The Personalized System of Instruction and Its Application to Engineering Education

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This is a paper about the application of Skinnerian behaviorism in one domain of education via a self-paced system of instruction known as the Personalized System of Instruction (PSI). PSI was an early example of an inverted classroom developed by Skinner's close friend and colleague, Fred S. Keller. Utilizing Thorndike's theory of effect and broader behaviorist principles about learning, PSI was built around small study units with tightly specified learning outcomes. Based on ideological as well as theoretical commitments, PSI was also designed around the concept of mastery, so that only students scoring 100% on the unit tests were allowed to proceed on to the next unit. In return, every student who completed all of the units in this programmed learning environment earned an A. With PSI, the grade, as well as progress towards a grade served as a generalized reinforcer in a manner similar to, and indeed paralleling the development of token economies in the 1960s. This article is grounded in the pluralist framework for the behavioral sciences established by Longino (earlier[1]; 2013). It also draws on an ecological outlook towards knowledge in paying close attention to the political contexts, institutional ecologies, and the circulation of knowledge that contributed to the rise and fall of PSI. This will take the story into some fantastic terrain, from Brazilian revolutionary history, to post-Sputnik concerns about an engineering manpower(*sic*) crisis, to the growing concerns about stagnating US industrial productivity during the 1970s that contributed to the downfall of PSI. We focus on PSI's application in engineering education because PSI enjoyed a broader circulation there than in any other discipline.

Allow me to note at the outset, at least for the purposes of this review draft, that I am a historian of technology with little prior exposure to the history of the behavioral sciences. A colleague of mine and I have been working on a book-length project on the history of engineering education reform, which led us to teaching, to pedagogy, to educational research, and to PSI. This paper is therefore a gesture, an attempt to open an interdisciplinary dialogue, not only with those familiar with Skinnerian behaviorism, but those in the history and philosophy of the behavioral sciences who may be better positioned to interpret certain aspects of this history. Whether or not this paper's content is deemed, in the end, to be appropriate to the audience of the *Journal of the History of the Behavioral Sciences,* I would appreciate it if the reviews could be approached in this spirit.

This story will be told in narrative form in order to allow the subtle interplay between a complex array of explanatory factors. Nevertheless, the complexity of the story is such that it is beneficial to provide some analytic scaffolding by which to interpret the narrative. First, this account draws on

[1] THESE NOTES ARE STILL UNDER CONSTRUCTION!! This is a working manuscript that is being "rebuilt" for consideration in the Journal for the History of the Behavioral Sciences, and the footnotes are being reworked for the new manuscript. It contains my own notes on tasks that I need to do! Please ignore all extra notations. [-Atsushi]
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Longino. By historicizing, in effect, the unity of physics, Longino's pluralist framework opens up a wider space for social epistemological analyses of the behavioral sciences. Through her specific focus on politically charged issues Longino is able to demonstrate how social values inhabit competing epistemic cultures for the study of human behavior. As a historical case study, this article documents not only that similar processes were at work in the earlier history of Skinnerian behaviorism, but that the persistence of an epistemic culture could be upheld through its circulation and its applications.

The idea that behaviorism has been upheld through its applications has been studied directly by Rutherford (date[2]) through her focus on the "technology" of behaviorism; it is further documented through any of a number of other studies of behaviorist applications. Although intellectually challenged by the emergence of a cognitive paradigm since at least the 1950s, behaviorism continued to gain ascendance through the 1960s and 1970s, specifically through its applications. But an entry into applications was not without its consequences. As Campbell (2007[3]) demonstrates with regards to behavioral pharmacology in drug addictions research—Campbell also utilizes Knoor-Cetina's framework of epistemic cultures—adaptation to, and even colonization of other disciplines could result in a softening of, or hybridization of behaviorism's conceptual commitments. Indeed, as behaviorism went from being the radical new idea to that representing the psychological establishment, many researchers began to face up to some of the limitations of radical behaviorism.[4] As a case study, PSI documents one of the other ways in which behaviorists came to terms with the utility and limitations of their ideas, even as they built on their utility.

In this respect, PSI represents nothing more than a case study. Nevertheless, it is an interesting case study because of what is unique about the epistemic culture surrounding engineering education and educational research. We might note, for instance, ?'s observation in *Elusive Science,* where educational research as a whole has failed to serve as a vehicle for advancing the underlying knowledge within this interdisciplinary arena of research; put simply much of educational research has been labeled inadequate, specifically because of an instrumental orientation that sees little purpose in advancing the underlying sciences of learning that undergird their applications. However, the epistemic culture of engineering educators is also interesting precisely because of their instrumental orientation. So although the relationship between the context and content has been a point of contention in the sciences, it turns out to be a routine performance in within engineering. Engineering educators, in particular, regard it to be their cultivated responsibility to adapt their knowledge in response to "changing time and needs," and routinely engage in a body of practice they recognize to be educational reform, in both reexamining and reconfiguring the epistemological foundations of their discipline. This tradition of self-study has been quite fundamental, as the emphasis in engineering has shifted from apprenticeship, embodied knowledge, the sciences, design-and-creativity, and humanistic breadth, and in their different combinations. PSI was clearly one instance of the engineers' drive for educational reform, where attention to the detailed texture of this reform will reveal the specific encounter between the epistemic cultures of engineering education and behaviorist research.

