Biological Relatives

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On November 17, 1944, U.S. president Franklin Delano Roosevelt commissioned a report from the Office of Scientific Research and Development intended to “make known to the world as soon as possible the contributions which have been made during our war effort to scientific knowledge.” His intentions were both reparative and translational. As one of his last acts in office, the author of the New Deal sought to turn swords into plowshares by bringing the science of war into the service of peace, “with particular reference to the war of science against disease” and an emphasis on “what the government can do now and in the future to aid research” (Roosevelt 1944). The resulting report, “Science—the Endless Frontier,” authored by Vannevar Bush, head of the Office of Scientific Research and Development, was published in Washington in 1945, shortly after Roosevelt’s death and just before news of the atomic bomb was released to the American public. An “instant smash hit,” as one of Bush’s colleagues is reported to have remarked on the day following its release (Kevles 1977: 23), the report’s contents would not only guide science policy in the United States throughout the twentieth century and beyond, but would define an enduring worldwide ethos—and lasting idiom—for the scientific pursuit of the unknown in the name of the public good.

Roosevelt’s letter introduced the now-famous frontier analogy that would guide his final mission on behalf of science. Evoking the spirit of national repair that infused many of his speeches during the Depression era, he imagined the progress of science as a new American frontier. The letter ended with a call for a new kind of pioneering on the “frontiers of the mind”: “New frontiers of the mind are before us, and if they are pioneered with the same vision, boldness, and drive with which we have waged this war we can create a fuller and more fruitful employment and a fuller and more fruitful life” (Roosevelt 1944). Bush began his ensuing report with reference to the defining historic
role of the U.S. government of protecting access to new frontiers, claiming it was an “American tradition” that “has made the United States great”: “It has been basic United States policy that Government should foster the opening of new frontiers. It opened the seas to clipper ships and furnished land for pioneers. It is in keeping with the American tradition—one that has made the United States great—that new frontiers shall be made accessible for development by all American citizens” (Bush 1945).

Bush was an engineer from New England, educated at MIT, and deeply involved in the scientific contributions to U.S. military efforts during both world wars. He later became the first director of the National Science Foundation in 1950, on which organization’s website his famous report remains prominently accessible more than half a century later. The American frontier analogy he was bequeathed by Roosevelt to guide his task of redefining the postwar role of American science would quickly become one of the most frequently employed idioms to describe the pursuit of scientific knowledge and discovery, as well as the translation of science into useful applications, now defined by the National Science Foundation as the “critical path.” Today the frontier analogy is ubiquitous in descriptions of scientific exploration, and is virtually synonymous with scientific discovery. It is the dominant trope of many countries’ science policy discourse, and much academic scholarship on science as well as media coverage, corporate mission statements, and product advertising. Everything from stem cells to nanotechnology is today described as a new frontier—indeed it might be even argued the concept of the frontier has been reborn in these contexts (see figure 3.1).

The Reproductive Frontier

Reproductive biomedicine is a good example of a twentieth-century science that came of age on the postwar scientific frontier mapped out by Bush. Indeed, given its agricultural origins and often pragmatic aims, reproductive biology could be a poster science for the frontier ethos on which Bush’s report is based. Control of reproduction, or what Philip Pauly calls “culturing nature,” was a prominent American frontier concern because of its importance to both horticulture and husbandry during the transition from settlement to industrialization. To a large extent it was an experimental science that began on the farm in the form of agricultural improvement—or what Deborah Fitzgerald (1990) calls “the business of breeding.” Both plant and animal reproduction were dominant concerns at newly formed, postsettlement Midwestern U.S. colleges such as the University of Illinois—founded in
1867 and originally named Illinois Industrial University. The founding of the Society for the Study of Reproduction at the University of Illinois at Urbana-Champaign in 1967 reflects the field’s significant and ongoing links to the land grant universities established to provide education in the settlement areas, with their prominent emphasis on agricultural improvement, the veterinary sciences, and medicine—as well as industry. Postwar reproductive bioscience, as both Adele Clarke (1998) and Evelyn Fox Keller (2002) have shown, was part of the shift to biology that characterized the second half of the twentieth century, with its emphasis on the logics of life rather than the physics of death—thus in some ways confirming exactly the transfer Roosevelt envis-
aged from the sciences of war into a war on disease. The development of IVF, like the earlier introduction of artificial insemination into livestock breeding, recapitulates many of the definitive features of technological innovation that characterize postwar reproductive biology and its translation into more widespread commercial and industrial applications.7

However, and as this chapter charts, the evolution of IVF was also—perhaps more like an actual frontier—often haphazard and fortuitous (as is the business of breeding). Among other reasons for its meandering path, its history can be read as the evolution of technique through hands-on exploratory experimentalism, as much as the advance of basic scientific understanding or clearly specified practical goals.8 Not a few of the major techniques used in reproductive biomedicine were discovered by accident, such as intracytoplasmic sperm injection and the ability to freeze mammalian gametes (Gordon 2003). It is, as noted earlier, one of the most prominent historical ironies of IVF that much of the research leading to its eventual transfer “into man” was originally intended to restrict, not promote, fertility. As we shall see in this chapter, several of the most prominent figures associated with the development of human IVF, including Robert Edwards, were funded by philanthropic institutions such as the Ford Foundation in order to improve the efficacy of contraception. The “developments in embryology” referred to by Shulamith Firestone (1972) in chapter 2, for example, were aimed at population control—a topic that she, like many political activists and social commentators in the 1960s and 1970s, considered to be the single most important issue facing the human race.

Although the frontier idiom as it is used to describe scientific progress is associated with the steady march of knowledge “forward,” other definitions of the frontier, like many frontier histories, emphasize the opposite—namely the frontier as a site of confusion, hybridity, destruction, and conflict. Both meanings of the frontier have relevance to the history of disciplining reproduction. In attempting to depict the early history of IVF in this chapter, I have emphasized both the search for knowledge that would offer a critical path to applications, and the haphazard quality of research in the area of human reproduction—arguing this was preceded by a similar pattern within experimental embryology. Generally lacking a unified hypothesis or theory, the history of embryology was characterized by Joseph Needham in the 1930s as largely “ad hoc” (1935: 17). In part this is because embryology, like most experimental sciences, is highly tool dependent. Episodes from the history of experimental embryology are thus presented in this chapter not only because they illustrate the technologization of reproductive substance that pre-
cedes clinical IVF, but because they confirm the importance of what Clarke and Fujimura (1992) describe as “the right tools for the job.” Even Wilhelm Roux’s work on “developmental mechanics”—often cited as the origin of experimental embryology—is more often celebrated for the innovative experimental technique he introduced than his often inconclusive scientific results. This emphasis on the importance of technical skill, and the invention of new tools, is very striking in the history of the reproductive frontier, and is defined by Needham (1935: 17) as the core “limiting factor” in the advance of embryology. Of course the interdependence of knowledge and technique characterizes all sciences, and it is not uncommon for technological discoveries encountered either by accident or by sheer luck to redirect scientific inquiry down new paths—paths that emerge in the wake of technological advances that make them both possible and passable, only acquiring a direction in retrospect. Interestingly, some of these new paths appear because technologies are passed around, being put to new uses that expand their remit, and thus acquiring value, like capital, through circulation. A chief means of technological passaging or transfer in embryology is the movement of technique across species—through interspecific technology transfer. For example, in the long-unsuccessful effort to fertilize a human egg in vitro, Robert Edwards eventually borrowed the culture media one of his graduate students (Barry Bavister) had developed for hamsters. Following its success with human ova, Edwards described this medium as a “magic fluid” that had helped not only to pave the way to human IVF but to topple scientific orthodoxy: “Once again orthodox scientific opinion had been proven wrong” (Edwards and Steptoe 1980: 82). Here, as is typical of the history of embryology, and of IVF, is the sequence whereby a cherished hypothesis falls in the wake of a successful, application-led, technical breakthrough. In vitro fertilization is not unusual in having a rather fumbling as well as an eventually distinguished scientific ancestry. This is what arguably makes it interesting from the point of view of understanding both science and reproduction as frontiers that are shaped by open-ended exploration largely based on the use of handmade and hand-held tools.

This chapter thus addresses “the question concerning technology” in relation to IVF by using the frontier idiom to explore what is meant by technological pioneering, manifest as the technical exploration of reproductive mechanisms. While offering a background of technique to IVF and embryo transfer, this chapter also focuses on what the terms “frontier” and “technology” mean in relation to each other, and what happens to this relationship when it is reproductive interiority that is being charted, mechanized, and
domesticated. How do we understand the concept, for example, of embryo pioneering? What does it mean for reproduction to be “made available for development” in order to produce a more “fruitful way of life”? What work does the frontier analogy do in the context of experimental embryology, and what kinds of contact, conversion, and contingency does an analysis of this analogic idiom reveal?

Like Marx, Joseph Needham argued that “the Carlylean tendency to regard the history of science as a succession of inexplicable geniuses arbitrarily bestowing knowledge upon mankind has now generally been given up as quite mythological. A scientific worker is necessarily a child of his time and the inheritor of the thought of many generations” (1935: 1). More recent science studies scholars, such as Joan Fujimura, similarly argue that the “problem path” of any particular experiment evolves through “situated interactions,” emphasizing, like Needham (1935: 7–8), that experimental embryologists’ problems coevolved with their instruments (Fujimura 1996: 156; and see also the work of Suchman 1987, 1995, 2007). Technology, in these models, cannot be separated from conceptual equipment, historical conditions, cultures of the workplace, or the wider social milieu. Scientific apprehension is based on a prosthetic imagination: experimental practice relies on inherited cultures of technique, and the maintenance of the traditional artisanal skills needed to reproduce vital equipment and devices. Inevitably, technological “probing” or “reaching” also implies a gap between the immediate conditions of work and a future yet to be shaped. As the British social anthropologist Alfred Gell pointed out in his essay on technology in 1988, “technology is coterminous with the various networks of social relationships that allow for the transmission of technical knowledge, and provide the necessary conditions for cooperation between individuals in technical activities” and these conditions, he adds, by definition involve “a certain degree of circuitousness.” He continues: “Techniques form a bridge, sometimes only a simple one, sometimes a very complicated one, between a set of ‘given’ elements . . . and a goal-state that is to be realised making use of these givens” (Gell 1988: 6). In other words, “technical means are roundabout means of securing some desired result” and “tools . . . are an important category of elements which ‘intervene’ between a goal and its realization” (6). In chapter 4 I return to Gell’s analysis of technology in the context of what he describes as “Technology of Reproduction,” namely kinship—“a set of technical strategies for managing our reproductive destiny via an elaborate sequence of purposes” (7). For the purposes of addressing ivf as a technology in this chapter, however, it is his discussion of technology’s connection to magic and free play that concern us first.
Following both Malinowski and Lévi-Strauss, Gell defines magic as a form of free play: “Magic consists of a symbolic ‘commentary’ on technical strategies,” he suggests, comparing it to the spontaneous imaginative play of children’s pretend games. This type of play is characterized by its imaginative projection (“Look, I am an airplane!”) that reaches “beyond the frontiers of the merely real” (Gell 1988: 8). Play, in this sense, is a prosthetic—a reaching, probing, exploratory exercise—to engage with what is beyond its actual conditions. Like magic, it “sets an ideal standard, not to be approached in reality, towards which practical technical action can nonetheless be oriented.” Gell continues:

