INTRODUCTION: SCHEMATICS

> The history of science is riddled with chance discoveries, discoveries that link science and art in a common irrationality.[1]
>
> Douglas M. Davis, 1968

Imagine you have a long, thin piece of plastic string. Now attach this spaghetti-like strand to a small electric motor. Then, wire this motor to an Ethernet cable so that whenever digital packets of information—an email, a music download—stream through the cable, the motor gives a tiny tug and makes the string twitch.

This was *Live Wire*, created by Natalie Jeremijenko in 1995 when the internet and the World Wide Web were still unexplored realms for most people.[2] For years, *Live Wire* was displayed in the corner of a busy hallway at Xerox's Palo Alto Research Center just off Stanford University's sprawling campus. When local network traffic was low, *Live Wire* remained relatively calm. But when the data flow surged from a trickle to a torrent, the eight-foot-long plastic string literally hummed and whirled with activity. A practical and tangible marker of the disembodied data streaming through cyberspace, Jeremijenko's creation could capture someone's attention or just as easily pass unnoticed. Unlike frenetic, real-time displays of network traffic, *Live Wire* was "calm technology," an artwork-as-instrument that provided useful information to people in the offices around it without being too obtrusive.[3]

Jeremijenko built *Live Wire* as both application and art. She, likewise, a hybrid, studying physics, chemistry, and fine arts in Australia before moving to the San

Francisco Bay Area and consulting for Xerox's "ubiquitous computing" initiative.[4] Jeremijenko later combined graduate training in design and engineering at Stanford with fellowships at the Exploratorium—an innovative science museum in San Francisco—and other such places. After getting her PhD in computer science and electrical engineering at the University of Queensland, she secured a tenured position at New York University where she built an international reputation as a self-described "thingker" who capably combined art and engineering.[5]

Writers' descriptions of Jeremijenko were as vague as her professional credentials were varied. In 2006, *Salon* labeled her an "artist as mad scientist."[6] Five years later, an engineering education publication reversed course and christened Jeremijenko a "scientist as mad artist."[7] Another magazine eschewed the trope of insanity altogether and called her an "engineer for the avant-garde," but then confused matters by noting, "it's art, all right. But is it engineering?"[8] Further categorical complications and a little feather ruffling ensued when Jeremijenko told the *New York Times* that the art world was a "prissy little thing over in the corner, while the major cultural forces" that really shaped people's everyday experiences were "being determined by technoscience."[9]

Artwork as opposed to instrument or experiment? Engineer versus artist? Even today, we often see these as two different cultures separated by impervious walls. But some fifty years ago, the borders between technology and art, long imagined as solid, began to be breached, even if they have not yet melted entirely melted into air. New collaborative communities of engineers, scientists, and artists, fragile at first but eventually durable enough to take root in universities, museums, and companies worldwide, emerged. This transformation's history spills beyond the frame of art and technology, providing color and depth to our picture of the era's broader economic and social contexts.

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Six decades ago, the professional boundaries between engineer and artist—their communities, activities, institutions, skills, and shared interests—seemed much more unyielding than they are today. Hadn't Charles Percy (C. P.) Snow, the British chemist turned government advisor and novelist, famously generalized that Great Britain's intellectuals and political leaders were conversant with the arts and humanities but remained willfully ignorant about technology and science? Even worse, as Snow claimed in 1959, the gaps between humanists and scientists—or, as labeled more recently, between “fuzzies” and “techies”—had dangerously widened to the point of mistrust and incomprehension.[10] Although Snow aimed his critiques primarily at humanists and scientists, his categories expanded to include artists and engineers.

Today, “bridging the two cultures” is, at best, a synecdoche for some form of interdisciplinarity. At worst, it’s a cliché overused by academic administrators and business leaders. More valuable when viewed in its historical context than for its analytical heft, Snow’s claims retained rhetorical punch well into the 1960s. Once removed from its original British setting, “two cultures” became a phrase in the United States that helped generate research funds, launch government-funded studies of creativity, and provoke calls to revise university curricula. Art-and-technology advocates imagined their intervention could help solve the “two cultures problem,” or at least lessen the animus. Viewed by some as too important to be left just to artists, making art was something to which engineers and scientists could and should contribute. Advocates claimed collaborative experiments, which allowed artists to explore new aesthetic possibilities that technologies such as lasers, microprocessors, and computers afforded, could electrify artworks while rewiring the work of making art itself. These activities, they argued, could simultaneously rehabilitate the public’s increasingly negative view of technology and its presumed masters: engineers.

Throughout the 1960s and up to today, artists and engineers engaged in “hybrid practices” that wired the realms of art, technology, and science together and generated a new creative culture.[11] Their collaborations, some fleeting and others long-lived, often produced thoughtful, aesthetically sophisticated, and visually arresting works of art. It also sometimes sparked new companies, patents, and commercial innovations. Divergent in their interests and professional knowledge, engineers and artists learned to speak one another’s languages, though at times imperfectly. By working as partners—even if the arrangements were occasionally unequal—artists and engineers came to appreciate and sometimes even adopt each other’s approaches to experimentation. I aim to explore the diverse strategies they adopted to build a new kind of creative sensibility.

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Well before the 1960s, artists had sporadically mingled with engineers and scientists. Artists, of course, relied on a range of tools while also experimenting with new technologies as they became both available and accessible (the former does not entail the latter). Artists’ embrace of photography in the mid-nineteenth century—a time when the word "technology" meant the *study* of the so-called practical arts, and not the products themselves—suggests how divides between art and technology are themselves historical constructs. Technology also offered potent subject matter as artists such as George Inness and Charles Sheeler recorded, in very different ways, the landscapes of American industry. Sometimes artworks critiqued modern technology's status and power. Diego Rivera's famous Detroit Industry Murals, made during the Great Depression, portrayed workers at Ford Motor plants along with the transformative power of science-based research. Thirty years later, Ed Kienholz used flashing lights, a telephone handset, and complicated-looking dials to make *The Friendly Grey Computer* resemble some sort of computing thing. But Kienholz constructed it in the approachable shape of a traditional rocking chair (and included what appear to be a child's feet, poking outward).