I reiterate that the above analytic framework is designed simply to help us interpret the historical narrative. Given the emphasis on engineering education, the story begins with a set of educational reforms at the University of Texas; describes the origins of PSI; documents its adaptation and dissemination within engineering education; addresses some of the subtleties of Skinnerian

[2] **Date**
[3] **Ver** date
[4] For behavioral pharmacology, this was the realization that animal models did not translate well into the phenomena of human addiction, and the resulting hybridization of both concepts and methods used to explain human addiction. See Campbell (2007),
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behaviorism as applied to PSI; and closes with an account about the decline of PSI before we return to the above analytic issues and the broader significance of this article.

Billy Vaughn Koen and an Emphasis on Teaching at UT Austin

PSI circulated broadly in engineering education largely through the efforts of Billy Vaughn Koen, a nuclear engineer at the University of Texas at Austin. A native Texas, Koen was born in Graham, Tex., and was the child of two educators. When Koen was still a young boy, his father changed his career from teaching to photojournalism and moved the family to Austin where he became the staff photographer for the University of Texas at Austin. (Koen's father took a famous photograph of the UT Tower sniper in 1966.) Being part of UT's public relations office, Koen's father became friends with many senior faculty members, including J. McKetta, the chair of the Chemical Engineering Department and later Dean of the College of Engineering.[5]

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.[6]

It was no accident that Koen chose to return 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[7]— brought the state to set its sights on nuclear energy. As such, 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 in nuclear engineering. But in the wake of Sputnik, there were also broad concerns about engineering education and an engineering "manpower(*sic*)" crisis. While the State had set up land-grant type institutions, as typical of a natural-resources dependent state, engineering education in Texas remained underdeveloped as compared against the East, and increasingly West Coast. What strengths that existed could be found in areas such as petroleum engineering and agricultural engineering. Seeking to expand and reorient his program to meet the state's changing workforce needs, McKetta, with the support of General Dynamics, established 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.[8]

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[5] 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. Interview segment 3-7. See also "Résumé: Billy Vaughn Koen," updated 1 September 2011, in author's possession.

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

[7] 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 "Peak Oil" entry. (Accessed 9/27/2013)

[8] 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

Being a home-grown candidate, and one who hailed from the Nuclear Engineering program at MIT, Koen could approach his interview with some hubris. By his recollection, Koen made exactly three promises to the senior faculty members on the search committee that 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 an award from the *Liberal Education* Division of the American Society for Engineering Education. In this article, we focus only on the productive tension between Koen's interests in teaching and research.[9]

In this respect, probably the most important thing to note 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 some expertise. It was through this process, and through information provided by an MIT classmate, that Koen discovered Keller's Personalized System of Instruction.[10]

PSI's Origin in Revolutionary Brazil

At the time that he developed PSI, Keller was the head of the Psychology Department at Columbia University. Between 1928 and 1931, Keller was part of a group of young Turks in Harvard's Psychology Department, headed up by Skinner, who as PhD students had dared to challenge the dominant introspective approach in American psychology. As will be familiar to most every reader of this journal, American academic psychology, while influenced by Freudian psychoanalysis but keeping an arms-length from it, continued to embrace an introspective approach that stood at one end of the spectrum defined by the Cartesian dualism. Riding on the crest of the 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 the entire history 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.*[11]

This was, however, work that was completed 20 to 30 years earlier. During the intervening decades, Keller had built up an experimental laboratory for behaviorism at Columbia, trained a large cadre of graduate students in the methods and doctrine of radical behaviorism, and with the ascendant demand for behaviorism, saw to the placement of his students in various fields of application. Because of Columbia's somewhat unique arrangement with its professional schools and the State, Keller also forged new institutional relationships, such as the arrangement with the New York Psychiatric Institute that enabled his department to extend its work to human subjects with regards to mental health.[12] Yet

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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.

[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] **Ver**

despite these accomplishments, Keller continued to operate in Skinner's shadow, especially as Skinner greater fame and notoriety based on his more speculative work published after his return to Harvard. Still, by 1960 Keller was approaching retirement having built Columbia into one of, if not the country's most significant shops for behaviorist research.[13]

But then in 1961[14], Keller received a rather unusual invitation. During the 1950s and 60s, Brazil was experiencing considerable 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 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—with the promise to deliver "fifty years of progress in five"— ignited the country's imagination, bringing with it a measure of 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. It also called for the modernization of Brazilian universities outside of Brasilia.[15]

Kubitschek's vision of "developmentalism" (*developmentalismo*[16]) was generally upheld by Kubitschek's somewhat more conservative successor, Jânio Quadros. It was under Quadros that the Dean of the Faculty (equivalent to Provost) at one of the leading national universities, the University of Sao Paulo, invited Keller to come to the university to help modernize its Psychology Department and curriculum. Unfortunately for Keller, by the time he arrived the dean had been ousted as a result of what political historians of Brazil regard to have been a political miscalculation: after seven months in office, Quadros tendered a resignation, apparently hoping that this would instead bring him broader powers. The ascent of João Goulart, then Vice President, represented a distinctly leftist turn in the government. This was the era during which the United States was struggling with Fidel Castro, and the U.S. had been caught meddling in this succession. While Brazil's established universities remained somewhat conservative institutions, Keller nevertheless 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.[17]

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, along with a graduate student, Rudolpho Azzi, who also happened to be an experienced teacher. If intellectual conservatism reigned within the context of Harvard University in the 1930s, Latin America's peripheral positioning produced a temporal elision[18] that extended that conservatism two decades longer so that neither behaviorism nor experimental psychology had developed a solid footing at the University of Sao Paulo. As such, Keller could simply replicate his work at Columbia. Drawing on the animal handling capabilities that were already present in an adjoining physiology lab, the group first assembled a modern research laboratory

[13] 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.
[14] **Ver:** date
[15] 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.
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[17] 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)
[18] **Vocab ck**

for experimental psychology built around classic Skinner boxes. The group then used their meager resources to assemble as well a teaching laboratory through the considerable efforts and dedication of Azzi. In the process, the group acquired the capacity to tinker with devices in the same manner that Skinner earned his fame. The teaching laboratory also made it possible to teach an introductory course in psychology built around behaviorist experiments.