Technology develops through a process of innovation, usually one which involves the re-combination and re-deployment of a set of existing elements or procedures toward the attainment of new objectives. Play also demonstrates innovativeness—in fact, it does so continuously, whereas innovation in technology is a slower and more difficult process. Innovation in technology does not usually arise as the result of the application of systematic thought to the task of supplying some obvious technical “need,” since there is no reason for members of any societies to feel “needs” in addition to the ones they already know how to fulfil. Technology, however, does change, and with changes in technology, new needs come into existence. The source of this mutability, and the tendency toward ever-increasing elaboration in technology must, I think, be attributed, not to material necessity, but to the cognitive role of “magical” ideas in providing the orienting framework within which technological activity takes place. (Gell 1988: 8)

One way to understand the frontier idiom, according to Gell’s description, is as a form of magical thinking, which sets an orientation to the task of exploration beyond the reach of existing elements or procedures “toward the attainment of new objectives.” This orientation is what directs the frontier exploration toward a reconciliation of mental and material equipment. Notably, as an orienting framework, the frontier is by definition temporary: eventually, frontiers become something else. An important feature of the frontier is that it is, like the horizon, a temporary line, establishing a relationship rather than a place—indeed its definition has less to do with an actual place than an imagined space. Above all the frontier describes a set of possibilities: like Gell’s imaginative play, it is a magical idea. Unlike the reach of Gell’s imaginative play, however, the frontier can be used to reimagine both the future and the past—thus functioning as a kind of conversion device, in both time and
space. The frontier idiom is most specific or real when it is imagined in the past, invoking an actual historical scene that serves as an originating ground of present-day conditions. This has been especially true of the frontier narratives of the New World, such as in the United States and Australia, where the frontier idiom has been accompanied by a distinctive national ethos. Here, the frontier idiom is at its narrowest and least imaginative—functioning as a defensive panacea or apologetic myth. At the other end of the spectrum is the translation of the lost frontier that is behind into a future-oriented idiom—such as that of endless scientific progress that lies ahead. In this context, the frontier that is still ahead is recharged with the promise of unexplored territory offering an open-ended prospect onto a promising unknown, the core symbol of which is discovery.

The translation of a historic frontier narrative into a future-oriented invitation is one reason why, despite its parochial and ideological American origins, the endless frontier analogy is today equally British and European in its widespread use as an aspirational discourse of scientific innovation. Indeed, the frontier analogy is among the paramount examples of idioms that have traveled back to Europe from the colonial context. The same can be said of the “manifest destiny” ethos that the frontier idiom expresses—the moral imperative to defend technological progress in aid of human betterment, also a colonial Americanism. Like the Californian vines expatriated to restock their terroir d’origine on the Continent in the wake of phylloxera, the American frontier analogy has gone inconspicuously native, even (and perhaps especially) in Europe.

The colonial connotations of the frontier idiom are, of course, not entirely absent from its current usage as an idiom for scientific progress. The image of “walking hopefully into the scientific foothills” is one that still carries with it the sense of duty and conquest that is as recognizably British or European as American, especially when it is used to describe medical or scientific exploration of the unknown. We need only listen to Sir Ian Lloyd in the British House of Commons in the spring of 1990, as Parliament debated the future of embryo research, at a turning point in the passage of legislation that has since made the United Kingdom a leading center of innovation in the life sciences, to be reminded of how seamlessly a moral sense of necessity, responsibility, obligation, exploration, and progress can be woven together by using the frontier idiom to evoke a sense of both destiny and duty. Describing the technologization of reproductive substance as a map, Lloyd argues its completion signifies no less than the successful passage into a new phase of human civilization:
The discovery of DNA, the very blueprint of life, is certainly awe-inspiring, and when the full map of the human genome is known . . . we shall have passed through a phase of human civilization as significant as, if not more significant than, that which distinguished the age of Galileo from that of Copernicus, or that of Einstein from that of Newton. . . . We have crossed a boundary of unprecedented importance. . . . There is no going back. . . . We are walking hopefully into the scientific foothills of a gigantic mountain range. Hitherto, man has had no option but to come to terms with a serious burden of human impairment, but now he can look ahead, perhaps a long way, to its eventual elimination. . . . For us to forswear the assistance which science can provide in modifying that code to the advantage of the human race would be an indefensible abdication of responsibility. It would cross the portcullis of this place with a most sinister and destructive bar. (Sir Ian Lloyd, HC, 23.4.90, cols. 96–98)

Significantly, the image of “walking hopefully into the scientific foothills of a gigantic mountain range” evokes the quintessentially American frontier landscape with figure (in Europe a frontier is a border between two nations). It invokes the equally American manifest destiny model of future progress to be gained through the risks and potential costs necessary to chart the unknown. Importantly, it is not only the process of discovery that is being evoked here, but its reward in the form of scientific and technological progress: in this case the “awe-inspiring” full map of genetic interiority that will inaugurate a significant new phase of civilization. The progressive, linear conception of history evoked in the image of looking ahead, “perhaps a long way,” conflates the time and space of progress into the single figure of a forward-marching pioneer, who in turn invokes the custodial, protective duty of Parliament. It is on behalf of both the lone explorer and the lives of future generations that Parliament must perform its forward-looking duties. Indeed, there is no going back.

As this chapter argues, there are many reasons why the history of IVF is imagined through the frontier idiom, particularly in its American form, in which the frontier is a crucible of rebirth. This was the meaning of the frontier that was pivotal to Frederick Jackson Turner’s influential hypothesis establishing the American frontier as the soil out of which a new kind of man was born—a man with his back to Europe, a new outlook, and a distinctive intellect (essentially that of an enterprising engineer). In the contemporary period, as we shall see, it might be argued that the frontiers of reproduci-
tion and regeneration have become yet again a different kind of crucible, indeed a literal set of containers for rebirth—the test tubes, petri dishes, and new labs in which the future of humanity is being regenerated and remade, in order to enact a duty, once again, of cultivation in the name of human progress. It is here too that we see in the idiom of the frontier the clear outlines of a model of technology as kinship, providing both the ethos and the map of civilized regeneration manifest as the cultivation of human reproductive substance.

Cultivating Technique
As well as providing an instrumental means, a cognitive orientation, and a kind of prosthetic reach, technology is a form of material culture—a legacy of technique as substance, inheritance, or stock. Just as the tools by which the soil is cultivated in any particular field or region of settlement are inseparable from its more general mode of reproduction, so any form of cultivation can be characterized, in part, by its technological culture—the specific form of its technological arts, tools, and devices. The history of embryology is not dis-similar to agriculture in having evolved as a tool culture as well as a conceptual one: its technical characteristics and its craft have developed inconsistently, and variously, but cumulatively and interactively across diverse fields of innovation and experimentation—not unlike viticulture, milling, or weaving. Although technological evolution is never purely technical, there is nonetheless a genealogy of technique that can be followed, in the form of a substantialized legacy of skill and knowledge—and one that is passed around as well as passed down. Such genealogies of technique can be seen in the development of experimental embryology as it is employed variously to investigate reproduction, heredity, animal and plant breeding, development, determination, growth, and myriad other topics on its way to generating the possibility of IVF “in man.” As noted earlier, this evolution is not simply linear but circulatory—we might even think of experimental embryology as an accumulation of techniques that evolve through circulation, as they are passaged through a range of contexts, becoming interwoven with a diverse set of fundamental and practical problems in the process. This is also how we might approach the sociology of technology: in the same way that Lévi-Strauss (1969: 479) borrows Maurice Leenhardt’s image of “the action of the needle for sewing roofs, which, weaving in and out, leads backwards and forwards the same liana, holding the straw together,” so do the tungsten steel needles and Spemann pi-
pettes of the embryologists (figure 3.2) substantialize a technological kinship, or tool genealogy, uniting nineteenth-century science with techniques that are still in use today, and agricultural applications with those of clinical medicine. The historical examples presented to illustrate this interwoven fabric, or texture, of technique in this chapter are thus not meant to imply that there is, in the conventional progressive sense, a linear process of embryo research culminating in the triumph of the miracle baby. Rather, in a more anthropological style of episodic or indicative description, and with Gell’s sense of play in mind, the techniques of embryology can be observed, like the famous circulating connubium, as transferable, interspecific relations that together substantialize a kind of technological kinship.17

In an attempt to explore these kinships of embryological technique as a background to contemporary IVF and embryo research, the following descriptions are intended to provide neither a Darwinian narrative for tech-
nology nor a progressive chronology of innovation driven by necessity and utility. The effort instead is to put under closer inspection the development of specific cultures of embryological technique, such as those discussed in chapter 2, in the depiction of how to passage a stem cell line, and to mine these examples for resources that are pertinent to the question of what it means to be after IVF.18 This chapter thus also emphasizes that despite its association with contemporary biomedical novelty, many of the basic techniques involved in IVF can be traced back to the nineteenth century and beyond. In terms of their development over time, what we can observe in the history of IVF is a pattern of technological transfer that circulates through diverse model organisms and animal models, creating a distinctive animal-tool interface in this interspecific field by interconnecting reproductivity across widely disparate sites of intervention. It is on the basis of this accumulated experimental and technical knowledge — of what works in one model system, and the extent to which it can be transferred (by analogy, model, or tool) to another — that much of the work leading to human clinical IVF was founded. This “inter” work principally involved the removal of mammalian ova, their culture in vitro, in vitro fertilization of the egg, and transfer of the resultant embryo either to a recipient uterus or to another glass container.

The process we can thus observe is one of building up an interspecific system of reproductive workings that combine technology with substance in the name of both exploration and control. As a work object, reproductivity thus acquires a new meaning and scale as a biotechnical entity that is at once both sub- and suprahuman, while technology in this system becomes a shared substance that can no longer be seen as separate from reproductive matter. One of the reasons it is in some ways surprising that IVF was not applied to humans much earlier is because of the intensity of research in the field of embryology in the first part of the twentieth century, followed by an equally striking concentration on early mammalian development in the post-war period. But human reproduction per se was not the primary goal of much research leading up to human IVF. At issue was the constitution of a much larger system of biotechnical reproductivity — and not so much a mode of reproduction as a model of it. It is in the context of this more general effort to model reproductivity that the unity of biology and technique are substantialized as its workings or mechanics.19

The late nineteenth and early twentieth century are renowned as a dense period of embryological investigation, conventionally associated with the technological and conceptual shifts that give rise to experimental embryology as an emergent modern scientific field (later giving way, as Haraway [1976]
chronicles, to the organicism and cybernetic feedback loops of the systems analogy that still predominate in biology today). It is during this period that the tool kit of embryology underwent one of the most important changes that would later enable the development of a huge variety of practical reproductive applications, as well as fundamental research experiments, namely the process through which the embryo is transformed from an object of study into a means of intervention. Rather than being simply passive unexplored anatomical terrain, which could be mapped and charted in the manner of a newly discovered geographic region, the interior of the embryo comes to be seen during the late nineteenth century more in terms of an organized mechanical system—subject to dis- and reassembly, with parts that can be extracted and transferred into other embryos. In other words, this is the point at which parts of embryos themselves become tools, a new species of investigative apparatus: they are no longer simply worked on or even worked up but become recombinant working models of themselves.

