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How to teach biology using the movie science of cloning people, resurrecting the dead, and combining flies and humans

Christopher Rose

While popular culture is generally acknowledged to have some impact on public opinion of science, attempts to evaluate this relationship have focused largely on how the public perceives science, rather than how well they understand it. Movies, television, and literature are usually argued to foster a negative perception of science and scientists among the viewing and reading public. What has been left out of this analysis, however, is the degree to which popular culture informs or misinforms the public about how science is done. Does the scientific accuracy and plausibility of a movie's story line really affect the public's understanding of the related science? As a science researcher, I am biased in my belief that realistic movies provide more engaging and thought-provoking entertainment than ones that violate obvious and well-understood scientific principles. However, whether realistic movies actually stimulate public inquiry into real science remains to be demonstrated. As a science teacher, I am also challenged to find ways to engage non-science students in learning about how and why science is done. To this end, I have developed a general science course called "Biology in the Movies," which uses biology-based movies as a starting point for discussing the fundamental ideas, techniques, and societal implications of such topics as human cloning, genetic screening, human origins and evolution, artificial intelligence, and recombining animals. Teaching this course has thus prompted me to consider the qualities of movies that make them useful for furthering public understanding of science. In this essay, I attempt to explain those qualities and explore how movies that treat similar scientific ideas with differing degrees of realism can be used to teach science. I close with comments on how movies can be usefully critiqued for their scientific plausibility.

1. Kernels of scientific truth

As a scientist and film buff, I find that the point of science in movies is usually to produce an immediate and unintended threat to the physical safety of the human protagonists. Also, the scientific explanation offered is usually limited to a sentence or two of jargon and

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buzzwords, and the neutralization of the threat usually involves an explosion rather than a scientific breakthrough. In contrast, the movies that suit the purposes of my course offer what I refer to as kernels of scientific truth.

These kernels come in several forms, as exemplified by the films *GATTACA*, *The Boys from Brazil*, and the 1958 and 1986 versions of *The Fly*. *GATTACA* offers a very plausible view of how the institutionalized use of assisted reproduction technologies could lead to widespread discrimination between genetically enhanced and unenhanced people (Kirby, 2000). In *The Boys from Brazil*, as I shall explain below, the protagonist and audience receive essentially a textbook explanation of cloning by nuclear transplantation. The two *Fly* movies explore the idea of combining two organisms (fly and human) into one, the earlier one at the level of cells and the later one at the level of genes. The kernel of truth here, however, lies not in the methodology (which is clearly impossible) or the results per se. It lies in the unexpected outcome of the science, which has interesting but obscure parallels in real science. For example, scientists have tried combining the cells of sheep and goat embryos, with the goal of producing a sheep fetus with goat placenta. This methodology is intended for use in preserving endangered species, because it would allow their embryos to develop in surrogate mothers of a related common species without the risk of immune rejection. However, early attempts at this produced a "geep," an animal mosaic of sheep and goat cells that grew into a healthy adult of intermediate form and appearance (Fehilly et al., 1984; Meinecke-Tillmann and Meinecke, 1984). Also, after the developmental genes of the fruit fly were identified, it was a complete surprise to learn that mammals had similar genes. It was even more startling to learn that some of these genes function much the same way in both fly and mammal, and that fly embryos can use mouse or human genes to develop normal fly parts and vice versa (Awgulewitsch and Jacobs, 1992; Halder et al., 1995; Malicki et al., 1992). These examples illustrate that real science, like movie science, progresses to some extent on the basis of totally unexpected outcomes. That both movies predate their relevant scientific discoveries also demonstrates that kernels of scientific truth can be entirely coincidental.

So what information is necessary to qualify as a kernel of scientific truth? In introducing his book *The Biology of Science Fiction Cinema*, Mark Glassy (2001) argues that what makes films useful as a teaching tool is their informed speculation about the possibilities of science. Expanding upon this idea, I suggest that films must also convey a critical mass of information for the audience to know how the characters or the director are thinking about the science. Some films convey this information through dialogue or narration (e.g., *The Boys from Brazil* and *Jurassic Park*), some convey it indirectly through the action of characters (e.g., *Quest for Fire* and *Blade Runner*), and others work at both levels (e.g., *Contact* and *GATTACA*). In each case, though, the film conveys sufficient information for the audience to formulate some level of understanding of a particular scientific concept, technique, or discovery; it is not simply demanding the audience to believe in unexplained jargon.