There was as well a progressive, gender dimension to the institutional ecology that served to propagate behaviorism's epistemic traditions. Women had made limited inroads into Brazilian academe until this period, but new doors opened up especially under Goulart's regime. As such, one of the other key figures who helped propagate behaviorist approaches in Brazil, (?name[19]) Matos, got her start as an undergraduate, then graduate assistant in Sao Paulo's teaching laboratories.[20]

In any event, the work was deemed a success, and Bori, along with Azzi, were invited in 1963 by the minister of education to take their work to the University of Brasilia in order to establish a new department of psychology there. Keller and his younger colleague at Columbia, Gilroy Sherman[21], were invited to join them as advisors. With the university's doors yet to open, the group had the time and space to plan. It was in the course of designing a new curriculum from scratch 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 principle 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 the principle of reinforcement.[22]

To draw this out for a moment to the analytic level, it should be clear that the political context of Brazil, and the institutional environment of the University of Brasilia, created a space conducive to pedagogic thinking and experimentation. But the epistemic traditions of behaviorism also animated their thinking. In a rather elegant paper entitled, "The Phantom Plateau," written over a decade[23] after his wartime experience, Keller summarized the observations that had allowed him to make a contribution to the wartime training program. Quantitative studies of Morse code training regimes extended back into the 19th century during the early heyday of telegraphy. These studies revealed a classic plateau in the learning curve, where most trainees would fail to reach a standard minimum rate of transmission and reception required for certification. But they would then regain an ascending learning curve as some later point as they continued their training exercises. Those interpreting this curve speculated that students attained a certain cognitive state (switching modes, needed for further learning to occur[24]). However, a number of subsequent experiments had produced instances that exhibited no such plateau. Under a very different training regimen, certain operators could improve their speed on a continuous basis, and with a much faster learning curve.

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[19] **Full name**

[20] 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)

[21] **Ver name**

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

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By carefully analyzing the different training regimes through a behaviorist lens, Keller had ascertained that the problem lay not with the student, but with the curriculum. Training programs that produced the plateau effect did so because of a static training regimen that students quickly mastered, and further improvement had to wait until they discovered a way to learn that was not designed into the regimen. Those that allowed continuous improvement were designed to continuously cultivate new skills, much in the way that a good behaviorist experiment would design a system of contingencies designed to elicit ever more complex behaviors from its subject. The key realization, one that could be incorporated into a programmed learning environment, was that an instructor had to develop concise units with carefully specified learning objectives for continuous learning to become possible. What remained, then, was to specify the reinforcements that would motivate continuous progress.

Since PSI was initially developed for a laboratory based course in experimental psychology, one such reinforcement could be found in the lab itself. After all, 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.'" [25]

Incidentally, those involved with online education and distance learning 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 and technological arrangements.

In any event, as summarized at the start of this article, at the heart of the "Keller Plan," as it was also called, 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

[25] 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.

time on this class as compared to their other classes (this during an era prior to rampant grade inflation). Outside of Brasilia, this would also generate suspicion and envy on the part of other faculty.[26]

The political connotations and social implications of PSI in its final implementation were also quite apparent. The very architecture of Brasilia, with its high-modern Soviet-style housing units, spoke of a grand social experiment, an attempt to promote social harmony and to meliorate the social ills of a highly stratified society. Meanwhile, in the Northeast, Paulo Friere was developing his liberative pedagogies in his efforts to combat adult illiteracy. Keller and his Brazilian colleagues may not have been entirely swayed by Goulart's leftist agenda—Brazilian academic institutions remained elite institutions—but nevertheless PSI was attractive to pursue in this political context since it was potentially democratizing to its core. The underlying idea, if tainted with a twinge of social Darwinist thought found in much of behaviorism was as a whole, was that anyone who put in the time and effort could master any subject, regardless of their social background or innate abilities.[27]

By the same token, the University of Brasilia's leftist leanings brought the work on PSI there to an end. Following the military coup in 1964 that removed Goulart from power, the first two courses in the psychology sequence were allowed to run for two semesters before the entire university was shut down and its faculty dispersed to other institutions. Keller and Sherman had already left for a new position at Arizona State University. Still, having long operated in Skinner's shadow, Keller felt that, quite late in his career, he had finally contributed something truly original to the world of teaching, if not scholarship. At Arizona State, Keller and Sherman continued to utilize and work on PSI, albeit under less ideal circumstances.

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 right off to apply Keller's method to his senior-year nuclear engineering course. On the other hand, not one to do anything haphazardly either, Koen taught the course during his first year of teaching 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.[28]

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[26] 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).

[27] I found no ready source in English on the history of the University of Brasilia or 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.

[28] 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 presumably awarded to students who completed some specified portion of the units.

