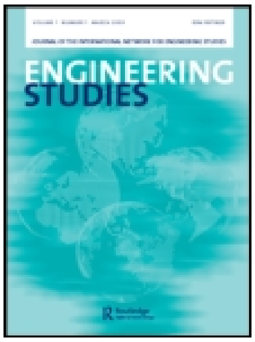

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"Suppose the World Were Already Lost": Worst Case Design and the Engineering Imagination at Harvey Mudd College

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This article investigates the origins, goals, and outcomes of modern design-based engineering education in the USA by analyzing an interdisciplinary project that asked students to collaboratively prepare for nuclear holocaust. Project NOAH, conducted at Harvey Mudd College, a pioneering institution in student-centered engineering education, generated national publicity and established an approach to design pedagogy that was observed, appropriated, and developed in parallel elsewhere. In addition to an exploration of the Cold War transformations of the meaning of design in US engineering education, Project NOAH offers three insights for today's efforts to cultivate students' design imagination. First, it reveals how the project's creators conceived of interdisciplinary problem-based design education as "good" engineering amid competing institutional, pedagogical, and societal contestations about the future of the profession. Second, it highlights the persistence of individual and collective tensions encountered by educators and students engaged in "real world" design curricula. Third, the project's directive to preserve culture in the wake of a human-made "worst case" disaster illuminates the knotted relationship between dominant practices of American engineering, the reformers who seek to alter them, and the nature of technology itself.

Keywords: creativity; imagination; design; interdisciplinarity; worst cases; Harvey Mudd College; nuclear war; engineering education; scientifiction; systems engineering; Warren Wilson; problem-based learning; disaster

The Swiss Family Robinson—that's what we'll call ourselves. (Kurt Vonnegut, *Cat's Cradle*)[1]

Introduction

Team C was afraid of the cockroaches. They will "flourish in the absence of their natural warm blooded enemies," the group reported, and would be a problem when returning to the surface. Team B envisioned 300,000 dinners. "Food substitutes such as algae could be used," they posited, but "people used to regular food would reject the substitute and possibly become mentally disturbed." Team A got to the heart of the matter: "the selection of 250 from 170 million people will undoubtedly be a hard task, for unlike technology, there are no exact measurements that can be determined for a human being."[2] Such were the burdens of mid-century engineering students as they learned to invent the future.

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[1]Vonnegut, *Cat's Cradle*, 1963, p. 276.

[2]Group A, *Project NOAH*, 1961, p. 36; Group B, *Project NOAH*, 1961, p. 59; Group C, *Project NOAH*, 1961, p. 4.

In 1961, Harvey Mudd College (HMC), the first new engineering school in the USA in nearly three decades, finally had its freshman design program up-and-running. The school had been inaugurated three years prior with an ambitious plan to educate engineers as liberal interdisciplinarians. Comparing itself to experimental colleges of the 1930s, a third of the curriculum would be devoted to humanities so students could “assume technical responsibility with an understanding of the relation of technology to the rest of society.”[3]

As the concrete-block campus designed by architect Edward Durell Stone was constructed around them, the eighty-three members of the class of 1964 received their instructions for Project NOAH[4] from Warren E. Wilson, HMC’s first chairman of engineering:

> Responsible men throughout the world are working to insure that nuclear war never takes place. Still the possibility remains, however remote, of a cataclysm which could eliminate human life as we know it. We therefore propose the question, “What can modern technology do to provide for the survival of human culture?” You are requested to study the feasibility of designing a system to assure the survival of a nucleus of human civilization and, if you decide that such a system is feasible, to present a preliminary design for it.[5]

Split into three teams, the students held elections for project managers; interviewed physicists, anthropologists, and local milkmen; and questioned the nature of humanity. Given highest national priority for acquisition of manpower and materials, teams were required to assure their colony was habitable for at least a century, could accommodate a minimum of a 100 residents with a 1:1 ratio of males and females, and would be self-sustaining. At semester’s end, the reports, which averaged 125 pages in length, were graded by faculty across HMC; evaluated for plausibility by the RAND Corporation; and lauded for their creativity in an Associated Press story reprinted in newspapers from the *Lubbock Avalanche-Journal* to the *New York Times*.[6]

Beyond the sheer attraction of peering over the shoulders of engineering students as they confronted technologically induced annihilation and then plotted salvation, Project NOAH offers a powerful case study for illuminating the meaning of “design” in postwar engineering in the USA and its relevance for engineering education today.

Project NOAH’s motivations, execution, and reception showcases the rise of pedagogical techniques for instilling a hybrid form of systems engineering—explicitly interdisciplinary, human-centered, and problem-based—that attempted to merge the civilian, market–oriented practices of the mainstream of pre-World-War-II engineering design with newer forms of computational engineering sciences. Scientization and its discontents is a major organizing theme of scholarship in the history of engineering in the Cold War era, which tends to present a competing binary between design education as traditionalist, practical manufacturing, and engineering science as the emergent modality of military-industrial-academic research.[7] This conflict model is informed by and informs philosophical and social studies of engineering by scholars such as Larry Buchiarelli, Eugene Ferguson, and Walter Vincenti,

[3]Harvey Mudd College, *Bulletin, 1958–1959*, 1958.

[4]Though its capital letters evoked the era’s penchant for acronyms, “NOAH” was not one.

[5]Conference on Freshman System Engineering, *A Comprehensive Survey of Freshman Engineering at Harvey Mudd College*, 1964, p. 44.

[6]Associated Press, “Project NOAH,” 1961, p. 80; Associated Press, “83 Collegians on Coast Design a Survival Colony to Keep Civilization Alive for a Century,” 1961, p. 117.

[7]Layton, “American Ideologies of Science and Engineering,” 1976; Kline, “Construing ‘Technology’ as ‘Applied Science,”’ 1995; Seely, “The Other Re-engineering of Engineering Education,” 1999.

who seek to define design as the essence of engineering distinct from the sciences.[8] Project NOAH provides a window into the tension between "design" and "science" as experienced by educators who attempted to synthesize the two domains at the moment when arguments about their differences were worked out in technical practice.

Project NOAH additionally sheds light on design as the terrain for interdisciplinary exchanges that connect engineering to a range of other professions from architecture to sociology.[9] These are issues of relevance to a growing body of literature in science and technology studies (STS) and design studies, particularly to recent historical accounts of the "design methods" movement that emerged amid the intersections of engineering, industrial design, architecture, and urban planning between the 1950s and 1970s.[10] The common assumption in this multi-disciplinary domain was that the making of things—whether transit systems, spacecraft, or solar cookers—had become too complex for existing techniques which failed to account for interactions between systems and users. Problem solving in this environment required collaborative teams and new vision. But, from there, methods diverged amid squabbles over who was to assume the identity of the designer. Moreover, educators committed to an encompassing philosophy of design struggled to implement curricula that achieved meaningful engagement of students and colleagues across academic units and individual plans of study.

Finally, by inviting students to stage a dialog between disaster and redemption in order to cultivate their design imagination, Project NOAH makes explicit the connections between the norms of the American engineering profession during the Cold War era, the ambitions of the reformers who saw design education as a progressive alternative, and the simultaneously disruptive and generative nature of technology itself. I use a combination of two overlapping theoretical lenses—*scientifiction* and *worst case* thinking—to make visible these linkages. The notion of scientifiction, developed by Bruno Latour in his study of the transit system Aramis, identifies an underlying structural similarity between narrative fiction and even the most mundane of engineering projects.[11] The concept of "worst cases," advanced by sociologist Lee Clarke, points to the value of "possiblistic" analysis as a tool for exploring the causes of disasters from 9/11 to Hurricane Katrina and potentially mitigating future system failures. These lenses share a common emphasis on the role of the imaginary in expert thinking at the core of Project NOAH's pedagogical goals.