The shift away from mere description is conventionally associated in the history of embryology with the *Entwicklungsmechanik*, or “mechanics of development,” of the German zoologist Wilhelm Roux, or the Swedish anatomist Wilhelm His—both of whom were inventive technicists as well as theorists. The shift was codified by turn-of-the-century biologists such as Oxford’s J. W. Jenkinson, who began his 1909 textbook *Experimental Embryology* with an account of “a new branch of biological science,” concerned with “the origin of form,” which the author dates back to a specific experiment: “It is with the origin of form that [experimental embryology concerns itself], and in particular with its origin in the individual. The endeavour to discover by experiment the causes of this process—as distinct from the mere description of the process itself—is a comparatively new branch of biological science, for Experimental Embryology, or, as some prefer to call it, the Mechanics of Development . . . really dates from Roux’s production of a half-embryo from a half-blastomere, and the consequent formation of the ‘Mosaik-Theorie’ of self-differentiation” (Jenkinson 1909: iii).

In contrast to the “mere description” of embryos via dissection, or classification of embryological processes via observation, experimental embryology is distinguished by its emphasis on direct interference with the internal mechanics of the embryo using manual or chemical intervention, such as investigation through fusion, stress, constriction, grafting, or recombination. Experimental embryology is also characterized by the attention paid by its practitioners to deviant, monstrous, and pathological formations—an interest that early on is envisaged as a means of exploring not only part-whole re-
lations but the extent and character of innate organic plasticity. It emerged in the period during which Darwin’s, Weismann’s, and later Mendel’s models of inheritance were being debated in relation to morphogenesis—the acquisition of form—with an emphasis on experimental means of identifying causal mechanisms and thus the workings of heredity. Much of the experimental work in experimental embryology was thus also highly conceptually—indeed to many philosophically—motivated, while at the same time becoming more boldly instrumental in disrupting natural trajectories and inventing, or forcing, new recombinant ones. New microsurgical tools and techniques were developed as part of an expanding culture of wrench-in-the-works experimentalism based on the transfer of substances between whole organisms in order to study the parts of organisms, or to create new mosaic organisms that were deliberately designed to be different from what would emerge normally. This newly interventionist embryology enabled mechanical parts of embryos to become tools of investigation to understand, or probe, the causal dynamics of morphogenesis, reproduction, regeneration, development, and heredity. Experimental progress could be made either by putting cells together or taking them apart—a constructivist ethos that was designed to elicit and explore the forces that controlled embryonic organization, growth, and the acquisition of form. Naturally existing forms and substances were increasingly viewed as biological mechanisms that could be imitated, inverted, reassembled, reverse engineered, or otherwise manipulated, while new things that had never existed could be created and observed in vitro in order to isolate individual controlling variables, units, or factors through the artifice of experimentation.

The ethos of experimental embryology, then, was not so much one of understanding how form followed function, or vice versa, as of manipulating both, often by transposing them—thereby converting the resulting organism into a double window onto development: the object of study (e.g., a fertilized egg) in its controlled environment (the experimental system) was one window, whereas what went on inside the entity (e.g., the mechanics of embryogenesis) became another. In the same way the in vitro dish renders entities that would be invisible in vivo amenable to observation and manipulation, so too do such entities themselves become in vitro containers for experimentation (its “vasculature,” as Marx might have said). Thus, Wilhelm Roux, a student of Haeckel, conducted experiments with amphibian embryos by recombining their parts to make new wholes (mosaics), while Hans Driesch, his contemporary, separated two sea urchin cells to demonstrate they could produce two independent organisms—manually splitting a whole entity to reveal
its innate properties of regeneration. The once-flat world of embryological observation had erupted: it was now a tooled-up experimental vivarium. As well as a looking-glass world, in which the workings of morphology were subject to remechanization, this is equally a push-me-pull-you experimental field of entities built through collision in order to model the invisible, otherwise imperceptible forces at work in the processes of reproduction, regeneration, and development.

**Embryo Pioneers**

As late nineteenth-century embryologists increasingly sought to tackle questions of organization, morphogenesis, differentiation, and recapitulation, embryological experiments became more technically ambitious and more prolonged over time—eventually leading to the in vitro dish window of tissue culture in the early twentieth century. As well as being tedious and time-consuming, such experiments were in other respects also similar to highly skilled manual crafts—based on precise, repetitive techniques and prolonged exposure to specialist tools and familiar research materials. Like that of jewelers, embryologists’ labor required excellent eyesight, dexterity, practice, and tenacity. As in other mechanical workshops, embryological artisans required tools to make tools, as well as accumulated knowledge about how to use them, often acquired through lengthy apprenticeships through which such knowledge was passed on to a new generation of experimentalists. A wide variety of optical techniques were used to visualize embryos, and new instruments were constantly being developed to manipulate them, as well as containers and solutions in which to keep them (figures 3.3 and 3.4). Chemical forms of preservation, marking, labeling, and interference were used, as well as handheld microtools. Equipment derived from watchmaking and eye surgery was adapted to embryological experimentation, and remade by hand. Staining, dyeing, and tattooing techniques were used, as well as wax modeling and sectioning. Passed on, remastered, and handed down again, these genealogies of artifice composed the technological infrastructure of increasingly adept manual control of reproduction.

These accumulated techniques can be interpreted in more Marxist terms as means of getting a better handle on reproductive substance, achieved through mechanical evolution. The constant redesign of specialist tools in the embryology lab is in this sense no different from any other artisanal setting, where practical and spontaneous innovations are constantly being made.
with a view to securing more purchase on the object being worked. Similarly, we can also approach these techniques, and their relations to their objects, as frontiers insofar as they constitute a zone of encounter characterized by contact and conversion—themselves also generative processes. From this perspective, we can appreciate why the idiom of the frontier—of open-ended exploration, unknown territory, and unexpected encounters—usefully emphasizes the fruitfulness of indeterminacy, particularly in the context of experimental science. From the point of view of the artisan, technician, or experimentalist, in other words, the frontier is never “toward”—for it is precisely the indeterminate nature of experimental outcomes that gives them value to the scientist. If, in other words, the idiom of science as a frontier as used in the British Parliament to describe “walking hopefully” into “a gigantic mountain range” conveys the helicopter view of science that is external to it, the experimentalist’s much more constrained outlook can only barely
perceive the immediate territory at hand, in other words, the experiment. No airy, Archimedean panoptic is available to the lone experimentalist—whose tools themselves are always part of what is being explored, and who is often working by habit rather than sight.

This internal sense of the frontier—the frontier as it is encountered from within science—and its equation with not only the exploration of objects but the technical means of doing so, is substantially evident throughout the history of experimental embryology, where scientific pioneering is closely associated with both the mastery of existing techniques and the development of new ones. Contrary to the view of the scientist as explorer walking hopefully into unknown lands, to discover and chart their interior (although not inconsistent with this depiction), is the pioneer embryologist as toolmaker—whose tools are themselves the path forward—or even the frontier being worked. Hence, for example, the biologist and historian Scott Gilbert, in his introduction to *A Conceptual History of Embryology*, writes that developmental biology is the offspring not only of “embryology’s concepts, organisms and sense of wonder” but of the “new set of tools with a resolving power far greater than what was available a generation ago.” Deploying a developmental analogy for the science itself (and echoing the reproductive double entendre of his book’s title), Gilbert describes the increase in “resolving power” available to a new generation of experimentalists as the result of a combination of new model organisms, new tools, and new molecular methods: “Frogs, chicks and sea urchins (along with nematodes, flies and leeches) are now being dissected with monoclonal antibodies, antisense mRNAs, and confocal microscopes. We are presently seeing a return to those old embryological enigmas that were abandoned for lack of such specific tools. The morphogenesis of the discipline continues. . . . Glory, indeed, to the science of embryology” (Gilbert 1991: ix).

The sense of the tool itself as a frontier is similarly captured by the use of the adjective “pioneering” to describe the development of tools and techniques in science—hence, for example, the description of Patrick Steptoe as the “laparoscopy pioneer” on his Wikipedia page. Thus also the frequent references to technical advances that open up new research opportunities and pathways forward in understanding. The pioneer awards common to scientific societies, health organizations, and academia are commonly associated with the development of new technology.

The annual Pioneer Award of the International Embryo Transfer Society (IETS), established in 1982, provides a useful picture of the range of em-
bryological techniques that have been seen to pave the way to new research advances in this field, as the frontiers of knowledge yield to new working methods. Specifically chosen for their technical contributions to science, the current list of thirty Pioneer Award winners includes many of the most eminent figures in modern reproductive and developmental biology (table 3.1). As can be noted from this list of the IETS embryo Pioneer Award winners from the 1980s and 1990s, advances on the reproductive frontier were often achieved in the form of both technological innovation and technology transfer. Although celebrated for the paths they individually opened up to other researchers, the general pattern of advance can equally be characterized as one of technological exchange—of sharing and comparing techniques to explore different biological mechanisms, at different stages of development, under varied conditions, and across a wide range of different animal species or models.

Also notable from this list is the striking number of Pioneer awardees who were centrally involved in the development of human IVF. Indeed, in its award to Robert Edwards in 1993, the society noted that it is “no accident that human IVF clinics are well populated by scientists and technicians who began their work with members of [the IETS]” (IETS 1993). As Edwards himself has noted, the road to IVF was not only long and bumpy, but also often haphazard and even directionless. As noted in chapter 1, Edwards did not initially set out to achieve human IVF, just as Chang did not originally intend to pursue IVF in rabbits. Indeed few of the scientists listed in table 3.1 had a clear path ahead of them as they moved forward, often instead being redirected as technical obstacles were overcome, opening new instrumental possibilities, and—equally haphazardly—new and unexpected avenues of inquiry.

Of the many questions that can be asked about the depiction of science and technology as frontiers, then, is how many there are. Taking the frontier to comprise a set of relationships, for example, we might consider at least three primary frontiers: between tool and object, object and knowledge, and knowledge and tool. Pioneering can occur in any one of these contexts, opening a way for others to follow or a new avenue of inquiry. A breakthrough can similarly transform any one of these frontiers, or more than one of them, in the way that the discovery of a viable culture medium for an embryo can enable it to be grown in vitro, cultured, transferred, frozen, or stored. What is made visible in the context of embryo pioneering, in other words, is the necessity for constant circulation of technique across a series of frontiers. More important, it is the inextricability of tools and objects that make of re-
Table 3.1. Selected embryo Pioneer Award winners 1983–1999 whose work contributed to the successful development of human IVF.

<table>
<thead>
<tr>
<th>Award Winner</th>
<th>Contribution</th>
<th>Year Awarded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Chueh Chang, Worcester Foundation for Experimental Biology</td>
<td>First successful IVF in mammals (rabbits, 1959) using capacitated sperm; codeveloper with Pincus of the contraceptive pill.</td>
<td>1983</td>
</tr>
<tr>
<td>Lionel Rowson, ARC Unit of Reproductive Physiology, Cambridge University</td>
<td>Use of rabbit incubator for long-distance transport of sheep embryos; development of media for bovine eggs.</td>
<td>1985</td>
</tr>
<tr>
<td>Christopher Polge, ARC Unit of Reproductive Physiology, Cambridge University</td>
<td>First successful cryopreservation of sperm and embryos; founder of the science of cryobiology.</td>
<td>1987</td>
</tr>
<tr>
<td>Anne McLaren and Donald Michie, Institute of Animal Genetics, University of Edinburgh</td>
<td>Refinement of embryo transfer methods to explore uterine effect on genetic development (epigenesis).</td>
<td>1988</td>
</tr>
<tr>
<td>John Biggers, Harvard University</td>
<td>Contributions to embryo culture, first mammals born using cultured embryos (with A. McLaren).</td>
<td>1990</td>
</tr>
<tr>
<td>Andrei Tarkwoski, Warsaw University</td>
<td>Development of micromanipulation techniques; transfer of half-blastomeres; production of mammalian chimeras.</td>
<td>1991</td>
</tr>
</tbody>
</table>

Productivity a complex work object in which tools themselves become working model systems.