The College's Bureau of Engineering Teaching, led by James E. Stice, Koen's senior by several years, took an immediate interest in Koen's success. Other instructors, especially in Mechanical Engineering, soon 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.[29] While PSI was utilized in other fields, including physics and (teacher education), in addition to psychology as the field of origin, the broadest circulation of the method occurred in engineering, as noted earlier.[30]

There was a specific logic to PSI's uptake. Ever since Sputnik, there were perpetual concerns about an engineering "manpower" crisis, and although the event, and the associated national response might have been expected to augment engineering enrollments, the dominant emphasis on science resulted in an actual decline in engineering enrollments during the latter half of the 1960s.[31] Although this situation was corrected by the end of the decade,[32] concerns about enrollment remained deeply embedded into the engineering educators' body of practice for educational reform. Meanwhile, one of the major contributing factors to the engineering workforce crisis was retention; at the time, as much as 60%[33] of those who entered engineering left the field before completing their studies. This was largely due to the fact that Engineering was regarded as a tough major with a highly compacted curriculum made "necessary" by the fact that universities continued to try to offer a professional degree in an ever more esoteric discipline in just four (and occasionally five) undergraduate years. Engineering's Cold War turn towards *engineering science,* which did not align well with an incoming student's image of engineering prior to their arrival, exacerbated this problem.

But rather than deal with these issues head on, in a convoluted logic that was itself integral to the engineer's problem solving repertoire, engineering educators determined that improved retention could contribute as much, if not more, to the manpower crisis than enhanced recruitment, and that more "efficient" and "effective" teaching methods would contribute directly to retention by allowing a greater proportion of engineering students to work their way through engineering's difficult content. It was for this reason that the Bureau of Engineering Teaching, which was apparently the first program of its kind among engineering schools, placed such emphasis on teaching effectiveness. From the point of view of effectiveness, any new pedagogic experiment that accelerated learning, and allowed 70% of the students to obtain 'A's, was a welcome development—although the bimodal distribution, and the number of incompletes and withdrawals, was also a concern from the point of view of retention.[34]

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[29] **Res:** Spell out institutions & where? Engineering?

[30] This excitement is captured in this publication, which was said to capture 75% of the papers published so far no 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.

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[34] **Notes:** Needed

More on the national scene, it is also clear that the experimental dimension of PSI contributed to its uptake by engineering educators. The very fact that student progress was measured using unit tests that occurred with high frequency—this was again based on Thorndike's "theory of effect"— meant that PSI generated gobs of data. The unit tests made it possible to document student progress on a quantitative basis. It made possible experiments with course design that aimed nominally to optimize learning outcomes. ASEE's Engineering Research and Methods Division (ERM) was already established several years earlier, but this simply meant that there was a group within ASEE that 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 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. Expressed in terms of epistemic cultures, this was a clear instance of the merger of two epistemic traditions, where the educational research that was already being carried out by engineering educators was augmented by the "technology" of behaviorism, rendered very concretely in this instance through a specific system of programmed instruction.

Although separated by more than a generation, Keller and Koen became fast friends. For Koen, Keller was an inspirational mentor, a renowned authority in behaviorist psychology who was making a new mark in educational psychology. For Keller, Koen was an unexpected and welcome disciple. While the method worked well enough in Psychology, there was a real appeal to applying the method to other fields, especially a field like Engineering where there was a well-defined content and therefore the efficacy of the method could be precisely measured. Insofar as Koen regarded himself to be a nuclear engineer, as opposed to an educational psychologist, Koen was also one of Keller's most faithful disciples. In fact, in a manner not unfamiliar to behaviorism as a whole, there remained an evangelical aspect to PSI that required faithful adherence to the basic tenets described above, a point we will return to below. Keller and Koen would in fact joke about those who would try to "improve" upon the method, only to find much disappointment. They referred to such efforts as being "SLI" or "something-like-it."[35][36]

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. 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 continued to regard this as a necessary evil. However, Thorndike's Theory of Effect operated here 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.[37]

[35] Ibid., interview segment 37.
[36] 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.
[37] Lawrence L. Hoberock, "Personalized Instruction in Mechanical Engineering," *Engineering Education* 60 (March 1971): 506-507.

The Behaviorist Foundations of PSI

There are important subtleties to the psychological basis for PSI that we need to work through before getting to the end of this story.[38] We can 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 behaviorist applications—from suggestive advertising to military interrogation and brainwashing—to realize just how far this line of thinking could go.[39] PSI was also born in the context of Brazil's radical social vision, and yet it was made to serve the much more conservative objectives of a Cold War state, albeit within a field—engineering—that did continue to 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? And what were the reinforcers?

Being a committed behaviorist, Keller offered one answer to this question in *The Keller Plan Handbook,* written along with Gilmour Sherman in 1974. Placed in tabular form, Keller listed the behaviors and reinforcers as follows (offered here in somewhat reduced form):

Behaviors

- **Study behavior,** including "patterns of response to stimulation from textual material" that form the association of ideas.
- **Supportive behaviors,** such as attending school, carrying out instructions, and moving from place to place (within a PSI classroom). Routine acts he must perform weeks on end in connection with every [PSI] course.
- **Collateral behaviors,** such as laboratory exercises and field trips

Reinforcers (for students)[40]

- **Understanding,** "those little explosions of satisfaction or relief from tension that come with understanding"
- **Getting ahead,** unit by unit, within PSI
- **Small work units,** that ensure more frequent reinforcement
- **Immediate grading,** that ensures the immediacy of reinforcement
- **Attention, approval, and even affection,** of the proctor
- **Token reward** of the 'A'[41]

[38] A link to a draft of a longer version of this paper is provided in the final footnote.
[39] Rebecca Lemov, World as Laboratory: Experiments with Mice, Mazes, and Men (New York: Hill and Wang, 2005).
[40] Keller, Sherman, Koen, and other PSI advocates all recognize that reinforcement existed for other actors in the system including the proctors, graduate assistants, instructors, and even administrators.
[41] Note on ref to token economy; credential or credit economy (equally interesting!) e.g. behavior of groveling for an A!