Project NOAH thus offers a set of textual artifacts from which to read the politics of design in engineering education through the case of a novel postwar institution as it engaged with a national network of educators and practitioners. One that, while premised on eschatological vision, was designed to develop engineers for the improvement of everyday and extreme living alike.

Movers of Worlds

It is difficult to convey the excitement felt by HMC's founders, who saw themselves at the forefront of a national transformation in engineering education, without being accused of

[8]Bucciarelli, *Designing Engineers*, 1994; Ferguson, *Engineering and the Mind's Eye*, 1992; Vincenti, *What Engineers Know and How They Know It*, 1990.

[9]See, e.g. Nieusma and Riley, "Designs on Development," 2010; Tatum, "The Challenge of Responsible Design," 2004; Irani, et al., "Postcolonial Computing," 2010; Light, "Taking Games Seriously," 2008; Anker, *From Bauhaus to Ecohouse*, 2010, pp. 68–82.

[10]E.g. Jones and Thornley, *Conference on Design Methods*, 1963; Upitis, "Nature Normative," 2008; Llach, "Builders of the Vision," 2012.

[11]Latour, *Aramis*, 1996.

nostalgia. Made possible by the greater Los Angeles military-industrial economy, HMC was located fifty miles westward in Claremont, the Golden State's take on a sleepy New England village. Faculty were lured from senior positions nationwide by high salaries, mountain views, collaborative opportunity with HMC's sister institutions, and the promise of a blank slate. HMC's first president Joseph Platt was an MIT Radiation Lab alumnus formerly of the University of Rochester where he had constructed a synchrocyclotron and directed the physics department. Sharing faith in the link between moral and technological progress, many on the faculty had Quaker roots, such as mathematician Robert James who arrived from Berkeley after refusing to sign an Oath of Loyalty.

The promise of liberal technological training was especially strong for HMC's humanists, who sang the praises of science, technology, and its makers as agents of democratic progress. After serving on the college's external planning committee, historian of technology John Rae left MIT to join the faculty. William Davenport, the chairman of HMC's English department, formerly of the University of Southern California, offered the most effusive interpretation of the college's ambition. "Tomorrow's engineer," he wrote in a 1967 humanities textbook for engineers,

> will have the fine attitude of the creative man … will need more than knowledge of fundamentals; he must be flexible, fluent and original …. The modern Renaissance finds him still the "artist and empiric," but also the psychologist, the sociologist, the economist and in many respects the mover of worlds.[12]

HMC's founders met in 1958 to map out a curriculum consisting of three components in equal balance: (1) education in the physical sciences matching the nation's top universities in rigor; (2) exploration in the liberal arts on par with peers such as Amherst, Pomona, and Swarthmore; and (3) a unique "system engineering" curriculum that would produce problem solving generalists rather than civil, electrical, or mechanical engineers. A strong base in science and mathematics was essential to modern engineering, according to Platt and the trustees, but HMC did not want to produce applied scientists. The humanities and social sciences would foster "intellectual penetration" "analytical ability" and "values," to be deployed in engineering design (Fig. 1).

As HMC's faculty and trustees began teaching the first class of forty-eight students, they faced a problem—*they lacked an engineering faculty*. It had been relatively easy for president Platt to find top-flight chemists, humanists, mathematicians, physicists, and social scientists committed to HMC's mission. Finding a chairman for the engineering department who balanced a distinguished career with HMC's holistic goals proved more challenging. Platt spoke informally to 130 candidates, interviewed thirty, and invited ten to campus before identifying Warren E. Wilson as the first chairman of engineering.[13]

The difficulty of establishing an engineering program was a local manifestation of a national debate over the future of the profession. As a consequence of World War II and the rise of the Cold War state, there were nearly a million engineers in the USA by 1960, a four-fold increase from 1945. The aerospace industry, which had operated as a craft enterprise prior to the war, had grown to produce some of the world's largest technological corporations (which were deeply entangled with government agencies) that employed over two million Americans. Engineers increasingly required graduate training to perform specialized operations on large teams. This dramatic growth altered the practices and identity

[12] Davenport and Rosenthal, *Engineering*, 1967, quoted in Bright and Dym, "General Engineering at Harvey Mudd," 2004.
[13] Platt, *Harvey Mudd College*, 1994, pp. 110–111.

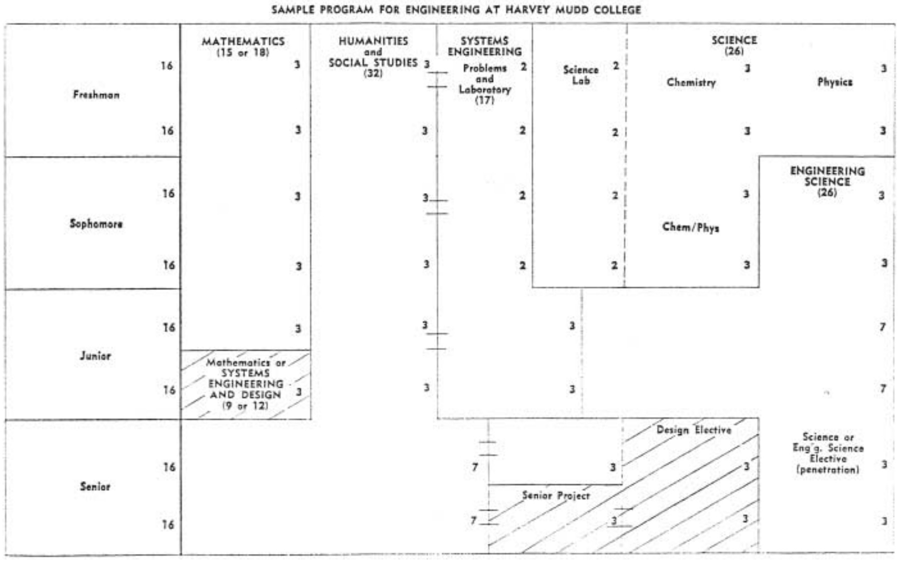

Figure 1. Training holistic engineers—HMC's founding curriculum.
Source: Harvey Mudd College, *Curriculum Study*, 1958, p. 35. *Courtesy*: Special collections, Honnold/Mudd Library of the Claremont Colleges.

of engineers but generated significant dilemmas, among them the simultaneous embrace by policymakers and educators of scientific research with a competing desire to maintain professional identifications distinct from that of the scientist, a tension exacerbated by the diversification and specialization of engineering manpower.[14]

Debates about the proper characteristics of modern engineering were especially heated among educators. Reformers sought to modernize a profession steeped in practical methods such as engineering graphics and machine shop training. Advocates of the engineering sciences argued that the physical sciences and calculus should constitute the foundation of engineering. Many educators, especially in land-grant colleges and vocational schools that had grown into regional universities, resisted the trend. The fault lines came to the fore in response to the influential 1955 Report on Evaluation of Engineering Education produced by the American Society for Engineering Education. Its primary author, University of Florida professor Linton Grinter, called for an overhaul of the engineering curriculum toward a foundation in science and advanced mathematics.[15]

Few educators were better positioned to navigate the countervailing pressures of American engineering as well as Warren E. Wilson. He came to HMC at the end of a journeyman's climb up the administrative ranks. His career straddled the divide between industry-oriented training and the engineering sciences, forging a path that would be difficult to emulate as the engineering professoriate academicized. He received his BS in civil engineering from Lehigh in 1928 and worked in industry before earning a masters from Cornell. He then headed west as an instructor at the South Dakota School of Mines. He was briefly assistant professor of sanitary engineering at Tulane, but returned to graduate

[14]Wisnioski, *Engineers for Change*, 2012, pp. 15–39.
[15]Grinter, "Summary of the Report on Evaluation of Engineering Education," 1955; Wisnioski, "Liberal Education Has Failed," 2009, pp. 753–764.