Technology itself stimulated both artists and artistic movements. In 1909, the Italian poet Filippo Tommaso Marinetti launched the futurist movement with a manifesto published in *Le Figaro*. Although the futurists glorified the speed and violence of automobiles and airplanes, they saw technology more as an aesthetic ideal and did not seek out collaborations with engineers. A decade later, Vladimir Tatlin, working in Russia under completely different political circumstances, articulated an artistic philosophy that informed the constructivist movement. He envisioned the liberation of modern materials and industrial techniques from the realm of factories to be used by artists. Like the futurists, Tatlin admired machine aesthetics, yet he imagined making art that served the state. For instance, after the Russian Revolution, Tatlin revealed his model for a *Monument to the Third International*. Designed as an amalgam of steel, glass, and revolutionary sentiment, the completed monument would have combined sculpture and architecture with mechanical movement and the projection of propaganda via electronic media. Intended to surpass the Eiffel Tower but never realized, building Tatlin's *Monument* would certainly have demanded engineers' expertise. In fact, when Tatlin exhibited a twenty-foot-tall model of *Monument* in 1920, the red banner suspended above it commanded, "Engineers, create new forms." Despite high-minded aspirations, productive partnerships between artists and engineers did not emerge as a feature of the constructivist movement or Soviet industry.[12]

After the chaos of World War I, German artists and architects considered how artists might productively work with manufacturers to foster social reform. The Bauhaus, started in 1919 by architect Walter Gropius, sought to fuse art with industrialization by integrating aesthetics and functionality into design and architecture. In his founding manifesto, Gropius stated his wish to end artists' exile from the worlds of craft and industry by conjoining the fine and applied arts. Four years later, when Bauhaus members organized their first public exhibition, Gropius spoke of a new unity that could arise between art and technology when artists designed attractive yet functional objects for the masses. The aspiration to join artists with industry ended, however, when the Nazis seized power and Bauhaus members dispersed to more hospitable nations.

Merging art with technology wasn't confined to manifestos and pretensions to spark social change. For example, shortly after World War I ended, Thomas Wilfred, a Danish-born artist living in New York City, built his first *clavilux*.[13] The name comes from Latin for "light played by key." Industrial technology of the 1920s helped Wilfred create an increasingly complex and sophisticated array of devices that could project a nearly infinite variety of colored, gently moving light compositions to large audiences. Wilfred's *lumia* reflected developments in modern science, especially visual imagery from astronomy and space exploration. (Similar topics fascinated Marcel Duchamp, who was making his famous piece, *The Large Glass*, also known as *The Bride Stripped Bare by Her Bachelors, Even*, at about the same time Wilfred was building his *lumia*.)[14] Favorable reviews and commercial interest in *clavilux*-like devices for the home followed. After World War II, Wilfred faded from public attention—the new technology of television was a factor—even as several of his large-scale programmed *lumia* compositions were displayed in museum galleries and corporate lobbies. Before Wilfred passed away in 1968, art writers had rediscovered him, situating him as an early pioneer who melded art with electrical technology.

Ambitious and innovative as these efforts were, this early activity failed to establish sustained engagements between engineers and artists nor did the artists' community manage to obtain sufficient patronage from industry or museums. In the 1960s, however, the situation started to change. This time, the impetus came from a multitude of directions as artists, engineers, corporations, universities, publishers, and museums each sought, in their own ways, to splice and solder art and technology together. This plurality of strategies created new technological communities with both engineers and artists as members.

I have deliberately chosen the word "community." It provides my basic unit of analysis, to use a historian's jargon, for several reasons. Where an art movement represents aesthetic tendencies—think of modernism's preference for clean lines, rational design, and geometric shapes—a community is less stylistic than it is sociological. Larger than a lab group or artists' collective, but smaller than a professional society or academic discipline, technological communities have a fluid, interdisciplinary membership that changes over time. Such communities coalesce with varying degrees of formality around particular projects, research questions, or scientific instruments, maintain their cohesion for a time, and then, as often as not, dissipate. Community members bring their own specific sets of skills and knowledge, such that the whole is greater than the sum of the parts.[15] Finally, "community" implies a sense of collective action as well as inclusivity and belonging (and sometimes, of course, ostracism and withdrawal). For many participants in art-and-technology activities, their involvement was personal as well as professional.

In the 1960s, the art-and-technology movement that took form at multiple sites around the world existed in the shadow of that era's other more visible social crusades—those addressing civil rights, the Vietnam War, and the environment—but it shared some similar concerns and goals. It differed, however, from earlier examples of interest in art and technology in several key ways. At a time when the technologies of mass media themselves were changing, public interest and critics' attention were amplified by dozens of well-publicized museum exhibitions and gallery shows. Hundreds of books and articles—from cultural arbiters in New York to flash-in-the-pan newsletters and underground zines—reported on and critiqued the new nexus of art and technology, even as high-profile public relations efforts promoted it. At the same time, artists increasingly began to work outside the "sanctity of the isolated studio."[16] In the 1960s, art became an extension of big business as artists—like engineers—acted not just as creators but as managers of technological processes. Generous financial support from Fortune 500 firms and major cultural institutions helped sustain and enlarge (sometimes to impracticable degrees) this first wave of art and technology. Meanwhile, some corporate managers, informed by psychological concepts, such as Abraham Maslow's "hierarchy of human needs," sought new ways to encourage self-fulfillment among their employees.[17] For the engineers intrigued by such ideas, one path to this was partnerships with artists.

But, more than anything, the desire shared by engineers and artists to *collaborate* distinguished this first wave of art and technology.[18] Sometimes these partnerships were between individuals. In other cases, they involved hundreds of people supported by multimillion-dollar budgets. Compared to pre-1945 examples of art and technology, these alliances coalesced as the result of both top-down initiatives and grassroots-level organizing. In these new social spaces, engineers and artists, as members of professional communities that each changed in profound ways during the 1960s, partnered to make art and also produce a new, hybrid form of creative culture. I should note, given the indiscriminate deployment of the word "creative" by today's life coaches and thought leaders, I suggest something closer to its original meaning: from the Latin, *creare*, to bring forth something new.[19] The people in this book all derived significant satisfaction from making novel and aesthetically pleasing things.

