1
What cloning is and why it matters

Cloning technology was invented during the twentieth century and now is poised to help define the twenty-first. Almost everyone has heard of Dolly, the cloned sheep born in 1996 but what about the rapid progress made since then? Scientists now count horses, cows, cats, and dogs among the many animals they can clone. This progress raises a host of questions. Are you comfortable drinking milk or eating meat from a cloned cow? Should we clone extinct or endangered species? Will the April 2005 birth of Snuppy, the world's first cloned dog, usher in a new era of cloned pets? Should we clone embryos to generate embryonic stem cells and help develop medical therapies? And perhaps the most important question of all: when, if ever, will this progress lead to the first cloned human?

Although scientists are nearly unified in their opposition to cloning humans for reproductive purposes, on-going research toward other goals makes this likely, if not inevitable. For the most part, this research is driven by the hope that cloning technology will have significant health benefits, perhaps leading to transplantation therapies that use embryonic stem cells specifically tailored to individual patients. Of course, if a cloned human is ever born, the desire for fame will almost certainly play a role. Looking back to the media frenzy surrounding the birth of the first test tube baby in 1978 or the clamor surrounding the birth of Dolly, it is not hard to imagine the furor that a cloned human baby would generate.

As modern biotechnology is increasingly applied to humans, it raises important questions for society to address. Should we, perhaps in the relatively near future, allow infertile couples or single mothers to use cloning technology to try to produce a child? Should we, in the longer term, permit parents to use cloning technology not just to have children, but to have children with specific genetic modifications or enhancements? Debates on cloning technology and its implications are, all too often, hijacked by advocates or opponents who skew the science to fit a particular view. Although the details of cloning research are complex, the general technique is not particularly difficult to understand. And understanding this general technique and its consequences is more than enough to participate fully in these important debates and to see through the many myths clouding discussions of cloning.

What cloning is

Cloning is, at its most basic level, reproduction without sex. "Sex" does not refer to the act of intercourse but to sexual reproduction – the joining of genetic material from two parents into an embryo that may, if development goes well, give rise to a new adult organism. All humans alive today were born through sexual reproduction; a single sperm from the male joined with an egg from the female, creating an embryo with half its genetic material derived from each parent. This mixing of genetic material introduces an element of chance into reproduction, ensuring that children differ genetically from their parents. In cloning, offspring are genetically identical to their single parent. Such offspring are the products of "asexual" reproduction.

Cloning, rather than relying on the merging of egg and sperm, uses the genetic material or DNA from a single cell. This cell is joined to an egg from which the DNA has been removed. Next, this construct is coaxed to develop as if it were a newly fertilized egg. If development proceeds normally, the resulting organism will be genetically identical to the single donor. In this case, reproduction no longer generates new combinations of genetic material but faithfully duplicates previously existing ones.

Although mammals do not normally reproduce asexually, nature does provide a close analogy: identical twins. Roughly one out of every 250 human births results in identical twins – siblings that are genetically identical. Because a cloned child would be genetically identical to its DNA donor, it can be helpful to imagine cloning as a form of delayed twinning. If cloning technology were perfected and applied to humans, the birth of a cloned human would not be altogether unlike the birth of identical twins but instead of a few minutes separating the two births, there could be many years.

Scientists speculate that a cloned human and his or her parent would typically be less similar than identical twins. This is because the environment plays an important role in development. Identical twins usually share much of the same environment, while a cloned human and his or her genetic parent often would not. Identical twins develop in the same uterus and usually grow up in the same household. In contrast, a cloned human would probably be carried in a different womb and grow up in a different household from its genetic parent. The cloned child would also be born into a world that had changed significantly. The importance of environmental influences has led bioethicists who have considered the possibility of human cloning to focus on its unpredictability. It is not clear that a child cloned from Mozart or Pavarotti would grow up to perform or even appreciate music.

