connection between this story and the pedagogic philosophy that remains embedded in contemporary online and distance learning environments. The Kahn Academy, MOOCs and other forms of online learning share with PSI and Skinner's focus on educational technologies not only the self-paced and/or inverted classroom approach to engaged learning, but they all function by breaking up learning into more discrete unit and rely on rapid, and indeed immediate feedback as a means of motivating the students and reinforcing their learning. Many have in fact made the connection between Skinner's work on educational technology and online learning environments, and recognize the behaviorist foundations that can be counted as an advantage in all forms of computer assisted instruction. Koen himself has worked on translating PSI for the current, online distance learning environment.[44] Meanwhile, it is instructive that one of the greatest challenges that developers of all distance learning environments face is that of reproducing a learning community for students engaged in any form of self-paced instruction.[45] Taking the Johns Hopkins University Center for Talented Youth's online courses in which one of my sons is enrolled as an example, we hear from one of its instructors an open admission that online learning (and teaching!) can be a lonely experience at times.[46]

Here, PSI provides valuable lessons that might not be apparent at first glance. It suggests that learning communities can emerge not only around shared content, but shared learning experiences and learning environments. Grades may be powerful motivators, but the motivation can be amplified when tied to mastery and progress (as opposed to degree of mastery), especially when rendered in a visible form accessible to the student's learning cohort. Perhaps most importantly, PSI points to the value of a shared learning environment in teaching higher-order learning skills that go beyond course content. The implications of these lessons will vary depending on what technological and institutional opportunities one has for producing a learning community. But especially for those who are pursuing blended learning environments, PSI (including Keller's approach to laboratory instruction) should suggest specific options for course design that should not be ignored.

The broader lessons have to do with the institutional and sociopolitical contexts that shape and animate educational reform initiatives. (Engineering education reform is indeed the focus of the book project from which this case study is drawn.) Here too, the lessons to be gleaned from this story are many, although it may require a greater degree of reflection to draw effective inferences that span the gap between past and present. This will also provide us with an opportunity to draw out other lessons that remain embedded in the historical narrative.

As a matter of first order, it should be apparent that educational reforms arise within institutional contexts where there is a strong and genuine interest in teaching. Certainly, PSI was partly a "product of the 60s," which, at least in the United States, extended into the early part of the 70s. However, if we were to map all of the places that were willing to give PSI a try, this would supply us with a snapshot of a more specific geography (i.e. the syntagmatic extension) of the institutions that maintained a commitment to undergraduate education. If we were to then follow this with a more fine-grained analysis of differences—the circumstances at the University of Texas as opposed to West Virginia University, where John T. Sears implemented a highly compromised version of PSI—this can then lead us towards a more subtle understanding of the different institutional contexts that either contribute to or hinder the advancement of a specific reform initiative. Through additional reflection, we could then ask how well the specific reform initiative or initiatives that we individually espouse today fit within the historic and institutional contexts to which we too are inextricably bound. Those of us in the Liberal Education / Engineering & Society Division have, for example, thought extensively about how relevant humanistic and social scientific content is in the face of the present emphasis on training “global engineers,” and the different strategies for integration that seem best suited to different institutional settings.

Meanwhile, PSI’s fantastic origin in Brasilia points to the direct influence that historic context can have on the pedagogic orientation, which is to say the actual content of an educational reform movement. PSI’s behaviorist underpinnings were consistent with a political context that favored broader access to higher education, even as—or even though—its adoption in the United States was motivated by a Cold War engineering workforce crisis and the specific desire to improve engineering student retention by embracing a more effective means of instruction. In other research on the history of engineering education reform that a close colleague and I are working on, it has become evident that engineering educators possess a distinct set of practices for reexamining and changing the epistemic foundations of engineering in response to “changing times and needs.” Through reflection, we can again ask whether the specific reform that we wish to pursue today fits within the current political economic context, or better yet, draw inspiration from the current context to develop new ideas about reform. On the other hand, other research has demonstrated that engineering educators have historically been able to maintain some distance from the immediate political economic context in charting a course for engineering education. We would certainly encourage all engineering educators, and not just those affiliated with our division, to consider the broader social and ethical foundations for engineering education that go beyond the most immediate political and industrial (and even professional) interests.