school—at Caltech for a masters in mechanical engineering in 1939, and to the University of Iowa for a PhD in hydrodynamics in 1940. He subsequently was appointed head of the Colorado School of Mines's department of mechanics; left in 1941 to chair the department of fluid mechanics at the Armour Research Foundation; and, in 1943, became president of the South Dakota School of Mines, where he spent a decade modernizing the curriculum and enhancing the scientific content of the vocational school. Throughout his career he worked as a consultant for the mining industry, where he developed a theory of the behavior of particulate matter in fluid flow for mineral processing applications.[16] In the 1940s and 1950s, he placed special emphasis on bringing research to design. His book *Positive Displacement Pumps and Fluid Motors* positioned his work as composed of "scientifically correct" and "rigorous" solutions derived from "basic principles" as opposed to "a design handbook," which was more typical for such a subject.[17] He left Rapid City in 1953 to serve as director of engineering and science at the US Office of Ordinance Research on the campus of Duke University. In 1954, he became Westinghouse Professor of Engineering Education at Penn State and was tasked to study national trends in engineering education, surveying 800 educators on their attitudes about curricular change in immediate response to the Grinter Report.[18] In 1956, he again was on the move, accepting the position of dean and then president at Brooklyn's Pratt Institute. Three years later, Wilson came to HMC with a recommendation from Grinter himself. Incidentally, president Platt learned while interviewing Wilson that he had been under consideration for Platt's own job.[19]

Experience spanning the elite and parochial spectrum of the profession shaped Wilson's conception of who engineers should be and what they should know. Engineers, he argued, were above all *designers*. His vision of the design engineer united the elements of civilian engineering oriented toward low-cost production with the research-focused "military-aerospace" market oriented toward the creation of novel, complex systems reliant on computational analysis and electronic feedback.[20] In 1965, he published the textbook *Concepts of Engineering System Design* for freshman engineering students, which described system engineering as "creative design in the broadest sense." Creativity dispelled the organization man image and distinguished engineers from scientists and technicians. It also contributed to visions of professional colonization in which the engineer's problem-solving techniques could offer universal applicability. "The concept of system engineering," Wilson wrote in his 1965 textbook, "is new and is the most important recent achievement of engineering, not only as a technique of engineering design and creative professional effort in our technology but also as a discipline with the potential of many applications in other fields." Its range, he claimed, was "essentially limitless."[21]

Wilson was part of an important and understudied group of reformers who blended "system engineering" and "engineering design" to walk a line between engineering science and more traditional modes of engineering. Though historians of technology and historians of the Cold War have highlighted the significance of systems analysis in postwar America, existing interpretations tend to paint a homogenous picture of technocratic rationality achieved through computational techniques. But the overlapping domains of design and systems engineering contained a variety of motivations and techniques with differing

[16]Wilson, "Pipe-Line Flow of Solids in Suspension," 1942; Wilson, "Launder Design," 1943.
[17]Wilson, *Positive Displacement Pumps and Fluid Motors*, 1950, p. vi.
[18]Wilson, *Opinions of Engineering Educators*, 1956, p. 53.
[19]Platt, *Harvey Mudd College*, 1994, p. 131.
[20]Wilson, *Concepts of Engineering System Design*, 1965, pp. 4–5.
[21]Wilson, *Concepts of Engineering System Design*, 1965, pp. 9–10.

conceptions of the expert's role in problem solving.[22] Wilson participated in the establishment of a network of likeminded design advocates whose scope and goals can be gleaned from the 1962 Conference on Engineering Design Education. The event was organized by Allen B. Rosenstein (director of UCLA's Ford Foundation-funded Educational Development Program), Morris Asimow (author of one of the most widely adapted new textbooks on systems design), and design faculty from Stanford, Berkeley, Purdue, MIT, Case Institute of Technology, and Carnegie Institute of Technology.[23] This network of design engineers were in the main mid-career faculty with hybrid experiences in industry and academia that resembled Wilson's; that is, they had PhDs and worked in centers of engineering science but they preserved a notion of the engineer as a multifaceted professional and manager, and had received their initial training in industrial-era design engineering. The UCLA event and others like it in the USA and Britain also demonstrated the openness of design engineering to methods from architecture, computer science, industrial design, and the social sciences, manifest in participants such as Stanford's Robert H. McKim, author of the influential (and possibly lysergic acid diethylamide inspired) *Experiences in Visual Thinking* and the famed industrial designer Henry Dreyfuss.[24] Through these connections, the systems design engineers were important players in the interdisciplinary space that became know as the "design methods" or "design research" movement. These engineers (and the broader design methods movement) emphasized the case study method of problem-based learning through systematic analysis that drew upon engineering graphics, computational techniques, and engineering sciences alike as any particular case dictated.

When Wilson arrived in Claremont in 1959, he set to work convincing the scientists and humanists at HMC to integrate all dimensions of a student's coursework toward "comprehensive system design."[25] The same tensions that existed nationally shaped local disagreements about how to proceed with HMC's engineering program. Wilson, however, had the advantage of being able to convince his small cohort of colleagues individually and to use his ambitious students as agents in the process. He helped HMC implement a two-semester freshman sequence. The first semester dispensed with traditional introductions to engineering drawing, which Wilson called the "work of the technician," and instead gave weekly lectures with all students in a year's class, held small group discussions, assigned calculus programming exercises on the campus's IBM 1620, and had students prepare designs for common subsystems such as devices for sensing temperature and controlling the flow of gas in a pipeline. The second semester was dedicated to a collaborative open-ended problem meant to draw on every facet of the problem that HMC's faculty could offer.

Project NOAH, in sum, was conceived of at a transitional moment in engineering education in the USA. For over a decade, professional leaders, accrediting bodies, and a new generation of engineering educators had worked to make the engineering sciences the standard for engineering education. At the same time, a host of design advocates were beginning to resurrect and redefine design in a way that did not throw the baby out with the bathwater.

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[22]This variety persists in contemporary systems engineering. Akeel and Bell, "Discourses of Systems Engineering," 2013.

[23]University of California, Los Angeles, *Proceedings of the Second Conference on Engineering Design Education*, 1962. There were a number of new design textbooks at this moment, e.g. Goode and Machol, *System Engineering*, 1957; Hall, *A Methodology for Systems Engineering*, 1962; Asimow, *Introduction to Design*, 1962.

[24]McKim, *Experiences in Visual Thinking*, 1972. On the LSD connections see Markoff, *What the Dormouse Said*, 2005. Dreyfuss is most famous for his notion of "human factors," see, e.g. Dreyfuss, *Designing for People*, 1955.

[25]Wilson, "Engineering Problems at Harvey Mudd College," 1963.

HMC's *raison d'être* was to make engineers who, while scientifically expert, were societal leaders with interdisciplinary training responsible for designing technological systems to manage an uncertain future.

The Design Imagination

What does it say that teaching engineers to become professionals in society's service began with nuclear holocaust and the granting of biblical power to its pupils? In a milieu that gave us *On Thermonuclear War* and *Failsafe*, we might emphasize in Project NOAH the ubiquitous presence and specific inculcation of what Paul Boyer calls "nuclear consciousness" in the newest ranks of the military-industrial apparatus.[26] Or we might find parallels to Sharon Ghamari-Tabrizi's description of Homeland Security scenarios as "lethal fantasy" in which students engaged in "the contemplation of nightmares rather than identifiable social, political, and climatological realities."[27] Likewise, we could explore how Project NOAH's Old Testament overtones resonate with David Noble's analysis of the role of religious vision in technological production.[28] To fully understand the pedagogical intentions of Project NOAH, however, we need also look beyond death, paranoia, and megalomania to focus on the role of the imaginary HMC's curriculum was designed to inspire.