Humans have not been cloned and few plausible reasons exist to clone humans for reproductive purposes. Some have suggested that cloning might provide a means for infertile parents to have a genetically related child. However, fertility research seems likely to lead to other, more effective and less controversial, approaches to treat the few couples for whom this last resort might be necessary. Others have suggested cloning may be justified when a child dies young; believing parents would deserve a chance to bring their lost loved one back to life. But many think this would lead to

THE NATURE VS. NURTURE DEBATE

The human cloning debate is closely intertwined with the long-running argument over the relative importance of genes (nature) and the environment (nurture) in shaping people's physical attributes and beliefs. This debate pits those who believe one's place in life is determined primarily by innate abilities against those who see cultural and environmental influences as the most important factors shaping human lives.

Numerous attempts have been made to tease out the relative importance of these two factors, including comparisons between identical and fraternal twins. The story that has emerged is complex. Few traits are purely genetically or environmentally determined: most are influenced by both factors. Height, weight, intelligence, and many personality traits, to name just a few examples, are shaped by the interplay between one's genes and one's upbringing. However, the relative roles played by these two factors are unknown, ensuring that the nature vs. nurture debate will live on to be argued another day.

disappointment all round. Due to environmental influences, the cloned child would not be the same as the deceased child he or she was ostensibly replacing. Furthermore, the new child, forever competing against an idealized memory, might face unreasonable expectations. In the end, neither parents nor child would prosper.

Because human cloning seems remote and is generally undesired, cloning science today focuses primarily on animal research. In animals bred for human use, such as cows, pigs, and horses, the advantages of asexual reproduction are significant. The element of chance central to sexual reproduction frustrates animal breeders and livestock producers. When mating a prize-winning stud to promising mare, horse breeders aren't excited by the chance that the resulting foal will randomly receive the parents' worst genes: they want to propagate the genes that turned the stud into a champion, in the hope of producing future winners. Cloning, by allowing breeders to produce genetic replicas of valuable animals, makes this process more efficient. For horse racing, this efficiency comes at a steep price, as cloned horses are currently forbidden from participating in officially sanctioned races. These sorts of restrictions don't apply to pigs or cows, which are bred to produce meat and milk for consumers, rather than for competition. Not surprisingly, livestock breeders, particularly in the United States, have shown interest in using this technology to make their operations more productive and more profitable.

What cloning is not

By and large, cloning is not what you see in the movies. It is not photocopying; or at best it is like using a slow and blurry photocopier – so slow, that by the time the copy is made, the original has changed. If you cloned your dog today, there wouldn't be an exact replica running around and barking tomorrow, as suggested in the Arnold Schwarzenegger hit, *The Sixth Day*. Rather, you would create an embryo that could potentially be transferred into the womb of a surrogate mother. Nine weeks later, if all went well, a puppy would be born. This puppy would be genetically identical to your dog but, obviously, much younger. It might look like its parent had looked as a puppy but it would experience a different environment and, perhaps, mature differently.

Movies such as *Multiplicity*, in which an overworked contractor clones himself to help cope with his busy life, ignore the time delay essential to cloning. In this case, the movie's premise, while entertaining, is absolutely wrong. The clones, rather than helping out at work and around the house, would be a burden. They would be infants, not adults as portrayed in the movie, and like any human infants would need nearly constant attention. As any parent can tell you, adding a baby (or several) to your family is not a good strategy for gaining extra time.

Nor does cloning bring back the long-dead. Cloning technology, at least at its current efficiency levels, requires a significant amount of biological material. For living animals, it is simple to take a sample and preserve this material: Dolly, for instance, was cloned from frozen cells. However, finding enough genetic material presents a significant hurdle to cloning long-extinct species. For now, the cloning of dinosaurs, as seen in *Jurassic Park* and its successors, is no more than a scientific pipe dream. That said, scientists have made progress in cloning endangered species and some believe cloning may offer a promising conservation strategy. Attempts to clone recently extinct animals, such as the Tasmanian tiger, where preserved biological material may still exist, remain a possibility.

As we shall see, cloning is not easy. When Dolly was born, she was the only success in 277 attempts. Success rates have improved but the procedure remains inefficient. Many cloned embryos fail to develop, and when development does start, a variety of abnormalities are seen. Even in the most efficient operations, only a minority of the original cloned embryos develop to term and go on to lead healthy lives. At the moment, this inefficiency limits the usefulness of animal cloning for commercial purposes. It also raises the ire of animal rights activists, who complain that the technology produces deformed animals. Obviously, these inefficiencies would need to be overcome before scientists could even begin to consider cloning humans for reproductive purposes.