Finally, based on a very helpful suggestion made by one of the reviewers, I leave the reader with “some challenges for personal reflection and action” that also emerge out of this story about PSI. Being less connected one to another, they are presented in bullet form. And while I present the questions that are most apparent to me, I invite the reader to meander back through the narrative in seeking other points of reflection that resonate most with their interests.

- What are your own motives for pursuing educational reform? Are they well aligned to the current political economic context? To what your home institution is willing to recognize and support?
- If not, can you shift (or develop) your focus so that your reform efforts are better aligned with the present context?
- To ask this in a different way, are the reforms that you espouse born of a different era (as the often are)? Can they be renewed and revitalized? Or should you learn how to cut your losses?
- What are your goals as an engineering educator? Are there opportunities to focus on teaching and pedagogy, as opposed to curricula, to achieve the specific ends that you seek? Is there anything in the educational literature outside of engineering education that might inspire you to pursue a new direction?
- Given the impressive learning outcomes data of PSI, is it time that we revisited this method or “something like it,” especially given the current interest in online education? Did PSI fail because of the effort required, “inadequate technology,” the lack of institutional support, or the tensions that it produced among the faculty? Given the present interest in the quality of undergraduate education, is

there an opportunity to fix some of the historic problems with PSI for instance, by using computer assisted instruction or by crediting faculty with the time it takes to develop a PSI course?[47] (And should we be providing such support to those engaged with distance learning today?)

- What are the behaviorist foundations of online learning? Would the 100% mastery criteria from PSI enhance student engagement with self-paced distance learning courses?
- What does PSI tell us about the value of learning communities? What lessons are embedded here that apply to our own classrooms today?
- What does PSI tell us about the alleged tension between mastery and coverage? What are the underlying goals of engineering education, how is it structured, and are students, in the end, better served by an emphasis on mastery or a partial introduction to a diverse range of skills and subject matter? What is the right balance between (or what options are there to integrate) these two important aspects of engineering education, considering different work situations and contexts?
- The focus on educational research during Koen's time appears very similar to what we see today. Was this focus on educational research productive then? Did the research help improve teaching, or was it more about securing recognition, and if so, did that work? Does it work better today (and under what conditions)?
- Perhaps more importantly, are there ways to pursue educational research today similar to the way Keller turned to behaviorist principles in remaking the classroom? If you are committed to educational research, what opportunities do you have for pursuing more radical innovations in teaching, and how might you go about finding them? (Koen believed in canvassing the state of the art.)

Notes

[1] This paper is based on an episode from a book project on educational reform that Bruce Seely (Michigan Technological University) and I are working on. An earlier version of this talk was presented to a different audience at the 2013 annual meeting of the Society for the History of Technology in Portland, ME under the same title.

[2] Unless otherwise indicated, biographic information on Billy Vaughn Koen is obtained from an oral history interview in the author's possession. "Billy Vaughn Koen Oral History Interview," MP3 Audio-file, Indexed, 17 July 2012, Brunswick, ME. On PSI's relevance to distance learning environments today, see, for example, Robert Gray and Stevie Ash, "An Interview with Fred Keller," available online (Accessed 2/3/2014). Reference to Skinner and his early work on educational technologies can be found throughout the distance learning literature, especially in popular sources. Koen himself was involved in making the translation. See B. V. Koen and Kathy Schmidt, "ME205, A Web Based Implementation of the Personalized System of Instruction," *18th Annual Conference on Distance Teaching and Learning,* Madison, WI, 14-16 August 2002; as well as various publications related to a distance learning course on computer science that Koen developed in collaboration with Japanese colleagues at the Tokyo Institute of Technology. See "Résumé: Billy Vaughn Koen," updated 1 September 2011, in author's possession. Also discussed in oral history interview segment 74.