Aside from the fact that there appears to be some conflation between reinforcers and decisions related to the schedule of reinforcement, this offers one answer to the learning behaviors and reinforcements designed into PSI.

A close look at the data generated by PSI courses provides another window into the behaviorist dynamics of a PSI classroom. 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. This suggests that Koen, Keller and their cohort were conditioning their students to love the course at least as much, if not more so, than the knowledge that they acquired. Keller's list from above confirms this point, for all of the behaviors listed are learning behaviors, not, or at least only incidentally (e.g. test taking) the behaviors associated with the demonstration of knowledge.

Further understanding of the underlying dynamics of PSI requires us to delve into the subtleties of Skinnerian behaviorism. The notion of "operant conditioning" upon which Skinner based his reputation represented of course a move away from stimulus-response theory in that it assumed not only that biological organisms were capable of emitting novel behaviors that could be selected through reinforcement, but that operant conditioning produced knowledgeable entities capable of acting upon the world. This was in effect a "knowing self" produced through a long history of encounters with the environment, albeit not the autonomous individual born out of a doctrine of free will. Skinner, along with all other radical behaviorists would have still rejected such a label, criticizing it as an instance of mentalism that carried no explanatory power. Nevertheless, as behaviorists moved from the laboratory to applications, and from animal models to human behavior, they had to contend with the fact that the human behaviors they wished to understand and control resulted from a complex history of interactions that blurred the very boundary between subject and environment. In much of his postwar work on learning and "verbal behaviors," not to mention his social philosophical texts, Skinner resorted to a far more speculative methodology in exploring the wider implications of behaviorism. In doing so, he himself cast his early experimental work as but one window into what remained a complex array of human behaviors, not all of which lent themselves so easily to experimental analysis.[42]

This is not to say that Skinner was able to extract himself from the reductive habits of the Cold War manifestation of the experimental sciences. Skinner himself published a book on the subject of teaching in 1968, with the title, *The Technology of Teaching.* Using back of the envelope calculations, he estimated that some 25,000 reinforcements would be required to cover a basic subject such as arithmetic. Using the mode of logical reasoning that was within his scientific repertoire, Skinner concluded that mechanical aids were the only viable option for repairing the U.S. public education system.[43]

By contrast, Keller and Sherman, and presumably their Brazilian colleagues all recognized that the reinforcements that were designed into PSI could not be about reinforcing discrete learning events. Whether or not they fully recognized this at the time that they developed PSI, as experienced teachers

[42] 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.
[43] B. F. Skinner, *The Technology of Teaching* (New York: Appleton-Century-Crofts, 1968). See p.17 on the 25,000 estimate.

they understood, at least intuitively, that their focus had to be on higher order learning behaviors—how students read a technical text, learning not to procrastinate, knowing when to ask for help. These were all behaviors that the "good" students presumably had already acquired during grade school, which could then be reinforced, remolded, and accentuated within a college environment. And while PSI was cast as a form of individualized instruction, PSI functioned within an elaborate social environment made up of proctors, graduate assistants, and student peers who mentored, modeled, shared, and competed with each other in constituting a robust, peer-based learning environment.

As a nuclear engineer, Koen no doubt remained partially wedded to course content like his mechanical engineering colleague at Austin. Nevertheless, both for he and his behaviorist colleagues, the true goal of PSI was to cultivate sound learning habits and strategies conducive to lifelong learning. As it turns out, this was also something played directly into the priorities of the engineering education community. Given engineering's image as a "frustrated" profession,[44] where professional training remained relegated four, or at most five undergraduate years, there had been a longstanding call for inculcating a spirit of lifelong learning among engineering students.[45] However, few had found an effective way to reduce this to practice.[46] PSI did so. It did so directly because of its behaviorist paradigm. It was not just Koen who recognized this. Among the others to immediately catch the point was the associate dean fo undergraduate studies in UT Austin's College of Engineering.[47]

By 1974, Keller and Sherman had moved from Arizona State, to Western Michigan, to Georgetown University, having been invited to set up a Center for Personalized Instruction in the psychology department there. They understood that there was an opportunity to delve into the psychological foundations of PSI. By that point there were more than 300 papers, articles, and research reports about PSI. On the other hand, most of it was still dedicated towards documenting or assessing the method's efficacy. Sherman, in an essay titled, "PSI Today," directed those who continued to investigate PSI to take the positive findings of PSI now as a given, and "to direct experimentation toward an analysis of the system itself."[48]

Yet if measured by the standards of behaviorist research, Sherman's line of inquiry was disappointing. Instead of citing behaviorist research into the psychological foundations of PSI, the one exemplary study that Sherman cited in his essay was a two year research project, funded by the Alfred P. Sloan Foundation… and carried out by Koen and his colleagues at the University of Texas at Austin. A look at the research questions that the group presented in their proposal demonstrates little attempt to understand the psychological basis of PSI. The questions they asked—about efficacy, grade distribution, retention, faculty development, cost, attrition, and scalability—were all operational questions. Only some of the questions, such as understanding the "procrastination problem" and probing into the depth of understanding touched upon psychological issues, and it was not clear that a group of engineering educators was qualified to do such research.