Why cloning matters

Cloning matters because it is on the verge of affecting daily life around the world and its importance will only grow with time. Animal cloning will revolutionize food production in the coming years and may, by turning animals into biological factories, revolutionize pharmaceutical production as well. Moving from animals to humans, cloning technology may, if some expectations prove true, radically alter medicine, leading the way to an era of personalized transplant therapies. Finally, in the longer term, it opens the door to the cloning (and potential genetic engineering) of humans, perhaps changing the very essence of what it means to be a human being.

A growing scientific consensus suggests that milk and meat from cloned animals, or at least from their progeny, are safe for human consumption. In December 2006, the U.S. Food and Drug Administration announced preliminary plans to allow products from cloned livestock into the food supply. If finalized, such a ruling could have dramatic effects. Scientists can clone several important farm animals, including cows and pigs, but only a small number of cloned animals – none destined for consumption – live on American farms today. One industry insider has estimated that within twenty months of a ruling allowing products from cloned animals into the food supply, American farms would be covered with hundreds of thousands of clones.[1] This could occur despite widespread consumer discomfort with the very idea of eating products from cloned animals.

Thus far, the United Kingdom and most other European countries have shown more caution regarding the introduction of cloned animal products into the food supply. If, as appears likely, the United States approves these products first, it could contribute to continued trade wars. Although cloning does not necessarily include genetic modification, some cloned products will almost certainly also be genetically modified. Thus, trade in cloned products could get tangled in the on-going debate on the import of genetically modified organisms; a number of countries have limited their imports of agricultural products from nations where genetic modification is prevalent.

When Dolly was cloned in 1996, the research was primarily funded by a biotechnology firm that aimed to revolutionize the way drugs are produced. We'll learn more about this later but the basic idea is to create, through cloning, genetically modified sheep or cows that produce therapeutic compounds, such as insulin or growth hormone, in their milk. Pharmaceutical companies could isolate these valuable compounds from the milk for a fraction of the cost of traditional manufacturing methods. The milk would not be intended for human consumption and would probably be discarded after the therapeutics had been isolated. This technique, known as "pharming," offers potential economic benefits for drug companies and has taken off since Dolly's birth. Numerous cows have been bred to produce therapeutics in their milk and some scientists are exploring the possibility of harvesting drugs from other body fluids, including urine. Pharming raises a number of concerns, including the risk of drug-producing animals accidentally entering the food supply. Although the risks may be remote, even those of us unfazed by drinking milk from a cloned cow wouldn't be pleased to find out the milk was significantly enriched with a prescription medicine.

While cloned animals that produce therapeutic compounds already exist, the creation of cloned human embryos to facilitate medical therapies remains in the future and raises serious ethical questions. Many scientists are optimistic that cloning will, one day, regularly be used to create stem cells genetically matched to specific patients. These cells could, potentially, help treat a range of debilitating conditions, such as type 1 diabetes and Parkinson's disease. Because the cells would be genetically matched to the individual patient, they might avoid the immune rejection problems that complicate transplant therapies today. This potential therapeutic technique is controversial, however, because deriving these patient-matched stem cells, using currently envisioned approaches, would require the creation of a cloned human embryo. At five days of age, the stem cells would be isolated from the embryo and the developmental process halted. Dramatic advances toward this vision of regenerative medicine were reported by a group of researchers based in South Korea, but in late 2005 the veracity of this work was called into question: today, it is clear that most, if not all, these advances were fraudulent. Despite this set-back, many scientists believe the vision remains promising and "therapeutic cloning" is being pursued by scientists around the world.

Cloning also matters because, given the field's current trajectory, it is part of our shared future. From the food supply to the medicine cabinet, cloning technology is poised to change the way we live. But these changes are controversial. Each of us can and should participate in the debates that will shape the role cloning plays in the future. Before you say "yuck" to drinking milk from cloned cows or rush off to save your dog's DNA in preparation for eventual cloning, take the time to learn a bit about the science. Although cloning is fairly simple, misinformation is prevalent. Understanding the science behind cloning will help make these debates more meaningful and their outcomes more satisfactory for everyone.