Project NOAH's salient feature was its immateriality. Though it anticipated the conclusion to *Dr. Strangelove*, the faculty at HMC did not undertake the assignment to prepare students for an application they believed the future engineers would encounter in their lifetimes. It might seem counterintuitive to train engineers in this manner since their distinguishing skill set was supposed to be the ability to solve real world problems. Why not instead use historical case studies of archetypical design solutions or of famous innovations?[29] Alternatively, Wilson could have had students collaborate on local community needs. Indeed, these were commonly practiced approaches to engineering design.

By cultivating speculative creativity and global-scale thinking at the expense of immediate applicability, Project NOAH introduced HMC students to a quality of engineering that Bruno Latour has described as scientifiction. Technological projects, he argues, are inherently "fictions" and engineers are "novelists."[30] It is this imaginative process that separates analysis in design from analysis in science. Engineers make projects into objects through a complex process of translating material resources, technical knowledge, and the agendas and needs of multiple stakeholders into coherent narratives. They do so, moreover, in an environment in which these diverse actors and agents compete for that narrative to incorporate their point of view. The specific outcome of a project thus is highly dependent on how its designers contextualize (or fail to contextualize) its various human and non-human elements.[31]

Engineering educators in the 1950s and 1960s increasingly saw problems deliberately resembling science fiction as catalysts for instilling this imaginative quality of design in

[26]Boyer, *By the Bomb's Early Light*, 1994.
[27]Ghamari-Tabrizi, "Lethal Fantasies," 2006, p. 22.
[28]Noble, *The Religion of Technology*, 1997. Along these lines, it is notable that Project NOAH was executed the same year Walter Miller, Jr.'s religious exploration of humankind's technological condition *Canticle for Liebowitz* won science fiction's Hugo Award. Miller, *A Canticle for Liebowitz*, 1959.
[29]See, for example, the widely distributed curricular case studies of UCLA's Educational Development Program (EDP), such as Educational Development Program, "The Wright Brothers' Airplane," 1964.
[30]Latour, Aramis, 1996, pp. 23–24
[31]Latour, *Aramis*, 1996, pp. 133–134, 137–138.

students. Design advocates lamented that students entered college predisposed to rigid, unambiguous situations or that they adopted the disposition from their peers. This was exacerbated by increased emphasis on analytical problem solving in engineering associated with the physical sciences. Mechanical engineering professor John Arnold at MIT and Stanford, for example, recognized the frame-breaking power of speculation. Taking students outside their world trained the mind's eye to address fantastic problems so that students could solve real ones with new vision. In Project Arcturus IV, for example, students designed vehicles for a race of aliens evolved from birds with helium filled bones, three eyes, and X-ray vision on a planet with eleven times earth's gravity in a culture with nuclear power but no electronics. Student solutions included the "eggomobile," designed to sell by appealing to the security of the egg from which the Arcturians had been born.[32]

Aliens from distant planets were one thing. Preparing for nuclear holocaust was an exercise of the imaginary that forced confrontation with deeper truths about engineering practice.

"Suppose the world were already lost," the character Edward Hobson, Sr. posits in Richard Powers's *Prisoner's Dilemma*, a meditation on the alteration of the human imaginary brought about by the atomic age.[33] In the novel, Powers juxtaposes the Trinity test and Walt Disney through the life of Hobson, who seeks to build a model of a perfect town with an alternative history that erases the tragedies of the twentieth century.[34] What, Powers asks, can be learned about the human condition in attempts to build a world picture that is both hyper-realistic and incorruptible by the realities of the Cold War arms race?

Speculations of this sort have an academic champion in the sociologist Lee Clarke's advocacy for worst case thinking as a means of preparing for future disasters and interrogating the power dynamics and assumptions behind the design of existing technological systems. In this possibilistic mode of inquiry, the analyst is confronted not with calculations of likelihood (typically used to justify the construction of risky technological systems), but rather "imagination stretch" that can drive progressive innovation. Speculative thinking about socio-technical systems is diagnostic, Clarke argues, revealing insights about "how society works, and fails to work … about the imagination, about politics, and about the wielding of power." This analysis is especially relevant when applied to the domain of engineering design. Worst cases live in the mind, he writes, and "inherently involve people's considerations of the value of other people, their sense of mastery, or their feelings of power." Such imaginaries, however, are not universal or purely individualistic, thus "looking at ideas about worst cases is an opportunity to look at *social imaginations*."[35]

The complementary concepts of scientifiction and worst case thinking help to reconstruct Wilson's intentions and to interpret the results of his experiment. For one, they highlight the dialectic between hyper-reality and fantasy. In summarizing the results of Project NOAH, Wilson argued that: "stimulation of creative effort and interest in engineering are best obtained by bold strokes in setting design tasks rather than by insistence upon meticulous attention to trivial details of techniques and skills such as draftsmanship."[36] But this was a misreading of the actual reports the NOAH teams generated, which reinforced a powerful synthesis of bold fictional strokes with meticulous attention to such "trivial" details.

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[32] Pandora, "Redesigning the Engineering Mind," 2006.
[33] Powers, *Prisoners Dilemma*, 1988, p. 155.
[34] Powers was Latour's muse for the concept of scientifiction. Latour, *Aramis*, 1996, pp. vii–x.
[35] Clarke, *Worst Cases*, 2006, pp. ix, 5, 21, 130, 144–146.
[36] Wilson, "Engineering Problems at Harvey Mudd College," 1963, p. 463.

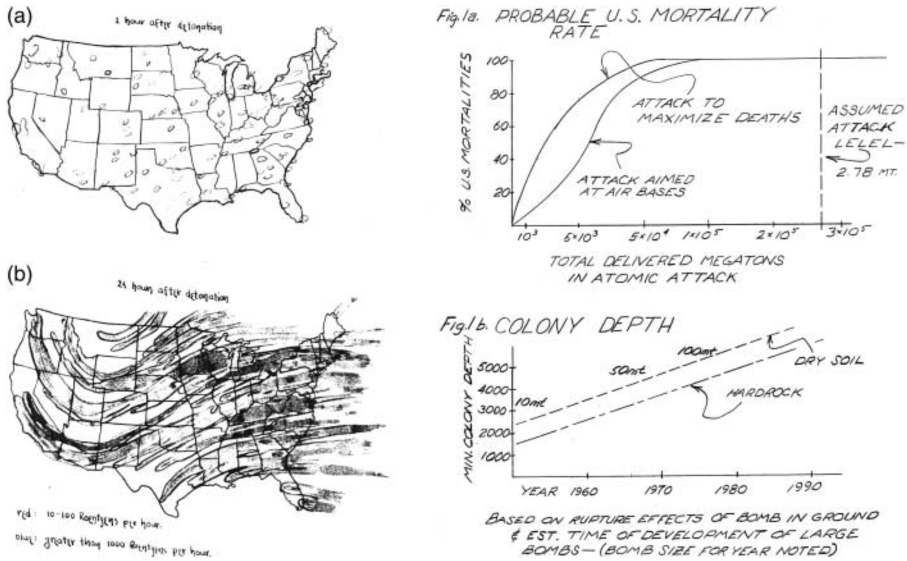

Figure 2. (a–b) Feasibility studies—learning about nuclear expertise and its critics.
Sources: Group B, *Project NOAH*, 1961, p. 77; Group C, *Project NOAH*, 1961, p. 5. *Courtesy*: Special collections, Honnold/Mudd Library of the Claremont Colleges.