By 1974, Keller was an emeritus professor and partially retired. However, Sherman was presumably young enough and had the requisite training to carry out such inquiry. While asking why a particular line

[44] Sociology of the professions; professional configuration
[45] Graduate education; 1929 wickenden investigations; 1940/44 Hammond reports; 1955 Grinter Report; 1968 goals report.
[46] Perennial concern for which there is dearth of articles in JEE
[47] **Cit;** associate dean article.
[48] PSI Handbook, p62

of research did *not* happen necessarily entails a high degree of speculation the question seems central to the history of behaviorism and many of its applications. Indeed, in much of the historiography of behaviorism and its applications, there is a curious apologetic in which it is noted that behaviorism has been surviving through its applications. The latent concern that is indexically referenced by this rhetorical trope was the possibility that the theoretical foundations of behaviorism had run up against its limits, irrespective of the apparent efficacy of behaviorism in its various domains of application.

I continue to tread on dangerous terrain, in entering into this speculative domain with no formal training in behaviorism. But it would seem to me that the very notion of efficacy implies that there were ways in which scientific questions could have been posed as a means of probing into this efficacy. In the case of PSI, for instance, if one were willing to break with the observational traditions of experimental psychology, one might utilize ethnographic observation to carry out close studies of the interaction between students and proctors, or the manner in which constructive behaviors for studying and test taking were shared (circulated and reinforced) among the students. Another interesting point of observation might have been to observe student responses at the moment when the latest data about student progress was posted on the class-wide chart, where the differential responses might have provided one clue to understanding the bimodal distribution in grades. Such observations could have produced a much more nuanced list of the behaviors and reinforcers that were operating in a PSI classroom. Moreover, if one were willing to break even further from the epistemic traditions of radical behaviorism, it might be possible to also interview students (and proctors) in assembling these students' own articulations about the motivating machinery of PSI.

There are several possible reasons for why those who studied PSI failed to move in such a direction. First, it is possible that as a laboratory-based discipline, behavioral psychologists who were involved with PSI had a difficult time envisioning PSI as a possible site for field work, where the subjects themselves were defining the social dynamics within the classroom, as opposed to the researcher who designed the experiment. (Keller's list of behaviors and reinforcers were based on his design of PSI and not, it would seem, what he might have observed within the classroom.) Second, once behaviorists brought their ideas into the domain of educational research, and came up with a pedagogic method that was as efficacious as PSI, it may have seemed more important to simply focus on the diffusion of the method. Sherman's criticism of the work notwithstanding, it was precisely the work that validated the efficacy of PSI that contributed most to its circulation. For better and for worse, this also fit within the epistemic traditions of educational research. It is therefore indicative that the two other projects at his Center that Sherman cited in his essay had to do with their publication of the *PSI Newsletter,* and an initiative sponsored jointly by the Carnegie Corporation and a unit of the U.S. Department of Health, Education and Welfare that enabled Sherman's Center to function as an information clearinghouse for PSI workshops, conferences, and publications.[49]

There is then one other possibility. In (Nancy's book title), Campbell demonstrates through the case of behavioral pharmacology that there were behaviorists who could soften their epistemic stance in ways that opened a path for a more integrative view of the mind. Forced to concede that animal models for addiction did not translate well to problems of human (opiate?) addition, behavioral pharmacology was one domain where the behaviorists and the experimental pharmacologists who had previously occupied this domain merged their ideas and methods in creating a hybridized epistemic culture. But radical behaviorism had been pursued with a fervor bordering on the evangelical. Skinner's own convoluted terminology that attempted to suppress any serious consideration of internal mental states spilled over

[49] **Full cit.** p.63.

beyond a methodological commitment to objective description to narrow the scope of observational practices and ideas accessible to many of his strictest adherents. For those bound by the ideology of radical behaviorism, an academic domain such as educational research could offer comfort, for it could offer truths without requiring one to reexamine behaviorism's limitations, even if this meant adding little to what was known within behaviorism itself.

I suspect that all of these forces were at work, and furthermore, that they were not inconsequential. Although this was not the only reason for PSI's downfall, without a fully scientific basis for understanding PSI's efficacy, it remained difficult to control its outcomes. As we shall see in the final section below, this left PSI vulnerable to the personal and administrative costs of the method that ultimately worked to limit its circulation.