[3] Koen received the Olmsted Award for the publication of an ASEE monograph entitled, *Definition of the Engineering Method* (Washington D.C.: ASEE, 1985), which emerged out of an honors course on the foundations and philosophy of engineering, which was offered to both engineering and liberal arts students. Based on

encouraging mutual conversations and an understanding of what engineering was and how it was practiced, this work espoused the values of ASEE's Liberal Education Division. Oral history, interview segment 66-70.

[4] Oral history interview segment 3-7. See also "Résumé: Billy Vaughn Koen," note 2 above.

[5] Oral History, interview segment 6-7.

[6] Railroad Commission of Texas, "History of Texas Initial Crude Oil, Annual Production and Producing Wells," http://www.rrc.state.tx.us/data/production/oilwellcounts.php. Cited in Wikipedia's "Peak Oil" entry. (Accessed 9/27/2013)

[7] See esp. "A History of the Teaching Improvement Program," in *Engineering Teaching Effectiveness Colloquia 1966-1967;* "Source Book 1962-1963: College of Engineering," and other documents in UT College of Engineering Records, 1923-2000 (hereafter, **CoE Records**), Box CDL3-A12. University of Texas Archives (hereafter, **UT Archives**), Briscoe Center for American History, University of Texas at Austin.

[8] See note 3 above.

[9] Oral history, interview segment 19.

[10] Oral history, interview segment 21.

[11] See esp. Daniel W. Bjork, *B. F. Skinner: A Life* (New York: Basic Books, 1993), and Daniel Wiener, *B. F. Skinner: Benign Anarchist* (Boston: Allyn and Bacon, 1995).

[12] Keller's scholarly life is best documented in the two biographies of Skinner cited above. See especially Bjork (1993), chs. 4 & 6; and Wiener (1995), pp. 32-37.

[13] E Bradford Burns, *A History of Brazil,* 2nd edition. (New York: Columbia University Press, 1980). The period from Vargas, through Kubitschek, Quadros, and Goulart, is described in chapters 6-7.

[14] Fred. S. Keller, "An International Venture in Behavior Modification," in Fred S. Keller and Emilio Ribes-Inesta, *Behavior Modification: Applications to Education* (New York: Academic Press, 1974), 143-155, 143-145; Sérgio Dias Cirino, Rodrigo Lopes Miranda, and Robson Nascimento de Cruz, "The beginnings of behavior analysis laboratories in Brazil: A pedagogical view," *History of Psychology* 15/3(2012): 263-272. Available online. (Accessed 2/8/2014)

[15] The work that Keller, Bori, and Azzi did during this period is best described by Cirino et al. (2012), as well as by one of the early participants, Maria Amelia Matos (Institute of Psychology, USP), *"Contingências Para a Análise Comportamental no Brasil," Psicologia USP* 9/1 (1998). Available online. (Accessed 2/8/2014)

[16] Keller (1974), Matos (1998).

[17] I found no ready source in English on the history of the University of Brasilia, but a substantial entry on the History of Brasilia exists on the Wikipedia's Brazilian site, which was consulted for the purpose of securing the necessary context. (Accessed, 2/8/2014) The origins of Brasilia under Vargas may be found in Burns (1980), 459-462, and Brazil under Goulart is described in pp. 487-504.

[18] From Fred S. Keller, "Good-bye Teacher…," *Journal of Applied Behavior Analysis* 1 (Spring 1968): 79-89, 83. Reprinted in University of Texas, College of Engineering, "The Personalized System of Instruction (PSI): The Keller Plan Applied in Engineering Education, ed. James E. Stice. Bureau of Engineering Teaching Bulletin No. 4, December 1971, 1-11. CoE Records, Box CDL3-A12. UT Archives.

[19] Ibid.; For the actual implementation of a PSI based course on the history of psychology, see Fred S. Keller, *The History of Psychology: A Personalized System of Instruction Course* (Roanoke: Va.: The Scholars Press, 1973).