When HMC students accepted the worst there was awareness of unspeakable tragedy, followed by liberation. Freed from the constraints of everyday life, they set to work on defining the constraints of extreme conditions. How many bombs would kill us all? Where would survivors be safest? Teams analyzed the physics, biology, and political science of fallout. For data they turned to places we would expect such as Edward Teller's *Our Nuclear Future* and *Readers Digest* articles titled "What will radioactivity do to our children?" But the largest source of public data about nuclear weapons in their reports—indeed in political discourse about nuclear weapons more broadly—came from the antinuclear movement. Team B, for example, reproduced its fallout map from Linus Pauling's *No More War!* and found authority in the *Bulletin of the Atomic Scientists* (Fig. 2).[37] These served as informal exercises in engineering drawing and the visual display of quantitative information, but also introduced students to the role of technical information in policy debates. Team A, for instance, concluded the worst-case scenario probably did not warrant their bunker. With their initial rationale rendered moot, they nonetheless redefined the problem as the search for a cultural system to eliminate humanity's original sin.[38]

After the shock of an assignment premised on mass death wore off, the pleasures of rebuilding mankind set in as students reveled in the details of their design solutions. One team holed up under Snow Valley Peak, Nevada to take advantage of Lake Tahoe for water and power; another in a salt mine in Louisiana; and the last in Australia. All three planned nuclear reactors. Students consulted with dining hall supervisors and chief engineers at General Electric. Emulating their project's namesake, they saved animals, but only those they could harvest. They mapped out gymnasiums, hospitals, and research labs. Total costs ranged from 85 to 360 million dollars (Fig. 3).

[37] Group B, *Project NOAH*, 1961, pp. 142–143.
[38] Group A, *Project NOAH*, 1961, pp. 1–3.

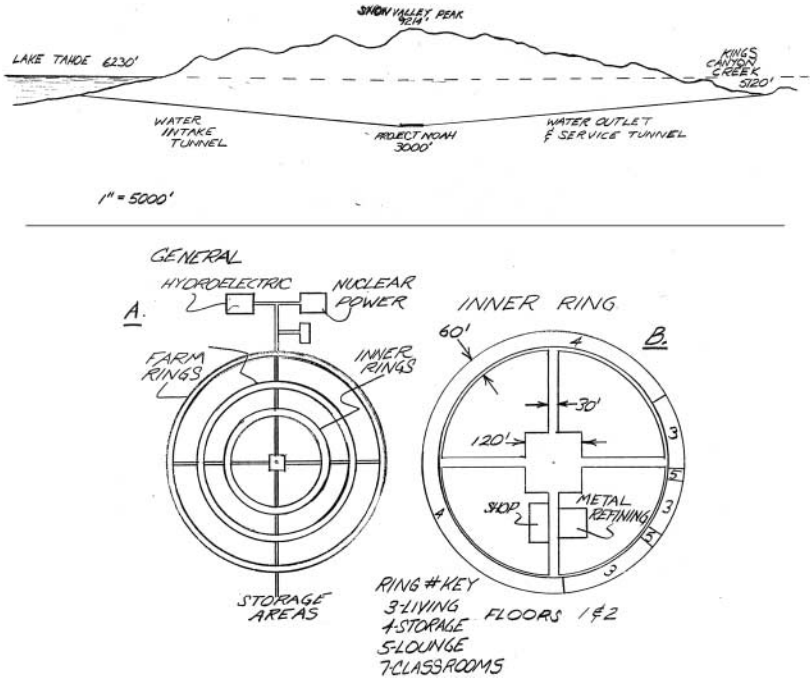

Figure 3. Colony siting and structure—informal exercises in engineering drawing.
Source: Group C, *Project NOAH*, 1961, pp. 13, 73. *Courtesy*: Special collections, Honnold/Mudd Library of the Claremont Colleges.

The speculative quality of Project NOAH offered students a practice-based introduction to comprehensive systems design. They were required to conduct background research, to use scientific principles to measure fallout, to explore energy technologies to power their colonies, to meet a budget, to accurately draw their underground lairs to scale, to investigate human physiology, to interview domain experts, even to learn about the competing arguments of cold war policy. Students had to work collaboratively to decide what was relevant and correct. Just as they would encounter in the solution of real world problems, there was no "one best" answer to these questions, but there were acceptable and unacceptable solutions. Project NOAH's genius, however, was its focus on culture.

Culture Machines

"Culture" lacks solid definition and on closer examination melts into air. But culture also boils the blood. It instills patriotism. It tells us all that is great and good about civilization. By asking students to preserve it, Wilson forced confrontation with the slipperiness of design assumptions and with engineering's normative nature. While engineers often claim that their work is strictly objective, engineering is by definition concerned with building social vision into material reality. Project NOAH forced the issue in starkest terms by asking: *Who are we? What do we value?* The students' scientifictions could not avoid a political motif.

In his systems engineering textbook, Wilson instructed that the designer's task was to optimize values but that the definition of values and morals preceded design and were the responsibility of citizen or client.[39] In Project NOAH, however, students were both client and designer. As such, they revealed a spectrum of cultural and political assumptions about worst and best cases (or at least those they imagined their evaluators wanted to hear) held by engineering students on the quiet side of the baby boom.

For Team A the apocalypse was an opportunity for progressive improvement. They concluded that no colony, no matter how large, could preserve existing culture. Moreover, the world's artwork, books, films, and material artifacts amounted to only a record "of something that has ceased to exist." They thus compromised on a narrower view of cultural achievement. The nation's brightest would run the colony; but such people were "instigators of change" so they were faced with designing for a moving target. Controlling the outcome of what "culture" was to exist at year 100 was impossible. Rather than a specific culture, Team A chose to preserve a high level of cultural achievement by embracing dynamism.[40]

Team B took the culture problem most seriously. They interviewed historians, sociologists, and psychologists across the Claremont Colleges and compared American and Soviet political traditions. Psychological adaptation, they learned from these experts, was a virtue because the values and morals of survivors inevitably would change. For example, they concluded that men and women would by necessity share tasks equally, which in turn would remake gender politics. They suggested a governance model based on the ideal of small town meetings, but leaned toward anarchism as a form of societal organization. Individualism and diversity were paramount, and, absent a legal system, colonists would be ruled by conscience.[41]

Team C had a more conservative vision. "The fundamental parts of society," they reported, "are the family unit and the democratic system of government." Domiciles for extreme living were modeled on traditional apartments (Fig. 4). With 150 souls left on earth, housewives would cook, rear children, and educate the young. Alcohol and cigarettes were banned. Everyone would be a political citizen in a city governance model with an elected council and committees. Above all, citizens needed to understand that they were "perpetuating a small part of American civilization."[42]

Constitutive of a culture machine were the people tasked to preserve it. Who tended the farm? How many children could be born? Answers revealed challenges of optimization that students would face in any engineering problem. Wilson sought to convince students that human factors were the most uncertain of design variables. Unlike mechanical parts, humans were not fully predictable and they depended on interrelationships. Nonetheless he wrote in *Concepts of Engineering System Design*, "the attitude of a person toward the task he is performing can be far more important than anything else that contributes to his action"[43]

For students this meant that colonist selection had to balance cultural preservation with staying alive, cost, and the technological state of the art. Team C outlined its population on utilitarian requirements—five nurses, for example, for the hospital. Colonists did not need college degrees, but should have above average intelligence and be free of genetic defect. The majority would be twenty to forty years old. None were older than fifty. No special provision for cultural production was defined.[44]

[39]Wilson, *Concepts of Engineering System Design*, 1965, p. 12.
[40]Group A, *Project NOAH*, 1961, pp. 110–112.
[41]Group B, *Project NOAH*, 1961, pp. 2–6, 28–30.
[42]Group C, *Project NOAH*, 1961, pp. 2, 39.
[43]Wilson, *Concepts of Engineering System Design*, 1965, pp. 68–69.
[44]Group C, *Project NOAH*, 1961, pp. 70–71.