The Challenge of Sustaining a Reform Effort

As PSI's implementation spread to faculty members unfamiliar with the psychological foundations of the method, 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."[50] 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 apply 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."[51]

Compounding the difficulties was the disciplinary 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 after some delay, meaning the next class at best. This ran against the principle of 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 preparing for the unit tests, with design exercises that added an additional learning objective to an already overburdened course. When students began falling behind, Sears instituted specified deadlines for every two weeks during the semester.[52] This was a clear instance of

[50] W. Lionel Carver, Jr., "A Realistic Appraisal of First Efforts at Self-paced Instruction," *Engineering Education* 64 (1974): 448-450, 448f.
[51] Ibid., 449.
[52] John T. Sears, "Developing Intellectual Skills in a Self-paced Course," *Engineering Education* 61 (March 1971): 515f; Oral history, interview segment 37.

what Koen and Keller worried about, a compromised, "SLI" (Something-Like-It) implementation of PSI that could only discredit the method.[53]

This example also points, if indirectly, to the broader circumstances surrounding engineering education that 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 background, innate ability, and intrinsic interest of each student.[54] Meanwhile, the "incompletes" that Koen and his colleagues frequently assigned to students as a way of getting around this problem drew unwanted attention from the registrar, who eventually prohibited its use for this purpose. 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 an educational method based on mastery, remained limited.[55] 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.[56]

All in all, PSI flashed across the horizon during a brief time between the late 1960s and early 1970s when student demands, faculty interests, the campus environment, and administrative expectations aligned within the United States to create an institutional context conducive to a real emphasis on teaching—at least across a certain range of institutions. (A map of the engineering schools that published on PSI would in fact offer a good first pass on the schools that took teaching most seriously during this period; as it turns out, this would have included MIT.) But 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 role that engineering research played in enabling a necessary transition to a "high tech" economy. Even at UT Austin, it became less fashionable for engineering faculty to express a strong interest in teaching.

PSI did continue to be employed at UT Austin, having found a solid institutional home there. Nevertheless, the fate of the method there remains indicative of broader, national trends. Given the inflated OPEC oil prices, Texas actually weathered the recessionary period of the 1970s quite well, and

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[53] 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.
[54] Gordon H. Flammer, "Learning as the Constant and Time as the Variable," *Engineering Education* 61 (March 71): 511-514.
[55] 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.
[56] 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 piece.

the state had made major investments in higher education amidst significant economic and demographic growth.[57] 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.[58] A shift towards research was already occurring b the late 1970s—Texas had already reached peak oil production in 1972—but it was this economic crisis that 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 "the oil and gas" of Texas' future economy.[59]

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 to the winning 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.[60]

Koen's own career reflected this turn of events at UT Austin. While Koen was tenured in just three years, it took him an additional eleven years to attain the rank of Full Professor. His *vitae,* while impressive, contained a mixture of research publications in nuclear engineering and publications pertaining to PSI and educational research. As such McKetta's successor, Ernest F. Gloyna, placed him somewhat low on the list of candidates for promotion to Full Professor in 1982. It was only as a result of winning a prestigious teaching award and, most likely, the backlash generated by the university's excessive emphasis on research that Koen received his promotion that year. And this still required the intervention of UT Austin's Vice President for Academic Affairs. While PSI continues to be used to this day at UT Austin in a somewhat modified form (to Koen's chagrin), even Koen grew more cautious about advising young, untenured faculty to invest their time heavily in teaching.[61]

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[57] 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.

[58] 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 tuition increase. 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 tripled to the still very low rate of $12/credit hour, although it should be noted that as done without adequate changes in financial aid, this no doubt produced hardships among low-income residents of the state, including the large and growing Hispanic population in the state. Transcript, Select Committee, Council on Higher Education, 16jan86, side 8, p. 4. SCOHE Records, Box 1, Folder 5.

[59] 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.

[60] "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.

[61] Oral history, interview segments 47 & 72.

Analysis and Conclusion

On the surface, this was an account about the rise and fall of a pedagogic experiment. Beneath it, this story about PSI provided us with an opportunity to delve into the epistemic culture of Skinnerian behaviorism as it entered into, found extension through, and was transformed by its application to education, and specifically engineering education. As noted at the outset, I chose a narrative mode of presentation to allow the many complex elements of this story, from Brazilian political history, to the epistemic practices and institutional commitments of engineering educators, to subtleties in the observational practices and theoretical commitments of radical behaviorists to all have fair play. By the same token, it is appropriate to return to an analytic register in order to extract out what may be some of the most interesting dimensions of this story.

I do so through several analytic points of entry that are related to, but in a way cut crosswise across the analytic frameworks introduced at the outset of this article. Thus, at the start of the article, invoked Longino's pluralist framework for epistemic cultures and their social epistemological origins; I then invoked Campbell (2007) to point to a historic moment when behaviorism had gained ascendance and those involved with its applications were confronting the limitations of their science and the epistemic culture of its origin; I then pointed to the epistemic cultures of engineering education and educational research as an arena for being colonized by, or absorbing elements of radical behaviorism's epistemic culture, and pointed indexically to the history of this encounter that were then described in the narrative. In the conclusion, I will turn instead to the notion of an ecology of knowledge; ethnomethodology and its insights about the practice of educational reform; and engineering professional configuration and how this contributed to the engineering educators' receptivity towards behaviorist ideas. This will hopefully be more than another instance of theory just being separated from narrative evidence. In a complex story such as this, there is a case to be made for the idea that the theoretical significance of the story will remain hard to discern until all of the narrative elements are in place.

First, ecology: It's quite clear that this story unfolds across a rather fantastic geography of time and space. From the struggles over behaviorism at Harvard in the 1930s; to the wartime training exercises developed by Keller[62]; to the developmental vision and its radical manifestation in Brazil and Brasilia; to a young boy in a small town raised by doting parents committed to teaching; to Cold War research at MIT; to State energy policies and the defense industry's workforce requirements in Texas; to university classrooms, the chamber of commerce, and the Governor's office and their response both to the OPEC Oil Crisis and the rising rhetoric of national competitiveness, the rise and fall of this one educational method traversed through a rather complex ecology of knowledge which, for PSI, constituted its intellectual trajectory. In terms of temporal extension and embodiment, it is interesting to think about how Keller embodied a scientific doctrine that spanned different historical eras, and how the politics of oil (including energy and nuclear energy) shaped educational policies in Texas. There was, in this story, even an NSA director who transposed the knowledge and suspicions born of the Cold War era into the emerging era of economic globalization and national competitiveness. The ideas and practices of PSI—the unit tests, eager students meeting with their proctors, the anxious faculty members preparing their study guides and pondering about generalized reinforcement—came into existence, circulated through, and faded within a rather elaborate ecology of knowledge that spanned institutions, disciplines, and continents.