**Hair Loop**

Hans Spemann’s experiments, conducted in close cooperation with his doctoral student Hilde Mangold, are often used to illustrate the importance of an evolving conceptual and technical experimental approach during the period
when embryology began to focus more intensely on causal mechanisms, such as induction factors—that is, how particular organizational steps were triggered by either internal or external stimuli guiding overall development of the early embryo. In 1906 Spemann developed a glass needle for surgery that has since proven a versatile and indispensable tool that is still in use. He also invented a microburner for pulling the glass tubes such as the capillary pipettes used for microtransfers in vitro. In a modification of his earlier constriction methods, Spemann famously designed a hair loop by threading both...
ends of a single human hair into a specially fashioned capillary tube and fixing them in place with wax. Mounted on a handle, this microtool could be used to move, flip, or roll eggs and embryos during experimental procedures, thus itself coming to play a developmental role in the biological workings of his model system.

Spemann also developed round molds to impress wax holders for eggs and glass microapparatus to facilitate grafting. These handmade microtools and associated techniques, including an early form of nuclear transfer, facilitated the exploration of individual differentiation for which Spemann was awarded the Nobel Prize in 1935, recognizing his efforts to experimentally chart the organizer effect by grafting part of one embryo onto another. Spemann’s experiments are in many ways the archetypal example of the importance of transplantation and transfer to experimental embryology and developmental biology, and the corresponding epistemic shift described by Jenkinson from anatomical description to experimental interference that marks the emergence of a field that relies more fully on techniques that today would be described in terms of bioengineering. Since the logic of this shift remains fundamentally embedded in modern reproductive biology, it is worth revisiting one of these now-celebrated classical embryological experiments that took place in Germany in the first half of the twentieth century. Importantly, Spemann’s grafting experiments involved the fusion not only of different parts of embryos, but of tools with reproductive substance.

The manual mastery of fine tools necessary for microsurgery, and the ingenuity involved in devising new experimental techniques, are often emphasized in textbook reproductions of Spemann’s famous constriction experiment (a predecessor to his grafting work), undertaken in three stages and published in 1904. “Developmental Physiological Studies on the Triton Egg” begins with a technical description of the methods and materials used in a series of experiments designed to bisect fertilized amphibian eggs at the early blastocyst (two-cell) stage using fine hair loops (in Spemann’s case using strands of hair from the head of his infant daughter Margrette; figure 3.5). The aim of the experiments was to characterize the relationship between the differentiation of structures (in particular the axial organs) by manipulating the interaction of their component parts. In order to understand how a radially symmetric egg acquires axial polarity and bilateral symmetry (and also switches from one to the next), Spemann devised a series of interventions into the earliest stages of development using constriction to explore axis formation by manipulating it.
Largely by perfecting techniques that had been less successfully employed by previous experimentalists, Spemann showed that by constricting newt (salamander) embryos at different stages of development with his hair loops, he could create wholly separate organisms, partially separated organisms, and a variety of asymmetrical organisms. In his hand-tied embryo experiments, Spemann observed that both the timing and the plane of constriction (median or sagittal) played a role in determining which kinds of developmental modifications could be induced by his precise micromanipulations. By so doing he elaborated one of the basic principles of experimental embryology described earlier by Jenkinson, namely that reproductive substance could be mechanically manipulated not only with tools, but as a tool. For Spemann, the constricted newt egg was a probe, a device, and a crucial piece of equipment. More than a model in the sense of being a static replica, the tied egg system functioned over time to enable—indeed to produce—visual data that yielded insights into the causal bases of morphological plasticity. Growth became a means to test the limits of form.

In his detailed reconstruction and analysis of Spemann’s experiments,
the biologist and historian Victor Hamburger (who was Spemann’s student at the University of Freiburg) describes his findings as “a graded series of anterior duplications” that corresponded to different types of manual constriction:

A medium deep constriction in the median plane gives two heads; if the constriction is somewhat deeper, there may also be two pairs of fore limbs and a merging of the two parts in one posterior trunk and tail with a single pair of hind limbs. If the constriction is very slight, then only the anterior head is duplicated. . . . On the other hand, if the constriction cuts very deep, and only a narrow bridge connects the two blastomeres, then the two embryos are fused only at the region of the anus. [A] complete separation of the two blastomeres results in identical twins. . . . Whereas constrictions in the early gastrula still produced anterior duplications, the capacity for regulation decreased with the progression of gastrulation, and constrictions in the early neural plate stage resulted merely in an indentation without duplication. Since regulation implies that embryonic parts can give rise to structures different from those they would form in normal development, the loss of regulation capacity at the end of gastrulation means that the axial organs become irreversibly determined during gastrulation. (Hamburger 1988: 17)

In this description are evident the two planes of force being explored in relation to one another through the coupling of the tool and organism to reveal form through growth. The interpretation of results relies upon a contrast between the inside and the outside of the model system. On the one hand, the developing embryo is subjected to a range of carefully controlled surgical forces, such as constriction, the results of which are observed over measured periods of time through visual inspection. On the other, this handmade model system is designed to explore the inaccessible, invisible, or hidden mechanisms of development or organization, described by Hamburger as regulation or regulation capacity—the factors or variables that are presumed to exist within the embryonic structures but cannot be observed. Like hand shadows projected against a wall, the precise manual micromanipulations are designed to reveal the workings of internal, invisible forces (factors) that cannot be observed directly but can be made to appear as biological form by reworking them. The retooled organism thus models, in sum, not only the outcome of these invisible factors but a new kind of biological control that employs
the mechanics of reproductive substance as both its means and proof, and in which the tool itself plays a developmental role.

While much commentary continues to surround the significance of Speemann’s experiments, the simple point for our purposes here concerns the shift they are understood to exemplify to commentators such as Jenkinson (1909)—which is not only a change in the understanding of the role of technology in manipulating an object, or its use as an extension of the microscopic gaze as a kind of probe, but the fusion of tool and object into a live model system. The second important point to notice in the context of understanding how technology comes to be merged with reproductive substance, as in the example discussed in chapter 2 in a contemporary stem cell lab, is the complex technological layering—or archaeology—here made visible, whereby tool, organism, and experimental system perform the work of modeling the fusion of internal organizing forces and externally imposed mechanical technique. It is because it is not the model organism per se, but the fusion of organism and tool into a model system that functions as a live apparatus, in effect, for recording life, that the question of what, exactly, the experiment represents becomes rather complicated. As noted earlier, the artificial generation being modeled here as a working system is always recursive, serving as a model in which the workings of technology and reproductive substance are fused to reveal their combined agency as biology. Yet the biotechnical artifacts that are produced by this method complicate the meaning of “biological” in the very effort to reveal the principles guiding the underlying mechanics of development. What are revealed instead are the results of fusing tools with reproductive substance.

As Nick Hopwood has illustrated in his analysis of the nineteenth-century embryological studies of Wilhelm His, the concept of development was as much a product as a precursor of experimental studies such as those of Speemann—it is in part what he worked to produce. Whereas “development is often taken for granted as what embryologists study,” argues Hopwood, it is instead what researchers such as His “labored to produce” (2000: 31). The account of IVF offered in this book shares Hopwood’s contention that the mundane practices and routine work of embryology cannot be separated from the material production of ideas that might otherwise appear entirely prior to these labors. Indeed it is a central argument of this chapter that the human application of IVF is as much a product of its history as a working model in the effort to work up reproductivity as of a guiding vision of this end during most of its development. As we shall see, the history of IVF as a technique is
both continuous and inconsistent, translational and transient, migratory—but perhaps above all it was “handy,” which is equally the appeal of this technique today.

In the same way that Spemann’s laborious study of constricted and recombiant embryos coupled technology and biological substance in order to explore the frontiers of organization, so too were concepts of heredity being manually and analytically refashioned during this period using a wide variety of embryological methods. Not all of these were directed at either development or organization. Some were directed to questions of heredity, while others had practical, agricultural applications (or combined the two, as had Mendel). Spemann’s grafts and constrictions concerned the origin of form, or morphogenesis, as well as the internal mechanics of these forces, which he investigated both by fusing parts of embryos, and by manually manipulating development, using tools. For other researchers, reproductivity was more explicitly engaged as itself a tool in the process of experimental proof. In turning to this context of more explicit reproductive technologies, we also observe the principle of biological transfer reworked somewhat differently.

Maternal Models

Among the embryo pioneers who are most directly relevant to the history of IVF (much as they might not have expected to have been) is the English embryologist Walter Heape. In his account of Heape’s now-celebrated embryo transfer experiments, undertaken between 1890 and 1899, the reproductive biologist and contemporary embryo pioneer John Biggers (1991) emphasizes their relationship not only to the conflict between Darwin’s Lamarckian model of pangenesis and the theory of germ line independence propounded by August Weismann, but to the much older debate that epitomized this conflict—namely that concerning “telegony,” the effect of prior fertilization upon reproductive outcome, or the ability of offspring to inherit the characteristics of their mother’s previous mates. “Many biologists of the time,” Biggers writes of Heape’s contemporaries, “including Darwin, believed that ‘if the male element can act directly on the female form,’ it would provide strong evidence for the inheritance of acquired characters” (1991: 179). The theory of telegony, in circulation since antiquity and propounded by Aristotle, remained influential well into the twentieth century. Its most celebrated airing is a famous letter by Lord Morton to the Royal Society in 1821 concerning his prize thoroughbred mare’s pairing with a quagga (a now-extinct equine species),
causing all of her subsequent offspring (sired by horses) to bear striped coats, stiff hair manes, and thus signs of the “preponderance” of her original mate.

The persistence of traits from a prior coupling, also referred to as “infection of the germ,” “fetal inoculation,” or “saturation,” exercised widespread concern among livestock breeders because of its deleterious consequences for otherwise valuable female stock. However, the controversy over Morton’s mare’s offspring gained disproportionate significance in the context of late nineteenth-century debates about inheritance because of the extent to which telegony served as a placeholder for much wider disagreements over the precise mechanics of conjoined reproductive substances in vivo (or, in this case, in utero). This question encompassed a broad area of uncertainty, namely how fertilization affected hereditary transmission of traits. Whereas Darwin had earlier advocated a model of heredity based on diffused particles (pangenesis) that allowed for the inheritance of acquired traits (according to which telegony was a plausible theory), Weismann proposed his doctrine of the continuity of the germplasm in 1893, insisting upon the absolute independence of the reproductive cells, as well as their immortality. Weismann used the theory of telegony specifically to denigrate “the doubtful effects of heredity” he claimed his experiments had disproved, arguing that the “throw back” model was, in effect, mythological. Herbert Spencer, whose theory of evolution preceded Darwin’s and was much more strongly Lamarckian, was one of many prominent nineteenth-century figures for whom the telegony debate took on great importance, for social as well as scientific reasons, in a debate that has been the subject of both enlightened and entertaining commentary by many historians of biology.