[20] Oral history, interview segment 30; Billy V. Koen, "Self-paced Instruction for Engineering Students," *Engineering Education* 60 (March 1970): 735-736; Also Billy V. Koen, "Self-paced Instruction in Engineering: A Case Study," *IEEE Transactions on Education* E-14/1 (February 1971): 13-20. Under PSI, Bs and Cs were generally awarded to students who completed some specified portion of the units.

[21] This excitement is captured in this publication, which was said to capture 75% of the papers published so far on the subject of PSI. Presumably it was produced for internal use by other faculty within the College of Engineering. University of Texas, College of Engineering, "The Personalized System of Instruction (PSI): The Keller Plan Applied in Engineering Education," ed. James E. Stice. Bureau of Engineering Teaching Bulletin No. 4, December 1971, 1-11. CoE Records, Box CDL3-A12. UT Archives; Also Lawrence L. Hoberock, Billy V. Koen, Charles H. Roth, Gerald R. Wagner, "Theory of PSI Evaluated for Engineering Education," *IEEE Transactions on Education* (February 1972): 25-29. Stice was older than Koen perhaps by about six years, and was still then an Associate Professor. The spread of PSI on the national level is captured by Keller in "An International Venture," 153.

[22] Oral history, interview segment 59; James A. Kulik and Chen-Lin C. Kulik, "Effectiveness of the Personalized System of Instruction," *Engineering Education* 66 (December 1975): 228-231.

[23] I note that this is my inference, not Koen's.

[24] Lawrence L. Hoberock, "Personalized Instruction in Mechanical Engineering," *Engineering Education* 60 (March 1971): 506-507.
[25] A link to a draft of a longer version of this paper is provided in the final footnote.
[26] Rebecca Lemov, *World as Laboratory: Experiments with Mice, Mazes, and Men* (New York: Hill and Wang, 2005).
[27] Koen, "Self-paced Instruction"; Meanwhile, the subtleties regarding Skinner's ideas, to the extent to which I have been able to correctly identify them, are perhaps best described in Derek Blackman, "B. F. Skinner (1904-1990)," in Ray Fuller (ed.), *Seven Pioneers of Psychology: Behaviour and Mind* (London: Routledge, 1995), 109-132.
[28] B. F. Skinner, *The Technology of Teaching* (New York: Appleton-Century-Crofts, 1968). See p.17 on the 25,000 estimate.
[29] W. Lionel Carver, Jr., "A Realistic Appraisal of First Efforts at Self-paced Instruction," *Engineering Education* 64 (1974): 448-450, 448f.
[30] Ibid., 449.
[31] John T. Sears, "Developing Intellectual Skills in a Self-paced Course," *Engineering Education* 61 (March 1971): 515f; Oral history, interview segment 37.
[32] Billy, V. Koen, "The Keller Plan," in Lawrence P. Greyson and Joseph M. Biedenbach (eds.), *Individualized Instruction in Engineering Education* (Washington, D.C.: American Society for Engineering Education, 1974), 37-42.
[33] Gordon H. Flammer, "Learning as the Constant and Time as the Variable," *Engineering Education* 61 (March 71): 511-514.
[34] The challenges of working within an existing administrative structure are noted by Koen as well as by Hoberock in L. L. Hoberock, "The Professor's Viewpoint," *Engineering Education* 66 (November 1975): 167-168. It is also reported more dramatically by a North Carolina State University faculty member in "To PSI and Back," *Engineering Education* 69 (February 1979): 399-401; and tabulated in John Hess, et al., "Major Problems Identified in the Use of the PSI Method," in Keller and Koen, eds., *The Personalized System of Instruction,* section 5, pp. 5-4f.
[35] See for example J. A. Roberson, and C. T. Crowe, "Is Self-paced Instruction Really Worth it?" *Engineering Education* 65 (April 1975): 761-764; and Johannes Gessler, "SPI: Good-bye Education?" Reader Comment, *Engineering Education* 65 (December 1974): 252-255, and the conversation that appeared in subsequent issues in response to Gessler's op-ed piece. Koen has an interesting story about enrolling his department head and associate dean by helping them to publish about PSI. This was through his realization that "administrators are pigeons too"—that the positive reinforcement of a publication would reinforce their commitment to PSI. However, the article itself, E[ugene] H. Wissler, "PSI Management: Down the administrative chain," and also Parker Lamb, "The Chairman's Viewpoint," *Engineering Education* 66 (November 1975): 165-167, also reveals some of the tensions that existed even at UT Austin. Oral history interview, segment 35.
[36] See note 34 on UT administrators.
[37] A record of the shifting emphasis within UT Austin's College of Engineering can be found in the annual reports and planning documents in CoE Records, CDL3-A13. UT Archives.
[38] Scott Bennet, "The State of Our State," *Texas Business* (June 1985). In RG 100, AC 1989/76, Select Committee on Higher Education (SCOHE) Records, Box 2, Folder 17. Texas State Archives, Austin, TX. The Texas State Legislature met on alternate years, and therefore passed the state budget on a biannual basis. The proposed 26% higher education budget cut was eventually averted primarily through a significant (200%) tuition increase. Still, because of the oil windfall, Texas was among the states to remain committed to a highly subsidized system of public higher education, charging only $4/credit hour, or an amount less than the University of California system, with its "tuition free" system, when student fees were considered. This was increased to the still very low rate of $12/credit hour, although it should be noted that as done without compensatory changes in financial aid, this no doubt produced some hardship among low-income residents of the state, including the state's large and growing Hispanic population. Transcript, Select Committee, Council on Higher Education, 16jan86, side 8, p. 4. SCOHE Records, Box 1, Folder 5.
[39] Gov. Mark White, Opening Address. Select Committee on Higher Education, Meeting Transcript, 14 October 1985. SCOHE Records, Box 1, Folder 1. Texas State Archives; See also Office of the Governor, Texas 2000 Project, *Texas Past and Future: A Survey* (June 1981). CoE Records, Box CDL3-A14. UT Archives.
[40] "Executive Summary: The Texas Incentive for Austin." RG 301 [Office of the Governor], 1991/141 Mark White Records, Box 6, Fld: MCC / Adm. Inman's Statement on Location in Austin. Texas State Archives; "MCC Commitments for Department of Electrical Engineering," CoE Records, Box CDL3-A2, Fld: Micro Electronics & Technology Corp. UT Archives.