The reasons why engineers and artists wanted to collaborate were complex, personal, and varied. For many artists, it was partly a desire to work with new and often unavailable technologies. Added to this was a sense of crisis about the relevance of commodifiable, object-oriented art made using traditional media in a rapidly changing art world. For engineers—who were facing mounting attacks about their complicity in the arms race, environmental destruction, and other global ills—the art-and-technology movement presented an opportunity to humanize technology and redefine their profession, if only on a personal level.[20] The fallout from these art-technology alliances also had the potential to benefit engineers' employers in the form of commercial products and intellectual property, while simultaneously expanding artists' aesthetic visions and opportunities. The point of collaborations, after all, is for people to create something together that otherwise could not be done alone.

Engaging with engineers opened new creative possibilities for artists. Electrifying the work of art meant experimenting with lasers, digital computers, video devices, miniaturized electronics, and new multimedia environments, technologies all developed during a tumultuous time that saw both the Apollo moon landings and the Vietnam War's escalation. And, like engineers, artists' professional world was changing in significant ways. The emergence of new patrons and cultural brokers coincided with shifting sensibilities about professional identity and methods of art making that went beyond questions of style alone. Taken together, these differences separated 1960s-era artists from their predecessors just a few decades earlier.[21]

International in scope and diverse in methods (remarkably less so in gender and race), advocates of art and technology sometimes expressed broader ambitions that reached toward utopian-seeming ideals. Together, their activities constituted a social movement that was small in scale yet possessed grand ambitions. Collaborations between artists and engineers offered, proponents said, a "revolutionary contemporary sociological process" that might "benefit society as a whole."[22] Advocates for the art-and-technology movement saw their activities transcending the making of art solely for the market, the gallery, or critics' appreciation. Their stated interest in exploring *process*, not making products, comported with broader ways in which artists were redefining the nature of art via minimalism, conceptualism, land art, and other 1960s-era trends. As artist Robert Rauschenberg saw it, spectators who came to art-and-technology shows should be encouraged to watch the setup of technical equipment as much as they would artists' performances. "They should understand," he said, "that we're involved in a process and not in presenting finished products."[23]

These alliances between artists and technologists can be understood as *experiments* in creativity, sociology, and even patronage, which could expand the artists' community and integrate it with industry and university labs. Science experiments and engineering designs often yield results that are imperfect yet still instructive. Advocates saw art-and-technology collaborations as an experiment with how people might engage with technology in a more positive manner while negotiating C. P. Snow's cultural divides.[24] Just as going out and haphazardly observing nature does not constitute a scientific experiment, simply expressing one's emotional inner world on a canvas would no longer do. This new type of collaborative experimentation required rigor, planning, structure, and considerable resources, both technical as well as fiscal.

Many of the art critics, curators, and journalists who responded to the art-and-technology movement, however, stubbornly kept their gaze on the products of artist-engineer collaborations. Here, the view was evaluative, asking if and how an artist was significant or judging a collaboration in terms of aesthetic outcomes, how it fit within a stylistic movement, or whether it pushed boundaries of a particular medium. At the most fundamental level, the question was "Is it art?" I am not concerned with such adjudication. What interests me more is not the art objects themselves—fascinating as they often are—but rather the activities that brought them into existence. This book, in other words, is not evaluative, but explanatory and descriptive. By reading a diverse range of historical sources differently, I instead address the ways in which technologists and artists worked to span divides between their professional communities to make art and also to achieve other goals.

Advocates for closer alignments between art, technology, and science adopted a range of strategies to achieve their ambitions. In Paris, American-born rocket engineer Frank J. Malina initially approached the task by becoming a professional artist. After some experiments in traditional media, he soon gravitated toward making works (like Wilfred, with whom he was often compared) that incorporated motion and electric lights. Working alone, or sometimes with a small cohort of assistants, Malina made scores of "electro-kinetic" paintings and became one of the leading figures of the midcentury kinetic art movement. Then, in 1968, he abruptly changed course and launched a new international journal called, appropriately enough, *Leonardo*. Malina explicitly fashioned *Leonardo* into a venue where artists and scientists could report on their art experiments, describe new techniques, and explore the nature of visual perception.

While Malina, the archetypal professional hybrid, was making art and preparing to launch his publishing experiment, Gyorgy Kepes, a Hungarian-born artist and educator, oversaw the dedication of the Center for Advanced Visual Studies (CAVS) at the Massachusetts Institute of Technology.[25] Kepes had advocated for such a center for years, imagining it as a place where artists, engineers, and scientists could reconcile the values and goals of their professional communities. The artists he selected to be fellows at CAVS would help integrate the visual arts into MIT's curriculum, creating a new generation of technologists familiar with both sides of the two cultures. In an era anxious over the missile gap between superpowers, efforts like CAVS can be seen as an attempt to address cultural gaps in the education of scientists and engineers.

Meanwhile, Johan Wilhelm "Billy" Klüver, a Swedish engineer employed at Bell Labs, was exploring ways to directly connect engineers with artists. At first, like Malina, he started at the personal level, writing essays for art catalogs, helping organize exhibitions, and partnering one-on-one with prominent artists. However, he soon pursued a strategy based on large-scale collaborations and expensive projects. In 1966, he helped establish Experiments in Art and Technology (E.A.T.), a New York-based group that aimed to link technological means with artistic ends to fulfill bigger social aspirations. The organization's large-scale approach mirrored the style of Cold War-era "Big Science" projects, making E.A.T. highly visible, sometimes successful, and—given critics' visceral reactions—often controversial.

The same year E.A.T. switched on its art-and-technology network, Maurice Tuchman, a brash new curator at the Los Angeles County Museum of Art, proposed to put his city on the cultural map. Enticed by the wealth of technological opportunities found in Southern California, Tuchman embarked on an ambitious and lavishly supported program that encouraged the region's high-tech corporations to support art. For five years, Tuchman shepherded an unruly ensemble of artists, engineers, and company managers for his Art and Technology Program, the result of which was a notorious 1971 exhibition.