Heape’s experiments, like those of Spemann, employed a type of part-whole dis- and reassembly, similarly harnessing transplantation as a method. His scientific goal was to disprove telegony, but he also sought to confirm a new means of investigating it using what is now known as embryo transfer. Unlike Spemann, Heape’s part-whole transplantation involved the surgical removal of an intact fertilized egg from a rabbit and its transfer into the uterus of a hare—thus using the uterine environment as his experimental crucible. Like Spemann, Heape relied on the bodies of his experimental offspring as his morphological map or proof to reveal the internal forces he was investigating—thus employing reproduction in a working (animal) model system to reveal heredity forces. He was also instrumentalizing the species boundary between two model organisms as part of the research design for his novel and laborious test cases.
The Heape technique for the recovery of fertilized ova from the fallopian tube was developed at the Morphological Laboratory in Cambridge, where Heape both trained and worked as a demonstrator under Michael Foster and Francis Balfour. To complete his project, Heape combined delicate manual technique with sophisticated animal husbandry in his hometown of Prestwich, near Manchester, where his technically demanding and unprecedented series of embryo transfers were conducted between 1890 and 1899. In a series of papers read to the Royal Society (which funded his work), Heape described the outcome of his experiments as a success, both in terms of producing viable offspring and confirming an absence of uterine effect (no telegony). He concluded his 1897 Royal Society paper on a technical as well as scientific note, suggesting, “It is possible to make use of the uterus of one variety of rabbit as a medium for the growth and complete foetal development of fertilized ova of another variety of rabbit.”

Although Biggers emphasizes that Heape did not envisage any practical application of his experimental methods (in the sense of using embryo transfer for livestock breeding, for example), his lasting contribution has in fact been a highly practical technical innovation for the pursuit of experimental science as well as the business of breeding. Heape is today celebrated as a pioneering technician. F. H. A. (Francis Hugh Adam) Marshall, whose 1910 textbook *The Physiology of Reproduction* is considered to mark the emergence of the new discipline of reproductive biology, draws heavily on Heape’s work and cites its pivotal importance in linking the study of animal breeding to the experimental study of reproduction—or what he denominated as a new field of science. Marshall, who wrote Heape’s obituary in 1930, dedicated his landmark textbook to him in recognition not only of his innovative and technically demanding experiments combining the analysis of reproduction and heredity, but for his substantial contribution to embryological methods. Despite his primary orientation toward a purely scientific question, Heape’s work, in a migration that is typical of embryological techniques, has become the foundation for the embryo transfer industry, which is currently the world’s largest embryological enterprise—and one of the closest kindred sectors to the global market in IVF (Gordon 2003). Indeed he is today acclaimed as the Patron Saint of embryo transfer and responsible for the twentieth-century “rekindling of interest in artificial insemination and the laying of a scientific foundation to the animal breeding industry with emphasis on its economic importance” (Betteridge 1981: 1). In the making of modern reproductivity, embryo transfer is a foundational technique that, along with the airline industry and cryopreservation methods, facilitates the purposeful and profitable circulation of reproductive
substance, passaging it across both time and space to maximize the benefit of prized genetic stock.

**Stem Technologies**

An important feature of Heape’s embryological experiments was not only that they combined an interest in heredity and reproduction, and pioneered a new technological means of transferring reproductive substance, but that they were conducted in mammals. From an embryological point of view, detailed knowledge of the events involved in the earliest stages of reproduction and development is more difficult to obtain in mammals for the simple reason that these events take place inside a living body. Unlike salamanders, frogs, axolotl, chickens, sea urchins, worms, tortoises, fish, or other common model organisms in embryology, the majority of mammals are distinguished by hemotrophic viviparity, or development of the embryo within the mother. Heape did not use specialist culture media, and he was not seeking to remove particular mechanisms, parts, or processes from the interior of live mammalian bodies in order to examine or observe mammalian development or fertilization through an in vitro window. This effort would await a later period and in particular, as is discussed below, the improvement of in vitro culture methods. Heape’s contribution had been to introduce a different medium in the form of another animal’s reproductive system, and to prove the viability of this system for experimental purposes. His contribution could be described as the generation of a new species of technique—a technique that has acquired a life of its own, so to speak, and is now so widespread and fundamental in its uses as to be considered a stem technology.

The role of stem technologies in the evolution of technique that Heape’s contribution exemplified in the form of embryo transfer similarly characterizes the development of **IVF** techniques, which can be viewed as sharing a technological kinship with each other, in spite of their enormously varied uses. As Barry Bavister notes in his account of the history of **IVF**, it begins its life as a specific kind of experimental technique: “A potentially useful technique is to recover fertilized eggs or early embryos from the female reproductive tract, and to study their subsequent development in vitro” (2002: 182). This technique becomes particularly useful in mammals by enabling the ex vivo modeling of reproductive events. In vitro culture of mammalian eggs, Bavister explains, allows for continuous and close observation of events that would be inaccessible in vivo both by replicating them artificially and by introducing systemic control mechanisms. “Information can be derived
much more readily from the study of eggs that are fertilized and then developed in vitro. Not only can the process of fertilization be closely observed, but factors contributing to normal and abnormal fertilization and development can be examined. The progress of fertilization or embryogenesis can be frequently, if not continuously, observed and the conditions of culture can be varied to examine their effects on development. Thus a wealth of information is available from studies in vitro, given the technical ability to accomplish them” (2002: 182). As Bavister, whose “magic” culture medium enabled the first successful fertilization of a human egg in vitro in 1969, notes in this description, the wealth of information that can be gained from in vitro studies depends primarily on “the technical ability to accomplish them.” The technical ability to experimentally manipulate mammalian reproductive substance within the in vitro observation chamber became increasingly various and sophisticated during the twentieth century, confirming the increasing inseparability between reproductivity and tools. In the case of IVF, it cannot simply be said that reproduction is assisted by tools, since the tools are part of the reproductive process—they are how it works. Predictably and, as Marx would probably have said, spontaneously, the experimental use of in vitro model systems for the study of mammalian development became increasingly intimately interrelated (or we might even say crossbred) with another crucial stem technology, namely cell culture methods. Versions of these methods, as noted earlier, were already part of late nineteenth-century embryology in the form of the various solutions that were used to maintain live cellular material in vitro, such as the salt solution developed by Sydney Ringer using the chlorides of sodium, potassium, calcium, and magnesium. Wilhelm Roux had also developed an early cell culture method using a mineral salt bath in a watch glass.

In the early twentieth century the American embryologist Ross Harrison, based at Johns Hopkins University, improved these methods substantially, demonstrating that live tissue fragments could be sustained in culture media for weeks at a time, through what is now known as tissue culture. As Hannah Landecker writes of Harrison’s work in her account of how cell culture systems became independent and autonomous “living technologies,” he established new methods to observe, control and manipulate living matter in vitro, thus “proving the possibility of observing internal body events without the body itself—observations that had been previously assumed to be impossible” (Landecker 2007: 15). She describes Harrison’s contribution to the development of in vitro systems as continuous with the “increasing emphasis on artifice in science” that is the hallmark of “what Philip Pauly has called ‘biologi-
cal modernism” (16). This means of cultivating life ex vivo in its own media required a working in vitro system combining control of temperature (incubation) and of infection or contamination (asepsis), as well as housing this controlled system in glass apparatus facilitating both manipulation and observation to make a looking-glass world. Like the development of dyeing and staining techniques in an earlier period, the goals of tissue culturists such as Harrison were essentially technological—to devise methods of seeing life develop within a controlled, external, closed, and transparent experimental system.

Prior to the ability to observe mammalian embryos in vitro, the main approach to understanding their early development was derived from the procedures introduced by experimentalists such as Spemann—which were not viable for mammals. As Waddington and Waterman note at the outset of their 1933 article “The Development in Vitro of Young Rabbit Embryos”: “Very little experimental work has as yet been performed on the early stages of the mammalian embryo. The two main methods of experimental analysis, isolation of the primordia and transplantation of fragments into different situations in the embryo, which have been applied with such success in the Amphibia, both present great technical difficulties when applied to the embryos of warm blooded animals” (1933: 355).

While Waddington and Waterman experimented in the 1930s with explanation of rabbit blastocysts to analyze early mammalian development in vitro, Gregory Pincus, while visiting Cambridge in the same period, took a different approach by revising Heape’s methodology of embryo transfer and combining it with in vitro culture methods more similar to those developed by Harrison to study extracorporeal mammalian fertilization. Whereas Heape had devised embryo transfer methods to investigate the relationship between gestation and heredity, by analyzing the effects of maternal environment upon transplanted offspring, his techniques were redeployed by Pincus using IVF as well—thus coupling together three stem techniques to create a powerful experimental platform. Substituting unfertilized mammalian eggs for embryos, Pincus attempted to achieve mammalian fertilization in vitro. Unlike Waddington and Waterman, who, like Harrison, sought to understand processes of “self-differentiation” and morphological development through an early method of cell culture, Pincus sought both to observe and to successfully replicate the entire process of mammalian fertilization, using surgically recovered rabbit eggs that, after what he mistakenly presumed to have been successful IVF, he then transferred to host rabbit does to obtain proof of his success in the form of viable offspring, just as Heape had done.
Pincus’s early attempts at \textit{in vitro} fertilization in mammals in the 1930s, and his later success in producing “fatherless offspring” via parthenogenic reproduction (dubbed Pincogenesis), provide useful examples of the modern biological study of reproduction as it emerged in the first half of the twentieth century and was transferred into mammalian systems by fusing together an increasing number of stem technologies. The effort to replicate the process of fertilization in glass reflects the continuing emphasis on combining biological substance with technology that had become more common during the last decade of the previous century, now adding the traction gained through experimental embryological studies that employed improved cell culture methods. These models both worked better and could do more work. They also circulated more widely across both species and continents, as well as lines of experimental investigation. From the perspective of the history of technique, a noticeable feature of the evolution of human \textit{in vitro} out of studies such as those conducted on both sides of the Atlantic by Pincus between the wars is their complex imbrication within so many otherwise unrelated experimental trajectories, or what we might call their very mixed, or hybrid, technical parentage. These thick genealogies of \textit{in vitro}, while intriguing in and of themselves, are also helpful in illuminating the instabilities that remain at the heart of human \textit{in vitro} today—for example in terms of what is meant, exactly, by fertilization, epigenesis, potentiality, or, for that matter, biological reproduction at all, once these workings have been increasingly technologized.

It is the technological kinship established through both meticulous training in received technique and the passing around of these experimental methods into different hands that enables experimental innovation to proceed along its continually meandering path—just as Needham described for the ad hoc embryology of an earlier period. What is visible from this point of view are the complex relationships linking ideas or concepts (experimental questions) with technical means (tools, technologies, or technics), and their various milieux—including both those that are inside the experimental system (e.g., culture media) and those that condition the experimentalist within a specific culture of science (e.g., developmental biology). These are what Andrew Pickering describes as “the continual reconfigurations of the material, conceptual and social strata of science that make it impossible to specify the relativity of scientific knowledge to any substantive variable”—a pattern that constitutes the “structure of practice” in science, and which he describes as “path dependency” (1995: 208–209). Thus we return again to the “magical” frontier space of a reaching beyond both the substance and the
technology at hand—a practice that arguably takes on additional importance when the frontier is the human conceptus in vitro.