[41] Koen was at Saclay, France between 1971-1972, and again between 1976-1977. There he developed a canonical method for assessing reactor safety that utilized artificial intelligence and an extension of the computational methods he became familiar with while at MIT. Oral history interview, segment 51.
[42] Oral history, interview segments 47 & 72. Also revised based on Koen's feedback on this manuscript. Conversation with author, 19 March 2014.
[43] This paper is also motivated by more theoretical issues having to do with institutional ecologies, the circulation of knowledge, and the epistemic practices of engineering educators that result in the routine reexamination of the epistemic foundations of engineering. These reexaminations wind up realigning what is central to engineering education to serve ever changing political and economic contexts. It is my intent to examine these issues in a longer version of this manuscript, which will be submitted to a historical journal. Should this academic discussion be of interest, I invite readers to examine an early draft of the longer manuscript, which I have posted publicly (URL:http://www.rpi.edu/~akeraa/articles/Akera-PSI Working Draft.pdf) as a work in progress. I invite any and all feedback about the ideas contained therein. The paper will remain posted until the manuscript is submitted for publication. A link to the published manuscript will be provided at this temporary site, once the manuscript is in print.
[44] See note 2 above.
[45] Koen himself made this connection. See B. V. Koen, "On the Importance of 'Presence in a Web-Based Course," Frontiers in Engineering Conference, Boston, MA, 6-9 November, 2002.
[46] Private correspondence, 11 February 2014, in author's possession.
[47] Koen has noted, in a conversation with the author, that while PSI requires greater up-front effort, the total amount of time required to teach using PSI may be similar to other courses over the lifetime of the course. This may depend in part on how rapidly the content—the field being taught—is changing, given the need to prepare original study guides. In a course with relatively stable content, what Koen says would much more likely apply. Conversation with author, 19 March 2014.