Whether the information need be accurate and the underlying concept a plausible one is more complicated. Filmmakers may try to make their science credible at some level in order to maximize emotional impact when the science gets out of hand and conflicts emerge. The underlying rationale is presumably that monsters attributed to jargon or movie-science clichés (e.g., Godzilla and other mutants induced by atomic radiation or toxic waste) do not have the lasting scare power of those with a potentially real biological basis (e.g., rogue sharks, Ebola virus, and gene splicing). The question of whether movie science should also be accurate so as not to misinform the public is a contentious one. Filmmakers are obviously constrained more by the demands of profitability and (one hopes) artistic expression than by the principles, laws, and limitations of real science. Some filmmakers, including Michael Crichton (1999), strongly defend the right to pursue their art form in purely fictional terms. At the same time, some scientists emphasize the necessity for realism on the basis that movie science has a major impact on the public's awareness of science, and thus misinformation in movies will undermine the public's ability to understand and respond to the real risks and consequences of scientific progress (Bradley, 2001).

2. Scientific accuracy versus plausibility in movies

Any debate over the primacy of fact versus fiction in movies seems bound to a stalemate of conflicting purposes. A more fruitful line of inquiry is to consider the relative significance of accuracy and plausibility in movie science. For this discussion, I use accuracy to refer to detailed information about scientific devices, techniques, and concepts that is likely to be known only to scientists with the relevant specialization. I use plausibility for concepts or techniques that may appear valid or feasible to a general audience on the basis of the information presented in the film and the public's understanding of related scientific knowledge. Although some attention to scientific detail is obviously necessary to root a plot in reality, I propose that plausible ideas have far greater potential than accurate details to motivate the public toward a better understanding of science. On one hand, inaccuracies that are evident only to the experts of a particular scientific subdiscipline are not likely to detract from the general perception of plausibility. From a teacher's point of view, explaining away such inaccuracies does not make a very interesting lesson in how science is done. In addition, the possibility that individual facts or interpretations are wrong is a fact of scientific life. Scientific discovery is driven by a plurality of changing and often conflicting ideas and approaches, and, to paraphrase one eminent biologist, some of the facts used to support any scientific theory usually turn out to be wrong. On the other hand, films that present plausible ideas are thought-provoking simply because they make people wonder whether the fictional science is possible. This opens up numerous opportunities for teaching and learning about science. The four questions that I use to focus my class discussions are: what is the additional science necessary to achieve the film's goals?; what are the theoretical flaws or technical limitations that might make them impossible?; are there any real science analogies to the fictional science?; and how do the goals and implications of the real science compare with the fictional treatment?

3. Plausibility and historical context

Appreciating scientific plausibility in films, however, usually requires some consideration of the historical context in which the fiction was created. Popular culture tends to mirror the scientific misconceptions of an era as well as its truths, and this is well illustrated by four movies about resurrecting and recreating life: *Frankenstein*, *Jurassic Park*, *The Boys from Brazil*, and *The Sixth Day*.

Frankenstein is the original story of people using science to manipulate their own fate. More specifically, an antisocial student of natural philosophy becomes obsessed with rebuilding a man from the parts of dead bodies and reviving it with electricity. As Mary

Shelley was only 18 when she wrote Frankenstein, and had received no formal education in science, her exposure to the research and ideas that inspired this tale is generally credited to her husband and father and their academic acquaintances (Goulding, 2002; Seymour, 2000). Regardless of her exact sources, Shelley's concept of reanimation draws upon an impressive number of contemporary scientific ideas and practices. Foremost is the belief in spontaneous generation, meaning that life could arise spontaneously from dead animal or plant matter. Another inspiration may have been the theory of epigenesis, which argued that the process of a single cell becoming a complex multicellular adult is controlled by a vital force unique to living tissue. Also, during Shelley's time there was considerable experimentation on the relationship between electricity and life, especially the role of electricity in stimulating muscle contraction. The electricity used for these experiments was generated by galvanism, meaning chemical reactions involving metals with different affinities for electrons. Whereas the 1994 film by Kenneth Branagh remains faithful to Shelley's choice of galvanism to reanimate the creature, James Whale decided that lightning would have more cinematic appeal than simply soaking the body in an electrolyte solution. Frankenstein's research methods were also probably inspired by everyday practices of medical doctors in nineteenth century Europe. To research human anatomy and causes of death, doctors usually had to resort to grave-robbing, because there was a general distaste for donating the cadavers of loved ones for this purpose (Gawande, 2001). Also, as this was the early days of the industrial revolution, one of the common tasks facing doctors was the amputation of limbs that got mangled in heavy machinery. "Sawbones" is in fact a nickname used for MDs in Robert Louis Stephensons' *The Strange Case of Dr. Jekyll and Mr. Hyde*.