[62] **Ck**, presence in body of narr

Next, ethnomethology: In a sense, it *is* heretical for a historian to be talking about doing ethnomethodology. Ethnomethodology presupposes a close observation of actions about which its is assumed that even the subjects often cannot articulate. (How do you teach?) But perhaps ethnomethodologists have defined their field too narrowly, influenced, if inadvertently, by the symbolic interactionists' early emphasis on work and occupations. From the standpoint of trying, at least, to account for what people do when they say they are pursuing educational reform, there are here at least the shadows, the traces of a body of ordinary, everyday actions that accomplished the result: A future Dean's conversations with a promising young student, and later faculty member; a collegial conversation in a revolutionary setting that produced the spark of an idea about applying behaviorism to the teaching of behaviorism; again, the eager interactions between a student wanting an "A" (and for such complex reasons!) and a proctor seeking to affirm her or his own "smart" and caring identity; and of the teacher turned quasi-behavioral experimentalist observing this encounter with a behaviorist lens. Conference talks, the askance glance between faculty members in the hallway, the excited presentations and the posture adopted by civic boosters and Governor's office staffers who brought MCC to Austin—if these are not immediately present in this account, they are, for what it's worth, possible to imagine as a result of the narrative elements. (It is also more obvious to the historian who has been immersed in the voluminous correspondence and other records in the archives.) These were the constitutive elements of a contiguous body of transformative practice dedicated not to preserving a body of knowledge or occupation, but of culling new ideas (and methods) from different contexts and applying them to the task of educational reform.

In the larger body of work which I am writing with my colleague, Bruce Seely, it is amply evident that engineering educators do possess a body of practice for carrying out educational reform. While I do not have the space to recount this work here, the engineering educators' use of PSI occurred during an era that spanned the gap between earlier reform traditions that included practices such as surveys and field research that drew on the broader practices of social reform and educational reform that were constitutive of the Progressive era; and the more centralized planning that arose, ironically, out of a political discourse of neoliberalism that granted the State and other entities such as ABET Inc. (the accreditation body for engineering) the power to formulate policy positions and to insist on their implementation through administrative practices that are often placed under the rhetorical umbrella of "reengineering" higher education. During this intermediate period, which existed alongside both earlier and later traditions of reform, universities and university faculty had considerable sway, buoyed by truly liberal (versus neoliberal) ideals about higher education that carried over into the 1970s (and for reasons of political timing, had an earlier existence in Brazil). The goal, at least in the United States, was to use these evolving bodies of practice to accomplish the continuous renewal of the engineering profession, again a body of practice not for sustaining a stable occupational definition, but adapting it to meet "changing times and needs."

This then brings us to the question of professional configuration. It will also explain why engineering educators were receptive to pedagogic experimentation and, at least partly, the epistemic culture of an alien field such as radical behaviorism during the period under study: While many continue to speak of engineering as a "frustrated" profession, sociologists of the occupations and professions have long since abandoned the view that medicine and law are ideal-typical professions. Medicine and law are, in many respects, *ideal-atypical* professions that haunt the conduct of other professions. What is needed is an effort to understand the distinct configuration of each profession, expressed, in general, in relational terms (e.g. relationship to clients, relationship to the state that confers authority and responsibility, relationship to other occupations, etc…). But while this is generally recognized, little has been done to map the distinct professional configurations that exist beyond the "true" professions.

Those who study engineering are quite familiar with the fact that engineering is fragmented along disciplinary lines, and that it is also characterized by the permeable boundary that exists between engineering and management. What is less well known is the fact that the strength of the U.S. land grant institutions and their ideological commitment to augmenting the national engineering workforce had allowed engineering educators, especially within the public universities (but through an influence extending into private engineering colleges as well), to serve as a centripetal influence in steering engineering education and curricula in the direction of regional and national economic needs. Within those institutions and during those time periods during which there was an interest in teaching, educators served as important agents for transforming engineering to serve "changing times and needs," as represented, for example, by the formation of the Bureau of Engineering Teaching at UT Austin. And despite the shortcomings that are often attributed to educational research, there remained sufficient contiguity in the practices of engineering research and educational research for someone like Koen to pick up a novel method, and to apply it in the name of a reform he was asked to implement.

However, this account also made evident the limits of such instrumental encounters. For engineers, even Koen, there still remained a boundary between their teaching and the research they did in the field in which they were trained, enough so that none were ready to make the epistemic shift necessary to recast their work in PSI as behaviorist research. Meanwhile, I have offered my speculations as to why the behaviorists who were associated with PSI failed to turn PSI into a site for more fundamental inquiries into learning. Given the current interest in online education and distance learning, and the obvious relevance not only of PSI but Skinnerian behaviorism as a whole to these new modes of instructional delivery,[63] this may be a decision worth revisiting.

[63] Note in notes that this has been noted.