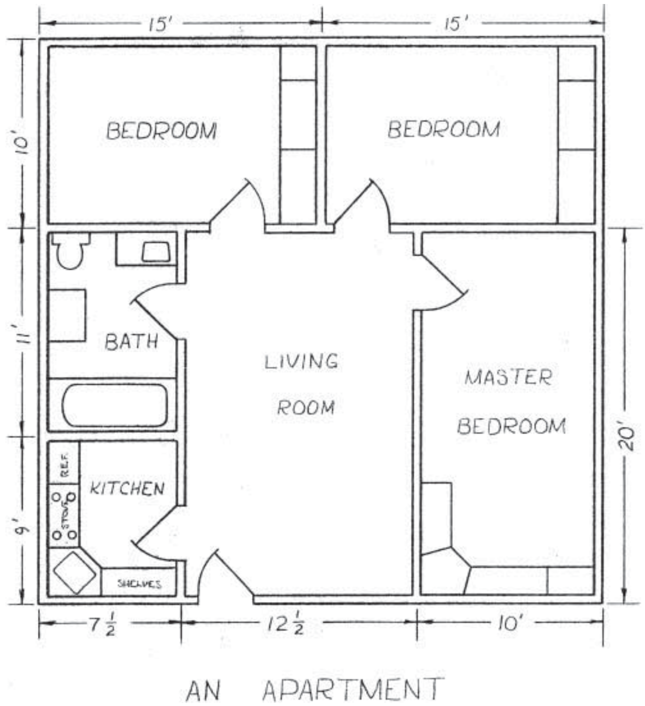

Figure 4. Preserving civilization with the three-bedroom apartment.
Source: Group B, *Project NOAH*, 1961, p. 100. *Courtesy*: Special collections, Honnold/Mudd Library of the Claremont Colleges.

Table 1. The Makeup of a Minimally Functioning Society under Extreme Conditions

Air conditioning operators	3	Engineers	30	Musicians	3
Anthropologists	2	English teachers' literature	5	Palentologist	1
Artist; painter; director	3	Geneticists	2	Philosophers	2
Astronomer	1	Geologists	2	Physical educationalists	5
Bacteriologists	2	Government administrators	3	Physicists	10
Botanist, zoologist, biologists	6	Historians	3	Political scientists	2
Chaplains	5	Hydroponics operators	4	Power plant operators	30
Chemists	14	Lawyers	2	Primary grade teachers	10
Dentist	1	Librarians	2	Professors of speech; drama	2
Dieticians	5	Linguists	4	Psychiatrists	2
Dirt farmers	5	Livestock managers	6	Psychologists	5
Doctors of medicine	10	Machinists	10	Sewage plant operators	4
Economists	2	Mathematicians	3	Sociologists	2
Educators (general)	3	Mineralogists	2	Water distilling operators	6

Team B designed the machine around its users. Two hundred fifty was the minimum population for a culture, but they aimed for 500 and planned the physical systems to serve it. In addition to thirty engineers, forty scientists, and various professionals they added anthropologists, artists, linguists, musicians, philosophers, and chaplains (Table 1).[45]

[45]Group B, *Project NOAH*, 1961, pp. 95–97.

Team A created an engineer's society. The group stipulated a single sociologist whose demands would be minimal and thus "this person [would] be working in another part of the colony for the major part of his day."[46] Colonists were chosen for superior intelligence. Most would have PhD's, which they argued was a measure of merit and diverse thought. Following their professor's advice, they contended that the most important criterion for entry was a "future oriented" attitude. "We would not give up because the odds were against us," Team A asserted, "we would find a way or make one."[47]

From the End of the World to the Real World

In 1965, Robert Boguslaw, a former RAND analyst, argued for the limitations of systems thinking in his book *The New Utopians*, declaring that systems designers were "unconsciously treading well-worn paths" created by nineteenth century utopians and building "the most fundamental errors" of those visions into "the most sophisticated pushbutton systems."[48] Boguslaw was on the leading edge of a backlash against systems design as practiced in the nation's think tanks, universities, and private firms. This critique reached its apex at the height of resistance to the Vietnam War in jeremiads such as John McDermott's *New York Review of Books* article "Technology: the Opiate of the Intellectuals," which took as its examples computerized bombing decisions.[49] By the mid-1970s, some in the design methods movement, such as architect Christopher Alexander renounced their role in creating formalized rules for design.[50]

Much of the wider criticism of systems analysis, however, was about its military-industrial application rather than the methods themselves. Such critiques combined with changing funding priorities redirected the aspirations of systems designers to a range of social problems with a more expansive interpretation of interdisciplinarity. At the same time, a minority of reformers in engineering and other design professions started to orient their work to appropriate technology projects that what we now call "design for the other ninety percent."[51] These projects, which soared in popularity in the early 1970s, emphasized individual (typically underprivileged) users as central to the design process. In industrial design, the charge was lead by Victor Papanek and his students at North Carolina State, Purdue University, and elsewhere. Papanek's book *Design for the Real World* simultaneously excoriated the design profession and offered a primer on the comprehensive method and specific techniques for another kind of extreme living, such as juice-can radios powered by paraffin wax.[52] In the engineering profession, the organization Volunteers for International Technical Assistance (VITA) was founded to put individuals in developing countries directly in contact with individual engineers through the mail. By the late 1960s, VITA had grown to include over 10,000 participants and become a symbol of the engineering profession's reformation in response to critiques of a litany of technological crises.[53] Systems design engineers championed the group and integrated real problems presented to and solved by participating engineers into their introductory textbooks (Figs. 5 and 6).

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[46] Group A, *Project NOAH*, 1961, p. 108.
[47] Group A, *Project NOAH*, 1961, p. 3.
[48] Boguslaw, *The New Utopians*, 1965, p. v.
[49] McDermott, "Technology," 1969.
[50] Wigley, "Whatever Happened to Total Design?" 1998.
[51] Smith, *Design for the Other 90%*, 2007.
[52] Papanek, *Design for the Real World*, 1971.
[53] Wisnioski, *Engineers for Change*, 2012, pp. 128–138; Williamson, "Small Scale Technology for the Developing World," 2008.

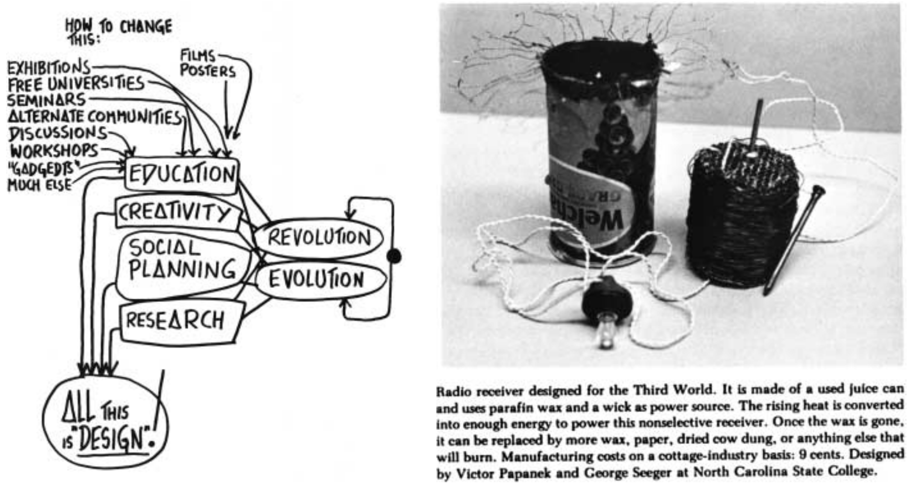

Figure 5. *Design for the real world*—complex system design for simple artifacts.
Source: Papanek, *Design for the Real World*, 1971, pp. 163, 276.