**Taking Fertilization in Hand**

Gregory Pincus had been a student of W. Z. Crozier, who in turn had been trained by Jacques Loeb, the German American scientist who developed “artificial parthenogenesis” at the Zoological Station in Naples in the 1890s, during the same period Heape was conducting his embryo transfer studies in mammals in Prestwich. Working with the traditional embryological model organism, the sea urchin, Loeb had sought to use experimentation as a more direct means of biological translation—driving biological processes forward to new speeds, as it were, by not only exploring but harnessing the developmental mechanics of eggs and embryos. Loeb pursued a philosophy of biological invention based on forcing biology into new shapes—much as a breeder might attempt to shape or mold an organism to develop to order. In pursuit of his bioartifice, Loeb developed experimental methods (based on botany) enabling him to chemically induce parthenogenetic division in sea urchin eggs by modifying the salt content of their nutritive medium—that is, by controlling internal events via manipulation of the *milieu exterieur* in an early version of what later became known as cell or tissue culture. Unlike Heape, whose interests lay in elucidating the basic principles of heredity as they would have occurred naturally and internally, Loeb’s experiment has been described as a more explicit turn toward an engineering ethic in biology that had the production of novel, synthetic, and unnatural biological forms as its goal. As the historian Philip Pauly describes Loeb’s interest in the artificial induction of parthenogenesis, it made manifest a new role for science and a new self-image of the scientist as the origin of biological control: a “conscious engineering standpoint” that “considered the main problem of biology to be the production of the new, not the analysis of the existent” (1987: 8). The author of *The Mechanistic Conception of Life* (1912), Loeb sought to exploit the analogy of mechanics from the problem-solving vantage point of a creative engineer: like the successful agricultural biotechnologist he later became, Loeb was less concerned with what biology is than what it could be made to become or do. He considered “successful experimental control [to be] functionally equivalent to scientific explanation” (Loeb, quoted in Pauly 1987: 9). He similarly considered audacious pioneering to be the best way forward on the uncharted biological frontier of the early twentieth century—an analogy
he saw as properly American, and through which he believed biology could be rendered more thoroughly technological.

Pincus was a scientist very much in the Loebian tradition, and Pincogenesis exemplified the engineering mentality described by Pauly, which prioritized the isolation and observation of a specific mechanism in order to establish “a constructive or engineering biology in place of a biology that is merely analytical” (Loeb, cited in Pauly 1987: 93). Whereas amphibian model organisms, with their useful capacity for regeneration, were well suited to illustrating the complex developmental mechanics of Roux, His, and Spemann, the ability to manipulate fertilization held out a more pragmatic promise to Loeb, who compared the production of whole, new, manmade biological constructions to the bold and unprecedented tunnels and bridges built by heroic Victorian engineers such as George Stephenson or Isambard Kingdom Brunel (or the steam engines designed by Watt). As Landecker points out in her account of the history of “culturing life,” Loeb argued that such experiments held out the promise of “a technology of living substance” (Landecker 2007: 1), the deliberate, creative redesign of which was no more unnatural or monstrous than motorcars or telegraphic communication. In this model, technology did not assist biology so much as produce a new definition of biological control. As Pauly stresses, Loeb was explicit in his goal of creating “new forms whose properties depended solely on scientific action” (Pauly 1987: 51). He was less interested in the character or properties or principles of biological entities and processes in themselves than what could be achieved through manipulating them toward specific ends—a position that, as Pauly observes, “reversed the priorities of analysis and control” (51). As a consequence, argues Pauly, Loeb sought to engineer biological substance beyond its merely natural limits purely in order to see how far it could be reengineered: “Loeb’s project was not applied science. It was a refocusing of biological inquiry itself around what Loeb conceived as the activity of the engineer. . . . He considered the distinction between natural and pathological irrelevant. . . . Breaking down the distinction between natural and monstrous would be a necessary preliminary to the development of an engineering biology” (51).

As Hannah Landecker has observed, this definition of biology as engineering emphasizes the importance of the tools and techniques the experimentalist can use to manipulate synthetic living systems, with the express purpose not only of observing their mechanisms or mimicking their functions but of redesigning and remaking new biological systems and tools. It is not only the difference between the natural and the pathological that is irrelevant to such a pursuit. Crucially, it is also the importance of the synthetic or artifi-
cial that is emphasized in and of itself as a singular goal. In other words, it is the collapse of a distinction between biology and technology that specifically distinguishes the mode of reproduction this definition of biology as artificial synthesis prioritizes. As a consequence, the differences between what is biological, what is a biological mechanism, what is an experimental apparatus, and what is an experimental tool are deliberately rendered opaque. In a word, biology is relativized. Within an artificial, handmade in vitro system such as Harrison’s hanging drop experiment, in which a fragment of tissue is enclosed in a droplet of lymph on a glass cover slip, inverted over a hollowed-out slide, sealed with paraffin, and incubated at the correct temperature to allow the tissue to grow for up to a month, it becomes entirely unclear where the biology ends and the technology begins. Self-evidently the entire setup is simulated: a bespoke synthetic, in vitro propagation of an organic mass that serves as a model biomimetic system. It no longer matters whether this bioartifice is about seeing or making, being or doing, knowing or controlling, or nature or culture—the point of this working model of life is that it is viable and accessible, that it can be observed and manipulated, and thus that it can be reworked. Such a system exemplifies the principle Hannah Landecker describes in her account of how living substance comes to be taken in hand, which is not only that life or biology come to be regarded differently in vitro, but that biology is changed by becoming a component within an artificial system. As she puts it more concisely, “biotechnology changes what it is to be biological” (Landecker 2007: 223). Arguably, as we shall see, what the history of experimental embryology and IVF also demonstrate is the extent to which biology changes what it is to be technological.

Indeed, the process by which biology changes what it is to be technological is exactly what both IVF and embryo transfer model as technologies of reproductive substance. Arguably what is also evident is the extent to which technology is biologized in the form of new living tools—a new species of tools that comprise a distinctive form of technological evolution. From the point of view of the evolution of technique, it is irrelevant that much of this work was experimentally inconclusive, misleading, or failed—because much of it was not result but technique driven to begin with. Its larger object was not only modeling biological mechanisms, or for that matter reworking them, but building a new biology in which tool and substance work together biologically. Gregory Pincus and Robert Edwards were remarkably similar in this respect—both were iconoclastic, antiestablishment, and controversial biological engineers, very much in the Loebian tradition of seeking social progress through controlling life. Pincogenesis, for example, was most successful tech-
nologically, establishing the viability of an ex vivo model system to replicate a biological process, despite the fact that it ultimately failed to demonstrate successful IVF. Biologically, in terms of what this term generally refers to at the level of fundamental biological processes, it remains unclear today what, if anything, Pincogenesis revealed about the primal scene it was designed to illuminate. What it confirmed instead was how different species of technique could be successfully crossbred in the effort to manipulate life more skillfully.

**Pincogenesis**

Ironically, it is precisely the technological success of Pincogenesis that obscured the very process Pincus was trying to observe in a telling example of how technology cannot reveal the workings of biology, because it changes them. In his 1961 reassessment of the literature on mammalian IVF, Austin cites thirty-five articles by twenty-one authors dating back to 1878. In only three of these studies were live offspring obtained, the earliest of which were the experiments by Pincus and Enzmann in rabbits in 1934. As Chang writes in his 1968 appraisal of these three experiments, none could reliably be confirmed to have been successful. “Due to the technical difficulties involved in conducting such studies [of mammalian IVF] and lack of confirmation of [the results of] these experiments by others, together with the unreliability of the criteria of fertilization used by some investigators, the evidence for fertilization of mammalian eggs in vitro even at present may still be in doubt, and it becomes to some extent a controversial issue” (Chang 1968: 15).

Ostensibly, part of the confusion concerned the precise mechanisms of fertilization and how they should be characterized, but much of it inevitably concerns the technical means by which this process is documented and analyzed. For example, in the early studies of both in vivo and in vitro fertilization, as Chang points out, “most investigators considered fertilization to mean the penetration of a sperm into the cytoplasm of an egg, but in reality this phase is only the beginning of fertilization” (1968: 15). “Biologically,” he continues, “fertilization is a physiological process, which starts with the penetration of sperm into the cytoplasm of the egg, and includes the subsequent formation, development and syngamy of the male and female pronuclei until the union of maternal and paternal genetic materials” (1968: 15, emphasis added). Austin, in his 1961 review, further emphasizes that the egg can only be considered to have been fertilized when it has begun to cleave. Pincus, in his early experiments on fertilization in the rabbit (1930) had observed not only cleavage but penetration of the spermatozoon into the vitellus, as well
as the existence of two polar bodies, although he did not claim at the time to have achieved fertilization in vitro. Both lack of sufficient knowledge of the definitive criteria for confirming fertilization, and inadequate technological control of the in vitro model system (it is very difficult to determine by sight alone if the spermatozoon has passed fully through the zona pellucida, for example) created uncertainties.

Serial failure, as much as serial success, then, was required to bring biology and technology sufficiently into alignment in order to both identify and achieve all of the necessary steps in the process of in vitro fertilization. In his later experiments with Enzmann, Pincus claimed to have successfully obtained live offspring using IVF and embryo transfer in mammals for the first time. However, since they only mixed the eggs and sperm together in vitro for half an hour, and then washed the eggs before transferring them to a surrogate doe, it is likely the offspring were the result of undetected sperm clinging to the eggs’ surface, which were then able to capacitate and fertilize the egg in vivo (an early version of what is now known as gamete intrafallopian transfer). Indeed, it would not be until the successful codiscovery, separately by Austin and Chang, of sperm capacitation (the need for mammalian sperm to be exposed to the female reproductive tract for a period of time before they are capable of fertilizing an egg) that successful mammalian IVF could be confirmed by Chang in 1959. Over time, the fertilization of mammalian eggs was only fully characterized and successfully confirmed as a result of a lengthy process of experimental repetition and innovation. Successful IVF in mammals resulted from the intergenerational acquisition of sufficiently elaborate knowledge and technique necessary to model the event in question. In other words, the ability to replicate the union of egg and sperm depended upon the success of a prior union between biology and technology, and this synthetic modeling project was itself an offspring of combined lineages of scientific expertise. The elaborate apparatus required to induce ovulation, surgically remove a ripe egg from the reproductive tract, culture it in vitro, fertilize it in vitro, and transfer it back into the uterus to establish a pregnancy could only be achieved through an increasingly intimate merging of technology and reproductive substance—to the extent that it is not clear which is the more successful coupling involved in IVF, that between the egg and sperm, or between artifice and biology. More to the point, it means that the only biology that can be fully characterized in the context of such modeling is that produced when reproductive substance can be brought into a successful working relationship with experimental techniques. That this forced, harnessed, or cultivated biology is at once more fully characterized and more surprising is
the result of the kind of biology it is—namely a biology that only works when it is coupled to the right tools.