These new art-and-technology projects (and others like them) burst forth in the 1960s from corporate laboratories, artists' lofts, publishing houses, museum galleries, and university campuses. Bolstered by generous media attention and corporate patronage, the desire to meld two seemingly disparate yet creative cultures was especially prominent in the United States. But fusing engineering with art was not solely an American project. Diverse projects, communities, and exhibitions appeared in the United Kingdom, Europe, Japan, and elsewhere. Taken together, these efforts reshaped public perceptions of both technology and art. This was no slow burn but an aesthetic explosion catalyzed by money, media exposure, and the creative energies of engineers and artists alike. For some participants, it was a short, tumultuous affair. For others, these interactions left indelible marks on the rest of their professional lives.

Then, after barely a decade of highly visible and expensive efforts, this wave of art-and-technology activity retreated. Although this turned out to be only a temporary ebb, art writers judged these attempts to meld art with high technology a failure. Critics attacked interdisciplinary partnerships as an aesthetic disappointment that had somehow polluted the art world. (Of course, such judgments erred wildly in presuming that art had ever been free from such corruption in the first place.) Similarly they castigated artists as amoral opportunists for collaborating with the stewards of the Cold War military-industrial complex. Meanwhile, the economic downturns of the early 1970s quashed the willingness of corporate managers and engineers to risk engaging with artists. By the mid-1970s, the art-and-technology movement appeared as out of vogue as moon landings, supersonic aircraft, and other techno-utopian projects launched in the mid-1960s.

Nonetheless, collaborations between artists, engineers, and scientists created an ad hoc but durable infrastructure that helped support future art-and-technology activities. It also established a model for a new creative culture based less on Snow's bifurcated categories. Even as partnerships and formal organizations slipped into hibernation or dissolved, university programs, publications, and personal interests aided the emergence of subsequent waves of what art writers and museum curators started calling "digital art" or "new media art."[26] By the 1990s, artists could access and experiment with cutting-edge technologies much more easily than their 1960s-era counterparts. But unlike earlier partnerships, which relied on technologies developed for the Cold War by military-industrial institutions, more recent engagements with technology often originate from today's information-entertainment complex as prominent companies such as Microsoft, Facebook, and Apple have helped support the work of hybrid artist-technologists.[27] As a result, many of the older divides between engineers and artists now seem less abyssal as new professional, technoaesthetic communities have begun to coalesce around the continued fusion of art and technology.

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Technology and science are central to understanding the larger historical contours of what scholars have come to call the "long 1960s."[28] In this tumultuous time period, bookended roughly by Sputnik's launch in 1957 and the final Apollo moon landing in 1972, engineers and scientists helped produce the foundations of today's techno-modernity: the personal computer, modern electronics, communications satellites, the internet, biotechnology, to name just a few examples.[29] Artists partnered with engineers even as the race for outer space and its older sibling, the nuclear arms race, influenced geopolitics and popular perceptions of technology. Electronic technologies and electrical engineers were especially critical for the aesthetic experiments carried out during this first wave of art and technology. During the 1960s, modern art literally became electric—wired, connected, soldered, and interfaced to computers, circuits, and cybernetic concepts.

This was also the same time in which, according to sociologists such as Daniel Bell, Western capitalism absorbed and appropriated the radicalism of the avant-garde arts scene. In *The End of Ideology*, first published in 1960, Bell argued that artists' creativity was now a potent ingredient for corporate research and development.[30] As engineers and artists collaborated, parallels began to emerge between artists' inventiveness and engineers' approach to creating new technological products.[31] As companies and economies were boosted by the extraordinary prosperity that marked much of the 1960s, Bell and other scholars predicted that engineers stood on the precipice of an eventual postindustrial society when skills for managing an expanding knowledge economy would take precedence over the traditional manufacturing of things.[32] Process would, the argument went, take precedent over products.

With the Ages of Apollo and Aquarius merging, engineers had a central role as builders and maintainers of complex technological systems that sprawled across the planet. Well-trained, firmly middle-class, and often white, male, and politically conservative, they were among the most plentiful of white-collar workers in Cold War America. In the United States and Europe, engineers were tenders of modern capitalism, providing technological prowess that made the conveniences of modern life possible. But, like artists, engineers were also experiencing profound professional changes while also seeking to demonstrate their relevance to society.

The vital importance of technology in this era presents us with a puzzle when it comes to historical studies of the art made during the 1960s. If one were to leaf through the glossy pages of art history surveys and textbooks (a slow-changing and conservative measure, to be sure), it's almost a foregone conclusion that there will be few if any mentions of the 1960s-era art-and-technology movement. Indeed, it's quite possible to find little to no discussion of technology at all.[33] In these narratives, engineers and scientists are invisible. This lack of attention is puzzling as several artists who populate the canon of modern art history—Rauschenberg, Cage, Duchamp, Warhol, Lichtenstein, Serra, Johns, and many more—worked with engineers at some point. But their experimentation with technology often appears camouflaged in favor of more familiar accomplishments. For the relatively small group of art historians who *have* considered the art-and-technology movement, their attention, unsurprisingly, has largely been on participating artists. This obscures key actors and communities—seemingly mundane engineers and scientists, corporate managers, benefactors, and publishers—to the extent that, until now, a larger and richer story, one that is about technology as well as art, has remained elusive.

One explanation for the absence of technology from most art-oriented histories stems from the prevailing but mistaken belief that a vast majority of Americans and Europeans in the 1960s rejected science and technology en masse. So perhaps it's expected that we would imagine the era's artists to have been likewise opposed. But such an assessment obscures the enthusiasm that many people had for *certain kinds* of technology, even as they rejected the missiles and mainframes of the Cold War era.[34] It was a time of moonwalks as much as Woodstock, after all.

Likewise, historians of modern science and technology have often focused their attention on the expensive, large-scale experiments and the effects of military patronage on knowledge production.[35] As a result, art and artists remain a relatively unexplored topic. Noting these absences of engagement is not meant as a criticism of scholars from either discipline. Rather it's an observation made in the hope of finding more common points of interest between two groups of scholars who often work in isolation from one another. I want to explain the recurring waves of interest and enthusiasm by drawing on ideas, scholarship, and research materials from art history *and* the histories of science and technology. I do this in three ways.