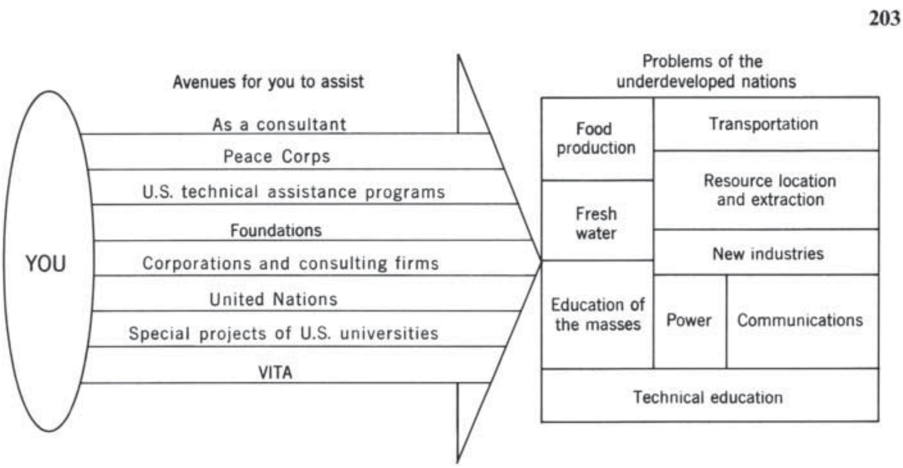

Figure 6. Humanitarian systems design—VITA.
Source: Krick, *An Introduction to Engineering and Engineering Design*, 1969, p. 203.

From HMC's founding, its faculty and trustees viewed humanitarian problems as pedagogical aids equally relevant for IBM research engineers and international development managers. In his textbook, Wilson argued that global problems such as assuring an adequate water supply and combating air pollution would "engage the highest talents of the engineer in the next century."[54] Chapter exercises built upon Project NOAH, asking students to consider the past record of attempted solutions as well as multiple stakeholder positions in confronting a problem:

> 1.2. The pollution of the atmosphere is progressing rapidly and, in the vicinity of large cities, is becoming a serious problem. Suggest solutions of this problem, taking into consideration the fact that air pollution is produced by industrial processes and automobiles. Give due though

[54]Wilson, *Concepts of Engineering System Design*, 1965, p. 16.

> to human reactions to suggested solutions; also consider carefully the fact that Los Angeles has not found it absolutely necessary to solve the problem, although the condition of the air is frequently objectionable.[55]

While considerations that we might attribute to humanitarian development and environmental protection were not front-and-center in Project NOAH, it introduced these topics by stealth. Students referenced desalination plants, pollution control systems, and alternative food sources. A side-by-side comparison of his textbook's identification of the most pressing engineering problems with those explored by students is revealing (Table 2).

Table 2. "Real World" Education in Project NOAH

Global engineering challenges in *Concepts of Engineering System Design*	Sample references cited in Project NOAH reports
1. Water supply	Cecil B. Ellis, *Fresh Water from the Ocean*, 1959
2. Air pollution	W.L. Faith, *Air Pollution Control*, 1959
3. Communication	Numerous interviews with stakeholders and professionals across industry and government from cafeteria employees to corporate managers at high technology companies
4. Transportation	"Bottom of San Francisco Bay Evaluated for Trans-Bay Tube," *Civil Engineering*, November 1960
5. Food supply	E.A. Helgeson, "Growing Plants Without Soil," *Bimonthly Bulletin of the North Dakota Agricultural Experiment Station*, 1938
6. Exhaustion of natural resources	Palmer Putnam, *Energy in the Future*, 1953

Later iterations of the freshman systems design project made these factors explicit. In the assignment's second year, students were asked to design an information network that would "serve the needs of the Claremont Colleges for technical and scientific information in the year 2,000." In year three, the dimensions that had been implicit in Project NOAH became the primary focus. Students themselves were prompted to identify "the *major opportunity to make technology serve human requirements* in the 21st century" and they selected the world food supply for the semester assignment known as the "Mass-Feeding Project."[56]

Project NOAH and its successor prompts, in short, instilled many "real world" design skills through open-ended tasks, teamwork, stakeholder engagement, and the exploration of societal challenges. But no matter how brilliant the students, solutions to world hunger, information infrastructure, and human survival were not probable semester outcomes. As speculative cases, the projects did not directly convey how in real world design the seemingly linear narrative from project conception to implementation can come undone at any moment.[57] Nonetheless, the HMC projects were not simply fictions; their ambition would prepare students to welcome Sisyphean grand challenges in their careers.

In the wake of Project NOAH, moreover, HMC was at the forefront of the move to real world problems. In the summer of 1963, the Sloan Foundation gave 10,000 dollars toward the study and implementation of a capstone experience for training professional engineers

[55] Wilson, *Concepts of Engineering System Design*, 1965, p. 21.
[56] Conference on Freshman System Engineering, *A Comprehensive Survey of Freshman Engineering at Harvey Mudd College*, 1964, pp. 46–47.
[57] Latour, *Aramis*, 1996, pp. 150–151.

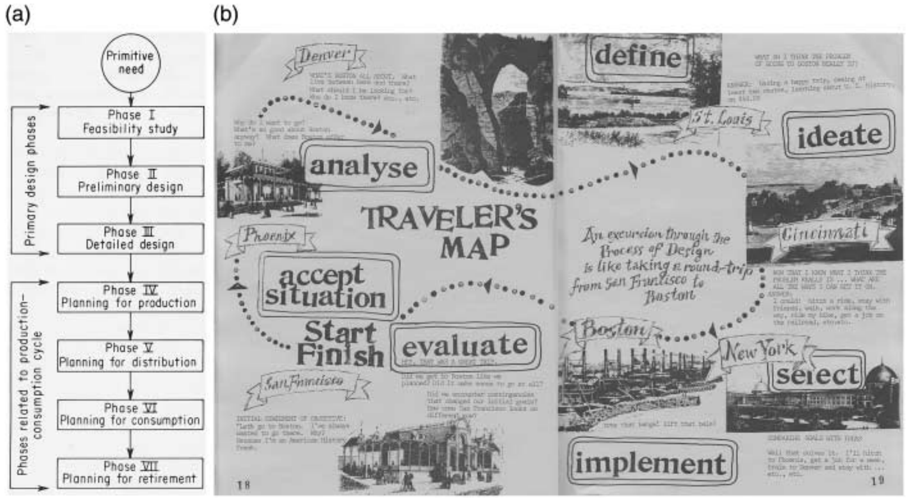

Figure 7. Changing approaches to introductory design pedagogy.
Sources: (a) Asimow, *Introduction to Design*, 1962, p. 12. *Courtesy*: Prentice-Hall. (b) Koberg and Bagnall, *Universal Traveler*, 1972. Adapted from *Universal Traveler, Third Edition*, a Crisp series book by Jim Bagnall, available from Logical Operations (www.logicaloperations.com). Used by permission.

that since has become the distinguishing characteristic of the school and a model for others.[58] The resultant “Engineering Clinic” integrated cooperative education, the “practice school” approach to engineering training, and the clinical education model from medical school. Its distinguishing feature was the presence of real clients from outside HMC who presented teams of three to five students with a “need” to be met by semester’s end. Many of the projects were for large aerospace and electronics companies, but especially in the late 1960s and early 1970s others had an explicit social justice orientation such as the design of chicken coops and comparative socio-technical analyses of mass transit systems.

This shift in emphasis to actual clients occurred simultaneously with the growth of a strand of systems engineering based on less structured design methods that emphasized group dynamics, interpersonal relationships, and the problems of uncertainty. In HMC’s post-1960s reconciliation with critiques of technology, the analytical approach of systems engineering textbooks were replaced with *The Universal Traveler: a Companion for those on Problem-solving Journey’s and a Soft-systems Guidebook to the Process of Design*. First published in 1972 (with eight subsequent editions), and written by environmental designer Donald Koberg and industrial psychologist James Bagnall, both at California Polytechnic San Luis Obispo, *Universal Traveler* analogized design to a journey and helped “problem-solving voyagers” visualize travel stages in the process (Fig. 7).