In addition to the domestication of semistandardized (well-trained) experimental methods (for animal husbandry, surgical procedures, culture techniques, incubation temperatures, etc.) and agreed-upon criteria for processes such as fertilization, another crucial feature of mammalian in vitro experimentation familiar from other histories of equipment is the effect of accumulated scale. The greater project of characterizing how reproduction works needed to be undertaken on a vast comparative basis, achieved through the circulation of both model organisms and proven techniques through many hands and over many generations, in order to fine-tune the workings they could reveal, or produce, in the laboratories of highly trained experimentalists. Scale is of course particularly important to science in terms of evaluating and reproducing experimental results, and in the identification and elucidation of missing factors—such as egg maturation or sperm capacitation. Gradually, over time, the differing reproductive cycles and mechanisms of various mammalian species have become part of a much larger archive of know-how that has in turn yielded new factors: how conception happened for hamsters, for example, could not be relied upon to establish its precise workings in mice, never mind goats, deer, or dogs. It was only over time, and with the benefit of increasing cross-species (interspecific) comparison (scale) that the early events of mammalian development could be more reliably characterized as a linear series of stages or steps—in order that they could be reliably (technically) reproduced. In their own cyclical way, basic techniques and experiments—including both IVF and embryo transfer—are also scaled up, thus sedimenting into place a stable base of stem, or platform, technologies that is endlessly repeated. These lineages of technique were literally fused with the lineages of model organisms used in embryology (which often became model organisms through the repeated application of particular techniques) thus comprising the inherited technical physiology of developmental biology. It is in the merging of these various tools and models that a new ability to work biology becomes more practiced and reliable—even if it is not at all clear what this functionality reveals in the curiouser and curiouser world of early mammalian development.

Thus, for example, Pincus begins his book *The Eggs of Mammals* (dedicated to Crozier) by typically comparing two very different model organisms through the same technology. “The fundamental control of the cleavage mitoses is alike in rabbit and sea urchin ova” (1936: 98), he notes. One lineage here is his direct academic descent from Loeb via Crozier, while another is
a technological inheritance—or kinship of technique—through the reprise of classical experiments, such as artificial parthenogenesis (à la Loeb) and embryo transfer (à la Heape). Despite the fact that Pincus’s book is largely descriptive and offers no obvious engineering solutions (and might even appear to be dedicated to the use of in vitro methods in order to return to an earlier era of classical or descriptive embryology characterized by “mere” observation\(^37\), his Loebism is apparent in his overriding emphasis throughout the 160-page monograph on the means of investigation. “The investigative aspects are what interest and intrigue me,” he writes (1936: vii). Here, then, as Hannah Landecker points out, the “cycle of artificial parthenogenesis” is proof of “a genealogy of plasticity [that] structures today’s experimental probing of the manifold potentiality of living matter and the practical experimental milieus in which cells are made to live” (2007: 8). However, we might add that this genealogy of plasticity is also one in which technology acts as a kind of shared substance of descent, remaking the science as scientists remake their work objects and technical objectives.\(^38\) This technical evolution, while linear, is thus also cyclical—endlessly recapitulating the alliance between the objects and methods that constitute its lineage—and recombinant, as it recirculates these elements, by passing them around, as it were, through a kind of experimental exogamy. The means of investigation—the constant remixing of known model systems and model organisms with new animal species and genres of technique—are thus as much an object of study, and source of discovery, as the processes they are designed to investigate.\(^39\) This circulatory recycling of technique fused with substance is, indeed, how reproductive biology reproduces itself as a science. The importance of passaging and transfer partially explains why the biological phenomena this branch of science investigates—be they fertilization, cleavage, ovulation, or heredity—are never purely biological, or for that matter never fully “understood.” Indeed, as Pincus says himself, his book about the eggs of mammals is as much about techniques as ova. It is “an examination [of] the experimental investigations of the growth and development of the mammalian ovum during the various stages of its life history in the ovary and oviducts” (1936: 128, emphasis added) (figures 3.6 and 3.7).\(^40\)

Landecker’s emphasis, like that of other historians of twentieth-century biology, on “those practices that exploit and explore the plasticity of living things” (2007: 8) is evident in Pincus’s use of IVF and artificial parthenogenesis in combination with techniques of both explantation (tissue culture) and transplantation (embryo transfer) to explore oogenesis across a range of model organisms from different animal species subjected to repassaged
Figures 3.6 and 3.7. Mammalian ova in culture documented by Gregory Pincus in one of the numerous tables of experimental data contained in his *The Eggs of Mammals* (New York: Macmillan, 1936).
and recycled species of technique. Pincus, like Robert Edwards, was strongly motivated by a conviction that inadequate attention had been paid to the living mammalian egg due to a technical deficit, or, as he put it, “because no technique was developed for preserving it intact in vitro” (1936: 2). Pincus was determined to remedy this technical deficit, and he provides an exhaustive review of existing tools and technologies (including cinematography) alongside those he has invented himself (such as a new form of pipette for removing ova during lapararotomy; 66–67). The outcomes of hundreds of experiments are meticulously recorded through “standard motion picture cameras adapted for microphotography” (66) in Pincus’s *Eggs of Mammals* over the course of ten chapters containing twenty-six tables, thirty-three figures, and thirty-six original photographic plates that together document a technological history as well as a physiological one. Throughout his technologically adventurous researches, Pincus was dedicated to an instrumental genealogy of technique: to “the experimental investigation of the growth and development of the mammalian ovum during the various stages of its life history” (1936: 128).

On the one hand, this question for Pincus concerned “the problem of the origin of the definitive ova” (128, also referred to as the origin of the “so called ‘primordial’ germ cells of the embryo,” 6), while on the other it was dedicated to another kind of development entirely, namely of the technical means available to pursue these obscure origins, ranging from the use of ultraviolet light and radiation (X-ray sterilization) to the injection of bespoke hormonal preparations. Both what Pincus classed as the “essentially descriptive” (1936: 5) observation of egg cell morphogenesis and the more explicitly interventionist “experimental investigation of the growth of egg cells” (6) achieved by “varying the conditions . . . and deducing from the derived data the nature of the factors concerned in the production of functional eggs” (6) relied on the constant development of new techniques, including those of visualization and calculation, as well as surgery, tissue culture, and the ability to artificially simulate both chemical and physical events relevant to “the physiological processes occurring in developing eggs” (53). As a record of what the effort to take living mammalian ova “in hand” involves, his portrait of an evolving technological milieu is as thorough as that provided by Marx of Adam Smith’s famous pin factory.

The experimental work for *The Eggs of Mammals* had taken place largely in the absence of any detailed understanding of the endocrinology of mammalian reproduction, but nonetheless made significant contributions to this field that would later be applied to the development of the first successful oral contraceptive pill—the achievement for which Pincus is historically most
well known. His own interests continued to focus on parthenogenesis, and it was his aim to produce live offspring from unfertilized eggs that had been artificially induced to begin development when he left Cambridge, Massachusetts, for a sabbatical in Cambridge, England, in 1937. He had noted in The Eggs of Mammals that although “we have seen that rabbit ova may be fertilized and cultured in vitro” it remained unclear “whether such ova may give rise to normal rabbits”—noting that on the basis of his published work with Enzmann (Pincus and Enzmann 1934) the “transplantation of such ova into the oviducts of pseudopregnant rabbit [reveals] that [only] ova fertilized in vitro and also normally fertilized ova kept in culture during the cleavage period apparently resumed normal development after transplantation as evidenced by the production of normal young at term” (Pincus 1936: 96). Pincus had concluded on the basis of this work that “it would seem then that parthenogenetic development may be induced in vivo” and that “presumably normal embryos might develop if a diploid cleavage nucleus could be induced to form,” suggestively adding that he and Enzmann had “in fact, found indications that such a process may occur in activated rabbit eggs” (1936: 111).

These published observations were the source of significant media coverage, including a New York Times editorial that compared “Dr. Gregory Pincus of Harvard” to the character of Bokanovsky, the Director of Hatcheries and Conditioning, in Aldous Huxley’s Brave New World. In 1937 Pincus was the subject of a sensationalist article in Collier’s magazine unfavorably depicting him as a well-resourced, impatient young scientist with a name “borrowed from a detective novel,” with “slender, almost feminine hands” and the grand vision of fatherless offspring: “the mythical land of the Amazons would then come to life. A world where women would be self-sufficient; man’s value precisely zero,” the article concluded (cited in Speroff 2009: 88). This negative publicity, combined with the advent of the Second World War, the demise of Harvard’s Department of Physiology and the Bussey Institution, and “the fact that he was Jewish” (Speroff 2009: 89), led to the termination of Pincus’s employment at Harvard while he was in England.

During 1938–1941, while Pincus was involved in a lengthy relocation to what would eventually become the Worcester Foundation for Experimental Biology (where both the first successful mammalian IVF and the birth control pill would later be born), another émigré biologist, Min-Chueh Chang, was earning his PhD in John Hammond’s Animal Research Station at Cambridge. Unbeknownst to either of them, and never having met in Cambridge, Pincus and Chang would spend the rest of their working lives dedicated to a lengthy series of experiments on the endless frontier of reproductive science, much
of it applied to American medical and agricultural problems, just as FDR had imagined. Indeed, Chang was to arrive at the newly established independent biological research facility in central Massachusetts, an hour outside Boston, almost coincidentally with the publication of Vannevar Bush’s influential report in March 1945. Together, Pincus and Chang would contribute to the curious evolution of IVF largely through their work on contraception—exactly the kind of applied project Roosevelt would have applauded, although with an outcome he is likely never to have imagined.

The Birth of IVF

As noted at the outset of this chapter, there are many reasons why the frontier analogy might be considered particularly apt to describe the postwar development of reproductive biology and its translational offspring in the form of human IVF, for it is possible to sketch the outlines of something very much like what FDR appears to have envisaged when we consider the postwar development of reproductive biomedicine and bioscience. However, I have also suggested that the frontier idiom is in some ways more complicated than it seems—at times even paradoxically so. These complications, I suggest, may be apt, since they provide a useful interpretive perspective from which to examine some of the more paradoxical aspects of the development of IVF and experimental embryology, as well as biology and the life sciences more broadly. The mixed idioms of the frontier and pioneering may help us to appreciate that being after IVF is not simply to be in a position to potentially benefit from a successful clinical application that was deliberately achieved at the end of a lengthy process of translational scientific advance. Instead, I have suggested, it may be helpful to distinguish between the frontier as it is encountered going forward and how it is reckoned in hindsight—in the same way we might somewhat skeptically view the technological progress narratives that are likely to appear more goal oriented from the point of looking backward, or from the standpoint of a proven technological success story (the miracle baby). This distinction is similar to that separating the forward-looking anticipation of the frontier as a gigantic landscape of opportunity, and the experience of probing more experimentally with the tools at hand. The difference between these two perspectives allows us to approach the question of the technological frontier less in terms of a specific goal, or aim, and instead, as Gell suggests, through the magic of an imaginative reach, or play, that extends beyond the merely real in an approach to the edges of the known. The resulting, ambivalent and fortuitous, model of scientific development is more
consistent with the haphazard evolution of IVF than the this-discovery-led-to-that-landmark-result model of technological development—as if it were a chain reaction, or even inevitable.