First, I shift focus by giving more attention to artists' underrecognized partners in collaboration: engineers and scientists. Despite their professional credentials and expertise, most contemporary observers relegated engineers to what historian Steven Shapin has called "invisible technicians."[36] This originally referred to the highly skilled craftsmen of the early modern period who helped perform key scientific experiments yet were later erased from histories of science that privileged their employers. Likewise, in his classic sociological study *Art Worlds*, Howard Becker surveyed the oft ignored people—paint makers, insurers, studio assistants, curators—who performed the mundane yet necessary labor that kept the art world working.[37] My understanding of the art world is similarly broad, encompassing more than just the upper echelons of artist stars, celebrity curators, and influential critics.

My aim is to help recover narratives that are more diverse than canonical art histories might suggest by restoring the technologists, who were central to the era's collaborations, to the foreground.[38] This approach helps recapture the experiences of technical experts who contributed time, skills, and, in some cases, aesthetic advice to their artist colleagues. So, in a sense, I'm reading this particular slice of modern art's history against the grain. During the time period covered in this book, the creative process of making artwork transformed. At the same time, the artworks that engineers and artists jointly produced performed a type of work as well, broadcasting a signal that the two communities had interests that imbricated and intersected. Reflecting the historical actors' larger interest in the process of making technology-based art, this becomes an account grounded in gerunds: organizing, writing, publishing, strategizing, funding, programming, wiring, soldering, exhibiting, and critiquing.

Second—again moving against the grain—this book questions the verdict imposed (at the time and sometimes retrospectively) that the art-and-technology movement of the 1960s was a failure. Instead, its ideals and ambitions provided a valuable institutional base for the university and corporate programs that followed. Moreover, even if a particular art-and-technology project didn't fulfill all of its advocates' ambitions, it's important to recapture the enthusiasm, excitement, and uncertainty of what it was like at the time.

This history of what might seem an obscure, long-ago trend in the "prissy" world of artists and curators remains relevant today. Creative collaboration and interdisciplinarity, two goals of the art-and-technology movement, are prized and promoted by corporate leaders and college administrators today. Conferences, journals, and societies devoted to activities at the interfaces between art, science, and technology are again proliferating. Since 2010, national education leaders have lauded the value of adding arts and design to the traditional science, technology, engineering, and math framework (sometimes this is branded as "STEM to STEAM," where the "A" refers to art, or, in other places, "SEAD" for science, engineering, art, and design).

These activities reflect aspirations expressed by art-and-technology advocates fifty years ago. This book, in other words, reveals the deep historical roots of these contemporary efforts. In fact, one of the threads running through my narrative is that the recurring waves of art and technology consistently reflect concerns about how engineering students should be educated and how the arts and humanities might contribute to their sense of social responsibility. For university educators, both fifty years ago and today, the question of how to humanize engineers remains a puzzle to be solved. And all of this debate, of course, reflects and responds to contemporary economic circumstances, from the unparalleled boom years of the long 1960s to the tumult caused by the Great Recession.

To be fair, art and technology was (and remains) just one small room in the expansive, quirky house called the art world. The results of art-and-technology collaborations inhabit their own niche here, found somewhere between the machine shop, the museum, and the market. In the spring of 2019, the big art news was that *Rabbit*, Jeff Koons's three-foot-tall, shiny, stainless steel bauble, had sold at Christie's Auction House for over $91 million, an auction house record. (By time you are holding this book, it's quite probable that this marker of cost, if not of taste, will have been broken yet again.) Despite the role of technology in transforming economies, geopolitics, and cultural consumption, today's digital and new media artworks simply do not command the attention of aesthetes and the affluent in the same manner as the sale of a David Hockney painting.

Finally, I see this book as an experiment of sorts in writing about the history of art and art making. It imports some perspectives and ideas from the histories of science and technology into a less familiar territory. This terrain has been surveyed and marked largely by academics and curators who write about modern art and new media. (As one can imagine, calling a particular media "new" while also writing about its history suggests something of a moving target.) Obviously, historians of science and technology know a good deal about topics such as creating research programs, evaluating the importance of experiments, and interpreting results as successes or failures. One lesson these histories impart is that we should do more than focus only on the (lucky) few people who made important discoveries or developed important inventions. Although quite a few of them populate this book, my attention likewise is not given only to artists deemed famous today.

As this book engages with the comingling of art, technology, and science, my narratives address topics familiar to historians of technology and science. These include the enthusiasm for and reaction against large-scale research collaborations, the prevailing political economy and institutional infrastructure that supported them, and the pursuit and effects of publicity and publishing on knowledge production. Engineers were *essential* participants in 1960s-era Big Science, and the same can be said for the Big Art spectacles of the same era. Art, to paraphrase Claude Lévi-Strauss, is good for historians to think with.

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As this book addresses both art and technology—ludicrously broad topics even if one stays within the narrow confines of the past half century—something needs to be said about the examples I've chosen as well as some distinctions I've relied on. These break down to questions of *signal*, *sampling*, and *static*.

I have been drawn most strongly to formal efforts like Experiments in Art and Technology and *Leonardo* as opposed to the many one-on-one efforts that dot this period. I'll borrow an electrical engineering term ("signal strength") as justification. Compared to artists and those who write about them, engineers often appear as relatively silent actors in the larger historical record. Moreover, compared with scientists, engineers are papyrophobic.[39] That is to say, they are less inclined to record their recollections and activities on paper. Compared to scientists, far fewer engineers write memoirs. But a strong signal from the many engineers who participated in the art-and-technology movement can be detected from the large, institutionally supported, well-publicized, and formal efforts. For example, the Getty Research Institute in Los Angeles has over 230 archival boxes and thousands of illustrations that collectively preserve the history of E.A.T. Among these hundreds of thousands of pages are letters and reports written by engineers who collaborated with artists. Well-documented efforts like these offer the best means of recovering signals—about engineers' perspectives, motivations, and experiences—from the noise.