A 1970s guide to HMC’s Clinic illustrates how far engineering design had moved in a decade, while nonetheless bearing the imprint of Project NOAH. It opened with dueling epigraphs from Nietzsche and H.G. Wells, the former advocating for the essence of education as “dancing with the feet, with ideas, with words,” the latter intoning that history had become “a race between education and catastrophe.” It fostered individual and collective actualization in which students were their own teachers. The take home message was of

[58]Bright and Phillips, “The Harvey Mudd Engineering Clinic,” 1999.

responsible professionalism: “You will no longer be playing the kid-in-class role .... If your wonder machine for killing fleas also kills dogs, you will have nowhere to pass the buck.”[59]

Conclusion: Assessing NOAH

The modal response upon encountering Project NOAH today is a kind of Kubrickian laughter. Confronted with the weapons systems actualized by the worst-case scientifictions of scientists and engineers during the Cold War, what other evaluation seems adequate? Indeed, with distance it is easy to scoff at a “progressive” interdisciplinary curriculum that inculcated students with the mentality of the defense-industry status quo and the trope of the heroic expert. A hostile reading of Project NOAH, however, overlooks the exercise’s utility as a reflective case study for its stakeholders, for historians, and for contemporary design educators.[60]

To HMC’s founders, Project NOAH was a successful prototype of systems engineering pedagogy that had the added benefit of bringing institutional publicity and forging networks with regional universities and companies. In a *Journal of Engineering Education* article published shortly after the project’s completion, Wilson concluded that “liberation of the student from the restrictions of a detailed set of directions for accomplishing the task” resulted in “superior accomplishments” among some students, particularly the project managers. But, the HMC faculty also found that “some students react in a violently negative fashion,” which Wilson recast as an unanticipated design feature—the HMC approach sorted out the creative designers from those not interested in “human interaction” who were better suited for chemistry, mathematics, and physics; in other words, it distinguished between who was a good engineer and who was merely a scientist.[61]

Despite its publicity and the pattern it established for future projects at HMC and beyond, there remained significant tensions around Project NOAH about what counted as successful problem-based learning, an anxiety familiar to anyone who has overseen student projects across disciplinary and professional lines.[62] In this respect, Project NOAH was a pilot study on which to build subsequent iterations. The aforementioned Engineering Clinic guidebook synthesized strategies that Project NOAH lacked, learned from a decade of experience. It included the incorporation of more attention to interpersonal dynamics, motivation, project management, and communication.[63] Even then a guidebook could help only so much for a pedagogical approach of learning by doing.

The challenges of interdisciplinary design education were amplified considerably by HMC’s desire to train experts with an emphasis on human-centered solutions. The fallacy of assuming a universal designer responsible for every socio-technical dimension of a project was instantly apparent to some of the HMC faculty. In 1968, June Louin Tapp, who had been

[59] Seven and Zagar, *The Engineering Clinic Guidebook*, 1973, pp. 1, 7.

[60] One area of applicability beyond the immediate horizon of my argument is the growing field of “disaster STS.” See, e.g. Fortun and Frickel, “Making a Case for Disaster Science and Technology Studies,” 2012. Peter Galison’s forthcoming work on nuclear containment similarly addresses themes of scientifiction in the handling and prevention of disasters. Kruse and Galison, “Waste Wilderness,” 2011.

[61] Wilson, “Engineering Problems at Harvey Mudd College,” 1963, p. 466; Conference on Freshman System Engineering, *A Comprehensive Survey of Freshman Engineering at Harvey Mudd College*, 1964, p. 7.

[62] Blumenfeld, et al., “Motivating Project-Based Learning,” 1991; Prince, “Does Active Learning Work?” 2004.

[63] Seven and Zagar, *The Engineering Clinic Guidebook*, 1973.

an assistant professor of psychology at HMC, looked back at Project NOAH with skepticism. She declared that the students' evaluation of human nature were "not so laudable, complete, or sophisticated." By her calculation only 5.3% of the 371 total report pages engaged directly with the "human variable." Frustrated by the "naiveté and superficiality" of their engineers' dreams, she created the course "Project NOAH Revisited," in which twenty students from the initial project, now sophomores, confronted the assumptions that had guided their design in a series of iterations after deeper exposure to psychological and sociological scholarship and in class conferences with a RAND psychologist. The class concluded with a design critique of the original NOAH assignment, asking students to rephrase the initial problem statement so that it would have prompted more attention to the "behavioral science aspect." Her expressed purpose, however, was neither to assert disciplinary privilege nor to disparage Project NOAH. Rather she wanted to analyze the benefits of "integrated and interdisciplinary teaching," through a comparison of NOAH alumni with students who took a disciplinarily oriented behavioral science course (the "Adam" group). Tapp found that at first the NOAH students displayed "boredom, hostility, frustration, and conflict" to this additional reflection on their work, but that compared with the Adam group, who learned psychology separate from their engineering project, the NOAH revisited group generated more "'psychologically oriented or knowing' physical scientists and engineers more willing and able to build bridges between fields of specialization" as well as "a marked increase in ability to recognize and continue to work with psychological problems."[64] Even in failure, she concluded, the learning outcomes of Project NOAH were superior to traditional disciplinary approaches.

What did students themselves take from the project? Assessing the impact of student learning is difficult enough for any assignment at semester's end, much less at a distance of forty years. Still, I was able to interview a few participants who to this day distinctly remember the novelty of teamwork and the challenges of self-education that the exercise generated.[65] Some went on to academic careers in mathematics and physics, while others became engineers in private industry. I could not reach one former student I located because his contact information was blocked by the US Pacific Command website where he specialized in disaster simulations.

It is this last career path that insists any assessment of Project NOAH move beyond general insights about design education to tackle its particular variant of scientifiction. The prompt for the project was laden with the biases of HMC's pedagogical reformers. After a career that spanned no less than ten institutions of higher learning, Wilson described the joys of building a curriculum "with no tradition whatever to tie our hands."[66] Just as Project NOAH gave students the possibility of erasing the burden of history and human inequity, the creation of HMC appeared to offer the opportunity of curating the best approaches to humanist and scientific pedagogy so as to educate progressive technologists unbound by parochialism or dogma. HMC would be a colony for remaking the profession by avoiding the false paths of the past.

But the worst case HMC selected went far beyond a quest for institutional identity or the ethos of the defense apparatus. Indeed, it is hard to fault Wilson for recognizing the state of American engineering at mid-century and the experiences of his students who hailed

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[64]Tapp, "Bridges for Modern Noah and the Old Adam," 1968. Tapp left HMC in 1963 to become senior research social scientist at the American Bar Foundation and a lecturer at the University of Chicago.

[65]Telephone conversation with Russ Merris, May 7, 2009; Email correspondence with Dan Nelson, May 8, 2009.

[66]Wilson, "Engineering Problems at Harvey Mudd College," 1963, p. 462.

from Southern California's aerospace cradle. Duck-and-cover drills and intercontinental ballistic missile conversations were a high-school routine. Students needed little instruction on where to find the evidence to calculate and prepare for the end of days.[67] It was instead their ideas about salvation that were drawn out and challenged in the act of designing. Again, to borrow from Powers, "forsaking everything" forced students to be clear about "saving what [they] cared for."[68] In other words, by presenting the task of designing for cultural preservation, Wilson asked engineering students to take seriously what many current design advocates view as their pedagogical responsibility. Humanist and engineer, the founders of HMC believed, were not so different. Both aspired to help students read the world so that they could see the inextricable mangle of culture and technology and at the same time to better alter it. Here was the object lesson of Project NOAH–design at its best imagines new worlds, and asks what we stand to lose in their creation.

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[67] Telephone conversation with Russ Merris, May 7, 2009.

[68] Powers, *Prisoner's Dilemma*, 1988, p. 155.

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