The second reason I have employed the frontier idiom as hermeneutic guide in this chapter is to exploit its traction as an analogy for conversion, through which what is beyond the merely real can become the “regular real”—as have airplanes traveling over the North Pole, or babies conceived in a dish (to name but two examples). From this point of view we can appreciate the process by which technology domesticates its objects—by making them workable and tractable, as well as viable and populous, through the sedimentation of relationships of technique that often have the reproduction of technology as their immediate goal. As is explored further in chapter 7, this transfer, or conversion, of the unknown into the known is what the idiom of the frontier delivers, or performs, as a representational device, or metaphor, to naturalize new relationships—such as those between biology and technology as evolving ways of life. By invoking this representational work of conversion and retrospective sedimentation, I want to suggest that the paths established in and through technological inheritance—what we conventionally think of as the advance of technology—is, like the frontier, more complex and multifaceted than it may seem. In vitro fertilization is a good example of this kind of complex evolution, as is the history of embryology, because the conversions and transmutations that occur in these realms (among others) not only stretch but frequently exceed the frames of the models, idioms, or metaphors used to represent them.

Like other technologies, IVF stretches and exceeds the frame of existing understandings—for example, by enabling an unusual transfer “into man” not only of a high-tech reproductive substance (an in vitro fertilized egg) but a living human tool. For in addition to being a biological relative, a much-desired would-be take-home baby, or a precious human embryo, the in vitro fertilized human egg cell is also a technology, in the most conventional sense of the term. But it is clearly also an unusual technology—a fusion of biology and engineering, a mechanization of substance that establishes a new biological relation to and as technology—and one that arguably becomes curioser and curioser even as it is more fully characterized in a scientific sense. What are we to make of the miracle baby’s complex ancestry on the technological frontiers that made his or her existence biologically possible as the offspring of a vast, interspecific project of reworking reproductivity? What are the implications for either biological or technological evolution of their union in the form of several million human offspring?
Before moving any further with this question, the final section of this chapter briefly completes the tool history of the world’s most famous embryo transfer, conducted by Patrick Steptoe in his Oldham obstetrical ward, following the successful fertilization of Mrs. Brown’s egg in Robert Edwards’s lab next door. It is Chang, working in Pincus’s lab, who is now acknowledged to have achieved the first live births following IVF in mammals in 1959—an accomplishment that was itself the offspring of a long lineage of successful embryo transfer experiments in the rabbit (1891), rat (1933), sheep (1934), goat (1934), mouse (1942), cow (1949), and pig (1951). It would be another two decades before this technique was successfully translated into a clinical procedure by Edwards and Steptoe following their recycling and recombination of several lineages of technique as well as their tenacious “forward march” into unknown territory. Like Pincus, Edwards was at least as interested in the development of new techniques as what they would reveal about the underlying biological principles they were intended to explore, and like Chang he was particularly interested to exploit the possibilities of IVF and embryo transfer in mammals for a wide variety of research purposes. Indeed, like many of the embryo transfer pioneers who preceded him, including both Chang and Pincus, Edwards was adept in exploiting the somewhat chaotic overlap between the actual and potential uses of embryo transfer for agricultural applications, as a research technique to address basic questions of mammalian reproduction and development, and as a potential clinical tool (the latter initially envisaged, as mentioned earlier, as a contraceptive device).

From Inovulation to IVF

Following his initial training in agricultural science in Wales, Edwards moved to Conrad Waddington’s bustling interdisciplinary Institute of Animal Genetics in Edinburgh as a doctoral student, where he was surrounded not only by high-quality experimental science but by the superb facilities provided by Waddington’s generous funding. Here he was inspired by a film produced by Alan Beatty titled Inovulation demonstrating a new method of cervical embryo transfer in mice, resulting in the birth of viable offspring. Sitting at the back of the lecture theater, Edwards recalls, “I became more and more excited. . . . There and then I knew what I wanted to do as a PhD student and who I wanted to supervise me” (Edwards and Steptoe 1980: 20). Having completed his PhD research by inducing chromosomal changes in mouse embryos, Edwards set off to California to embark on a new project in reproductive immunology, returning to a position at the National Institute for Medical
Research in Mill Hill, north London, in 1958. Here too his interests fluctuated: “I flitted from laboratory to laboratory in the UK and the USA, changed scientific and medical partners in a way unmatched in any barn dance” (37). Still motivated by his early work stimulating mouse egg development using gonadotrophins, Edwards resumed his embryological work at Mill Hill, only to discover that the in vivo maturation of mouse eggs in culture solution had already been confirmed by Pincus at Cambridge a quarter of a century earlier. And not only in mice, as Pincus had also successfully cultured human eggs. Initially disappointed (“I sat in the Mill Hill Institute library momentarily depressed; the novelty of my discovery had suddenly worn thin,” 40), Edwards soon reevaluated his discovery (or rediscovery) in more favorable terms. “As I drove home to Elstree I pondered, ‘Was it so sad?’ It was encouraging in practical terms. Human eggs, according to Pincus would ripen outside the body and become ready for fertilization” (40).

In order to explore these practical (now translational) frontiers, Edwards needed to make contact with clinicians. Extending the interdisciplinary barn dance about which he was already somewhat uncomfortable, Edwards was to find himself even more awkwardly situated in the surgeries he needed to visit to acquire human eggs for his research. Having gained the collaboration of Molly Rose, the consultant surgeon who delivered his first daughter, Edwards became a regular visitor to the Edgware General Hospital in North London, where he attended operations self-consciously “clutching [his] glass sterile pot—the receptacle for the precious bit of superfluous ovarian tissue.” Here, he felt himself both a novice and out of place—on the very threshold of the path to unprecedented future human applications, and yet ambivalent regarding this proximity. “‘What am I doing?’, I asked myself. ‘Do I really have a place in this theatre?’” (Edwards and Steptoe 1980: 42). Similarly, his new research on human eggs, begun with “high hopes,” soon “began to feel less certain.” None of the eggs provided to Edwards by Rose or other gynecologists showed any signs of ripening in culture. He decided Pincus had been wrong.

Pincus, whom I respected and whom I had met two or three times, was wrong [and] had been wrong before. His work on parthenogenesis during the 1930s, on the birth of fatherless rabbits, had failed to stand the test of time. All the same, I admired him enormously. Among the famous scientists whom I have met and come to know he still stands near the top. Pincus had helped to reshape modern life, especially for women, with his contraceptive pill. I thought then, as I think now, that he never received full recognition for his work. There are men—
pygmies compared with him—who have been awarded Nobel Prizes. Perhaps he was too controversial. . . . He was a fighter. He was gritty and outspoken. He would have made a fine Yorkshireman! (1980: 43)

Edwards was a Yorkshireman himself, and his admiring description of Pincus draws attention to many of the traits they shared. Eventually Edwards would also be awarded the Nobel Prize in Physiology or Medicine in 2010 for his work leading to the development of human ivF, which, like contraception, has reshaped modern life, especially for women. Edwards’s work was controversial, and ivF would not have been successfully achieved in humans had he not been a gritty and outspoken fighter, who valued his role as a pioneer. Like Pincus, who in many ways set the prototype for his unconventional, technique-driven, iconoclastic, and unusually interdisciplinary career, Edwards was a “scientific entrepreneur,” in the way Adele Clarke (after Howard Becker 1963) has applied this term to the reproductive sciences, emphasizing the extreme heterogeneity of relationships between professional worlds that must be negotiated by key actors, who require a wide range of skills, as well as the will and energy to interconnect them, in order to succeed. Like Pincus’s, Edwards’s career was challenged by what Clarke describes as the “enduring illegitimacy, marginality and controversial status of the reproductive sciences as a discipline” (1998: 18)—a situation Edwards met with a combination of verve, tenacity, and hard work that ultimately benefited from a generous dose of good luck.

As Martin Johnson (2011) has noted of the partnership that would develop between Robert Edwards and Patrick Steptoe, they were both outsiders to their professions and the establishment, known not only for their iconoclasm but for their ambition and talent. It can be added that theirs was in many respects a marriage of technique, beginning with a telephone conversation in 1967 about laparoscopy, and developing over the next two decades as a modern technological odyssey the adjective Promethean is not out of place describing. Along the road to successful human ivF in Oldham, Lancashire, in 1978, not very far from either Birmingham or Manchester, or the mechanical workshops of the Industrial Revolution, Edwards dug deep into the long legacy of technical innovation in experimental embryology described in this chapter, in order to rework human reproductivity to deliver a new mode of human procreation in which biology and technology were viably coupled. To this work Steptoe added the highly successful technique of laparoscopy (now the basis for keyhole surgery and many other clinical and experimental uses) while Edwards devised the means to fertilize human eggs in vitro.
While the obstacle of infertility confronted Steptoe in his practice as a gynecologist, it is clear that the value of IVF went far beyond the ability to assist conception in Edwards’s far-reaching vision of IVF as a platform technology for everything from preimplantation genetic diagnosis to stem cell propagation and tissue engineering. The confirmation of the birth of viable human offspring from this pioneering technique both inaugurated and legitimated the progressive expansion of the reproductive frontier into future applications that have since made of IVF what Walter Heape, a century previously, had established through mammalian embryo transfer—namely a platform or stem technology with a life of its own.

Thus, while the legacy of Steptoe and Edwards as the medical-scientific partnership behind the first successful human IVF may remain umbilically linked to the image of the test-tube baby, and the birth of reproductive biomedicine, it could equally be claimed that it is the transfer of the IVF platform into human use _tout court_ that has proven to be of an even greater significance we have only just begun to appreciate. The meaning of this legacy is the origin of _Biological Relatives_, in asking whether the logic of IVF extends beyond human procreation to other reproductive purposes. Even the somewhat surprising scale of human IVF’s expansion worldwide over the past thirty-five years may pale in the wake of its future significance—which will not only be measured by IVF’s expansion into genetic disease prevention, human embryonic stem cell research, and regenerative medicine, but must take into account a watershed point in the very meaning of the adjective “biological” as it becomes increasingly synonymous with technology. Reproductive technology is arguably a pivotal point of (con)fusion for the anxious contemporary question of what kind of kinship or relationality shared biological substance establishes, and what kind of mechanics reproductivity comprises, responds to, or delivers. These are not questions that can be answered in the lab unless it is the conflation of human experimentalism and human evolution that are considered to be the laboratory writ large in which the mechanisms of frontier reproduction will continue to be characterized over time.

But this future might be better charted by careful study of the past than by more open-ended speculation, and it is thus the lived relationship to early IVF that is the focus of the following chapters. In order to understand the condition of being after IVF, or biologically relative, it is necessary to examine yet another dimension of this process, in order once again to view it from a different angle. For if, as I have suggested, the kinships of technology that engender IVF must be understood as relational—uniting tools, objects, concepts, practices, and people—so too does their union reveal a new technology of kinship,
and a new biology. Indeed, this is the point of IVF—its goal is to produce new biological relations through technology, and thus a new future for reproduc-
tivity, as kinship both through and as technology. As we shall see, the bio-
logical relations established through new reproductive technologies depend
on genealogies not only of scientific technique but of even older social tech-
nologies. In the next chapter, then, we turn to yet another stem or platform
technology—the social and cultural organization of human reproduction as
kinship that has an equally elaborate set of exact mechanisms, if a somewhat
different set of tools. As we shall see, this apparatus also fuses the biological
with the technical—and indeed has done so for much longer than IVF.