Writing about the history of anyone or anything necessarily involves sampling. Many artworks resulting from these collaborations are best described using a term from the era. When British artist Dick Higgins coined the word "intermedia" in 1965, he was referring to art that "seems to fall between media." Intermedia art was understood as a hybrid thing, cross-fertilizing and blurring boundaries between traditional arts like painting, sculpture, and dance while adding film images, electronic sounds, and other technologies.[40] Higgins's term suggested a coming era when traditional borders between artistic media as well as academic disciplines and professional communities would shift and possibly be erased. The intermedia pieces engineers and artists created were, in effect, multisensory, interactive, aesthetic environments that broke down barriers between high art and its popular, commercial counterparts and, quite often, directly involved the audience.[41] However, my sampling means that not all media (electronic music, for example, presents its own fascinating but vast topic) receive as much attention as I have paid to arts that are primarily visual in nature.

Finally, there is the issue of static—what engineers colloquially call the distortions when radio or television transmissions became fuzzy or ambiguous. The metaphor of static can also be applied to overly categorical definitions of art, technology, and science (and their practitioners). Journalists sometimes labeled people like Billy Klüver and Frank Malina as scientists who built things. In other cases, they appeared as engineers who did scientific research. The differences between science, engineering, and technology might seem to be just academic semantics. But they *are* indeed quite different sets of activities. The knowledge and skills required to do electrical engineering are not the same as what a botanist or astrophysicist needs. And, although engineers and artists were understood as inhabiting two very different worlds, both communities based their professional success on how well they manipulated the physical world to make new things, something which often set them apart from scientists. As one scholar has framed it, scientists discover things whereas engineers (and artists) make things.[42]

Nonetheless, when it came to making comparisons and drawing boundaries in the 1960s, the established point of reference for art critics was typically the binary between art and science, not art and technology. Such conflations (and sometimes confusions) continue to persist today as art is paired interchangeably and randomly with both science *and* technology. One writer has used the term “artsci” to describe a multitude of “colliding worlds,” despite the fact that many of his examples are based on engineering, not science. Meanwhile, “artscience” and, more recently, “sciart” are pitched as a lab-based activity where different types of creativity come together.[43]

I don’t think there is an easy way to eliminate the static that can blur our view of these categorical boundaries. I also don’t think this is necessarily a bad thing. Often times, the historical actors in this book, unconsciously or not, made distinctions between art, science, and technology for reasons that made sense to them at the time. Each offers a regime where aesthetics, discovery, knowledge making, and creativity are important and, likewise, each serves as a historical category in its own right. So, rather than try to impose some pedantic demarcation, I instead accept my actors’ terms and follow their own occasional confusion as to the differences.

My personal interest in the art-and-technology nexus was first stirred by what I saw where I work—an office on the humanities side of campus. The engineers and scientists are on the other side, their bounty of ocean views suggesting how deeply C. P. Snow's claims of a bifurcated academic culture are baked into university architectures. But I routinely walk past a building where students and faculty create objects and installations that combine the visual arts and music with engineering. My school started its Media Arts and Technology Graduate Program more than two decades ago. Scores of universities around the globe have invested in similar programs, which are often explicitly presented to alumni and donors as valuable conduits across academic disciplines or as pathways to fostering innovation.[44] So I started this project with a historian's most basic question—*Why did that happen?*

My interest in the question of creative practices pulled me in further. I started my own career as a scientist before becoming a historian. I know how scientists do research and how historians write books. But I knew next to nothing about how artists make art. The historical contingencies and circumstances that brought engineers and artists together in the 1960s galvanized my enthusiasm further. And, as I looked closer, I started to picture how the confluence of art and technology produced waves that surged at various times and then diminished. These bursts of activity created ripples, sometimes even speculative bubbles, which then shaped the form of subsequent waves. At the same time, the participants in each new wave would often loop back to the past to find examples and justifications for their interdisciplinary activities and advocacy.

Looking at successive waves of enthusiasm for melding art with technology over the past half century reveals the shifting relationship between the worlds of culture, research, and business, as well as audiences' expectations and reactions. At its essence, this book finds that the borders of two important cultural realms—art and technology—are anything but separate, fixed, or immutable. As Natalie Jeremijenko's *Live Wire* suggests, art can be technology and vice versa, complicating categorizations and boundaries. The question lies not in the ways in which art and technology are different, but in the times, places, and spaces where these dynamic enterprises intersected. This common ground was generative, yielding surprises, and sometimes proving unstable. Likewise, we see professional identities of artists and engineers as evolving and flexible. By engaging with one another, artists and technologists have repeatedly built new creative communities in which participants can exhibit imagination, inventiveness, and expertise. And, in the process, they electrified both artworks and the work of making art.

NOTES

INTRODUCTION

1. Douglas M. Davis, "The New Combine," *Art in America* 56, no. (1968): 35.

2. Technically, *Live Wire* was an eight-foot piece of plastic string attached to a small electric stepper motor, which was controlled by local area network input. Activity in the network activated the string, its motion a function of digital traffic on the network. The piece is alternatively referred to in some forums as *Dangling String*; I've opted to use the artist's title. Unfortunately, no especially good images of it could be located.

3. Mark Weiser and John Seely Brown, "The Coming Age of Calm Technology," Xerox PARC (October 5, 1996), http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.129.2275.

4. Biographical information on Jeremijenko comes from several sources, including her current and archived personal web pages which include CVs and press kits as well as Jonah Weiner, "The Artist Who Talks with the Fishes," *New York Times Magazine*, June 28, 2013, 18–21, 38, https://nyti.ms/10iRiOy.

5. "The Q&A: Natalie Jeremijenko, thingker," *Economist*, September 20, 2010, https://www.economist.com/prospero/2010/09/20/the-q-and-a-natalie-jeremijenko-thingker.

6. Kevin Berger, "The Artist as Mad Scientist," *Salon*, June 22, 2006, http://www.salon.com/2006/06/22/natalie/.

7. Mary Lord, "The Scientist as Mad Artist," *ASEE Prism 20, no. 9* (2011): 24.

8. David Chase, "An Engineer for the Avant-Garde," *Yale Alumni Magazine*, March/April 2004, http://archive.yalealumnimagazine.com/issues/2004_03/jeremijenko.html.

9. Courtney Eldridge, "Better Art through Circuitry: Questions for Natalie Jeremijenko," *New York Times Magazine*, June 11, 2000, 25, https://www.nytimes.com/2000/06/11/magazine/the-way-we-live-now-61100-questions-for-natalie-jeremijenko-better.html.

10. C. P. Snow, *The Two Cultures and the Scientific Revolution* (Cambridge: Cambridge University Press, 1959). For the other terms, see Scott Hartley's *The Fuzzy and the Techie: Why the Liberal Arts Will Rule the Digital World* (Boston: Houghton Mifflin Harcourt, 2017).

11. The term comes from a recent volume, edited by David Cateforis, Steven Duval, and Shepherd Steiner, *Hybrid Practices: Art in Collaboration with Science and Technology in the Long 1960s* (Berkeley: University of California Press, 2018).

12. Stephen Bann, ed., *The Tradition of Constructivism* (New York: Viking Press, 1974), 9.

13. Biographical material on Wilfred as well as technical descriptions of his *clavilux* comes from two catalogs that accompanied shows of his works: Donna M. Stein, *Thomas Wilfred: Lumia—A Retrospective Exhibition* (Washington, DC: Corcoran Gallery of Art, 1971) and Keely Orgeman, *Lumia: Thomas Wilfred and the Art of Light* (New Haven: Yale University Press, 2017), as well as "Biographical Notes" on Wilfred prepared in the curatorial files of the Museum of Modern Art, New York (TW/MoMA).

14. Linda Dalrymple Henderson, *Duchamp in Context: Science and Technology in the* Large Glass *and Related Works* (Princeton: Princeton University Press, 1998).

15. My terminology here was informed by conversations with my much-missed friend and colleague, Ann Johnson, who described "knowledge communities" in her book *Hitting the Brakes: Engineering Design and the Production of Knowledge* (Durham: Duke University Press: 2009). Also, Cyrus C. M. Mody, *Instrumental Community: Probe Microscopy and the Path to Nanotechnology* (Cambridge, MA: MIT Press, 2011).

16. Caroline A. Jones, *The Machine in the Studio: Constructing the Postwar American Artist* (Chicago: University of Chicago Press, 1998), 361.

17. These goals fit into the larger rubric of the 1960s-era "human potential movement," which Maslow contributed to. Sarah Brouilette, "Antisocial Psychology," *Meditations* 26, no. 1–2 (2012–2013): 107–117, https://www.mediationsjournal.org/articles/antisocial-psychology.

18. Collaboration itself has been seen by some art historians as a significant theme in art making after 1950. See, for example, Charles Green, *The Third Hand: Collaboration in Art from Conceptualism to Postmodernism* (Minneapolis: University of Minnesota Press, 2001), as well as the catalog edited by Cynthia Jaffee McCabe, *Artistic Collaboration in the Twentieth Century* (Washington, DC: Smithsonian Institution Press, 1984).

19. Jody Rosen, "Does 'Creative' Work Free You from Drudgery, or Just Security?," *New York Times Magazine*, February 3, 2019, 9–11, https://nyti.ms/2GcWsXR.

20. Matthew Wisnioski, *Engineers for Change: Competing Visions of Technology in 1960s America* (Cambridge, MA: MIT Press, 2012).

21. Allan Kaprow, "Should the Artist Become a Man of the World?," *Art News* 63, no. 6 (1964): 34–37, 58–59; Barbara Rose and Irving Sandler, "Sensibility of the Sixties," *Art in America* 55, no. 1 (1967): 44–57; also, Jones, *The Machine in the Studio*.

22. Billy Klüver and Robert Rauschenberg in *E.A.T. News* 1, no. 2 (June 1, 1967): 1.

23. Quote from Simone Whitman, "Theater and Engineering: An Experiment, 1. Notes by a Participant," *Artforum* 5, no. 6 (1967): 28.

24. *E.A.T. News* 2, no. 1 (March 18, 1968): 1.

25. An excellent exploration of Kepes's career and work is John R. Blakinger, *Gyorgy Kepes: Undreaming the Bauhaus* (Cambridge, MA: MIT Press, 2019).

26. Michael Rush, *New Media in Art* (New York: Thames and Hudson, 2005).

27. Barry M. Katz, *Make It New: A History of Silicon Valley Design* (Cambridge, MA: MIT Press, 2015).

28. Jon Agar, "What Happened in the Sixties?," *British Journal for the History of Science* 41, no. 4 (2008): 567–600, doi:10.1017/S0007087408001179.

29. There are many ways one could bookend the long 1960s. While I've chosen one based around technology, a similar one might be based on US politics, starting with Kennedy's assassination in 1963 to the end of the Nixon presidency in 1974.

30. Daniel Bell, *The End of Ideology: On the Exhaustion of Political Ideas in the 1950s* (Cambridge, MA: Harvard University Press, 2000), esp. 313–314.

31. Cateforis, Duval, and Steiner, *Hybrid Practices*, 6.

32. Howard Brick, "Optimism of the Mind: Imagining Postindustrial Society in the 1960s and 1970s," *American Quarterly* 44, no. 3 (1992): 348–380, doi:10.2307/2712981.

33. For example, the index for the post-1945 volume of Hal Foster, Rosalind Krauss, Yve-Alain Bois, Benjamin H. D. Buchloh, and David Joselit, *Art Since 1900: 1945 to the Present* (New York: Thames and Hudson, 2011), doesn't include "technology" or "science," nor is there anything more than an occasional oblique mention throughout its 800-plus pages. Another book, an anthology of essays often used in university courses—Amelia Jones, ed., *A Companion to Contemporary Art since 1945* (Malden, MA: Blackwell, 2006)—includes a section on technology but has notable errors of fact and interpretation. See also, Edward A. Shanken, "Historicizing Art and Technology: Forging a Method and Firing a Canon," in *MediaArtHistories*, ed. Oliver Grau (Cambridge, MA: MIT Press, 2007), 43–70.

34. David Kaiser and W. Patrick McCray, eds., *Groovy Science: Knowledge, Innovation, and American Counterculture* (Chicago: University of Chicago Press, 2016), doi:10.7208/chicago/9780226373072.001.0001.

35. Classic studies include Paul Forman, "Behind Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940–1960," *Historical Studies in the Physical Sciences* 18, no. 1 (1987): 149–229, doi:10.2307/27757599; Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (New York: Columbia University Press, 1993); and Peter Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago: University of Chicago Press, 1997).

36. Steven Shapin, "The Invisible Technician," *American Scientist* 77, no. 6 (1989): 554–563.

37. Howard S. Becker, *Art Worlds* (Berkeley: University of California Press, 1982).

38. My book expands outward in several directions from scholarship done by my colleague Matthew Wisnioski, whose essay "Why MIT Institutionalized the Avant-Garde: Negotiating Aesthetic Virtue in the Postwar Defense Institute," *Configurations* 21, no. 1 (2013): 85–116, doi:10.1353/con.2013.0006, helped galvanize my thinking at the earliest stages of my research.

39. Derek J. de Solla Price. "Is Technology Historically Independent of Science? A Study in Statistical Historiography," *Technology and Culture* 6, no. 4 (1965): 553–568.

40. Dick Higgins, "Intermedia," *Leonardo* 34, no. 1 (2001): 49–54, https://www.muse.jhu.edu/article/19618, which was originally published in several places, including *Something Else Newsletter* 1, no. 1 (1966). Fluxus cofounder George Maciunas deployed the term "expanded arts" in the winter 1966 issue of *Film Culture*.

41. Elenore Lester, "Intermedia: Tune In, Turn On—And Walk Out?," *New York Times*, May 12, 1968, https://nyti.ms/1LXAv7W. Fred Turner, in his *The Democratic Surround: Multimedia and American Liberalism from World War Two to the Psychedelic Sixties* (Chicago: University of Chicago Press, 2013), proposed the term "surrounds" for these kind of installations, but I find the original term both more explanatory and historically accurate.

42. A distinction further complicated by Steven Shapin in his "Making Art/Discovering Science," *Know* 2, no. 2 (2018): 177–205, doi:10.1086/699899. For a sense of how variable and historically fraught the T-word is, see Eric Schatzberg, *Technology: A Critical History of a Concept* (Chicago: University of Chicago Press, 2018).

43. Arthur I. Miller, *Colliding Worlds: How Cutting-Edge Science Is Redefining Contemporary Art* (New York: Norton, 2014); see also, Leonard Shlain, *Art & Physics: Parallel Visions in Space, Time, and Light* (New York: William Morrow, 1991); Jill Scott, ed., *Artists-in-Labs: Processes of Inquiry* (New York: Springer, 2006); and David Edwards, *Artscience: Creativity in the Post-Google Generation* (Cambridge, MA: Harvard University Press, 2008). In most of the scholarly literature, the

prevailing focus has addressed the art-science nexus. For example, Linda Dalrymple Henderson, *The Fourth Dimension and Non-Euclidean Geometry in Modern Art* (Princeton: Princeton University Press, 1983); and Caroline A. Jones and Peter Galison, eds., *Picturing Science, Producing Art* (New York: Routledge, 1998). A significant exception to this focus on art and science is the topic of computer-generated art, which has received a great deal of attention to the larger exclusion of other art-technology activity. Some recent book-length treatments include: Hannah B. Higgins and Douglas Kahn, eds., *Mainframe Experimentalism: Early Computing and the Foundations of the Digital Arts* (Berkeley: University of California Press, 2012); Carolyn L. Kane, *Chromatic Algorithms: Synthetic Color, Computer Art, and Aesthetics after Code* (Chicago: University of Chicago Press, 2014); Grant D. Taylor, *When the Machine Made Art: The Troubled History of Computer Art* (New York: Bloomsbury, 2014); and Zabet Patterson, *Peripheral Vision: Bell Labs, the S-C 4020, and the Origins of Computer Art* (Cambridge, MA: MIT Press, 2015).

44. A recent and timely look at the landscape of SEAD programs at public universities is Kari Zacharias and Matthew Wisnioski, "Land Grant Hybrids: From Art and Technology to SEAD," *Leonardo* 52, no. 3 (2019): 261–270, https://www.muse.jhu.edu/article/728399.

CHAPTER 1

1. C. P. Snow, *The Two Cultures and the Scientific Revolution* (Cambridge: Cambridge University Press, 1959), 16.

2. February 15, 1953 letter from Malina to his parents; Folder 10, Box 22, Papers of Frank J. Malina, Library of Congress, Washington, DC (FM/LOC).

3. The most recent and well-researched examination of Malina's life, especially his rocketry and political activism in the 1930s, is Fraser MacDonald's *Escape from Earth: A Secret History of the Space Rocket* (New York: PublicAffairs, 2019). Malina wrote about his own activities in rocketry in several essays including "America's First Long Range Missile Program: The ORDCIT Project of the Jet Propulsion Laboratory, 1943–1946: A Memoir," in *Essays on the History of Rocketry and Astronautics: Proceedings of the Third Through the Sixth History Symposia of the International Academy of Astronautics*, Vol. II, NASA CP-2014 (1977): 339–383, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19770026104.pdf. In addition, I've drawn on several informative oral history interviews including an October 29, 1968 interview with R. Cargill Hall in the NASA Historical Archives and a December 14, 1978 interview with Mary Terrall in the Archives of the California Institute of Technology.

4. A good overview is Hunter Hollins, "Science and Military Influences on the Ascent of Aerospace Development in Southern California," *Southern California Quarterly* 96, no. 4 (2014): 373–404, doi:10.1525/scq.2014.96.4.373.

5. March 6, 1935 and February 2, 1936 letters from Malina to his parents; Folders 5 and 6, Box 21, FM/LOC.

6. Folder 9, Box 14, FM/LOC.

7. James L. Johnson, "Rockets and the Red Scare: Frank Malina and American Missile Development, 1936–1954," *Quest* 19 (2012): 30–36; Malina's involvement with the Communist Party and leftist politics in general while at Caltech is well documented in MacDonald, *Escape from Earth*.

8. My thanks to Fraser MacDonald for sharing the most recent copy of Malina's file, which he received in mid-2019.

9. "Art," undated notes (but likely 1937 or 1938), Folder 14, Box 14, FM/LOC.

10. Galerie Henri Tronche, "Frank J. Malina: Extraits de Presse," 1953; Folder 1, Box 39, FM/LOC.

11. Undated letter, likely late 1944, from Frank Malina to Liljan Malina; Malina Family Archive.

12. October 8, 1944 and October 13, 1944 letters from Frank Malina to Liljan Malina; Malina Family Archive.