Viewed against this historical backdrop, Shelley's story of transforming stitched-together body parts into a sentient being must have been very plausible for an 1820s public. And although Whale's movie comes over 100 years later, the intervening period of scientific discovery did little to dilute the story's plausibility or emotional impact. Certainly, when viewed against twenty-first-century science, the story's theoretical flaws are rather obvious. Shelley trusted in a force that does not exist, electricity is produced in living tissue but it cannot impart new life to dead tissue, and with the exception of animals that make cryoprotectants, the cessation of heartbeat and breathing sooner or later results in widespread cell death and chemical disintegration. These are irreversible processes that represent an absolute and insurmountable obstacle to this form of reanimation. Nevertheless, Shelley's anatomical concept of reanimation remains educational in a historical sense and, interestingly enough, has been revived in a modern-day genetic version.

In Michael Crichton's *Jurassic Park*, fragments of fossilized dinosaur DNA are extracted from amber and sequenced so that they can be reconstructed into chromosomes. The completed chromosomes are installed into an egg, which is triggered to undergo normal embryonic development to produce a baby dinosaur. Like *Frankenstein*, this fiction is plausible in the context of its contemporary biology. The 1953 discovery of the chemical structure of DNA led to an understanding of how DNA is replicated and how cells use sequences of DNA, or genes, to make RNA and ultimately proteins. The 1970s gave birth to molecular biology, the science of how gene expression is regulated, and the 1980s in turn gave birth to developmental genetics, the science of how individual genes control the development of organisms. The principal developmental genes of an organism were first identified for the fruit fly, and this work has facilitated the discovery and characterization of literally thousands of developmental genes in numerous organisms, including humans. Indeed, developmental genetics developed such momentum that many scientists gave in to hyperbolic speculation about the potential of genes to explain the properties of living organisms. A highly renowned molecular biologist and recent Nobel Prize recipient was quoted in the 1980s (see Lewontin, 2000) as saying that if he had the complete sequence of DNA of an organism and a large enough computer, he could compute the organism. The implication is that by knowing the entire sequence of DNA, he could predict the structure and function of all proteins made from the DNA and thus predict the development of the organism.

This idea of genes as a set of instructions, a recipe or blueprint for life, was obviously a major inspiration for *Jurassic Park*. It is also a very prevalent but misleading metaphor in modern biology. Another architectural metaphor helps to illustrate my point. In the same way that it is possible to predict the color and strength of a brick by knowing the chemical formula of the clay used to make it, scientists can predict some of the properties of a protein by knowing the sequence of DNA used to make it. However, the chemical makeup of the brick does not specify the way that that brick should be laid next to other bricks or the overall shape and size of the final building. Similarly, the DNA sequence of a gene alone does not determine when or where in a developing organism that gene should be expressed to make its particular protein, or, in most cases, the timing and nature of the protein's function. Additional information is required from beyond the DNA, meaning other molecules that are already present in the cell, and the environment of the cell, which includes its temperature, neighboring cells, and numerous other forces and factors. This dependence on information beyond the DNA applies to all organisms, all processes of life, and all stages of development, including the fertilized egg. The information that is put into the egg to control early development has yet to be fully worked out for any living species, let alone dinosaurs whose ancestors diverged from those of living species at least 200 million years ago. So even if it were possible to reassemble all of a dinosaur's DNA correctly, one would still need a dinosaur egg in which to insert that DNA.

A more complete discussion of the real science required to resurrect dinosaurs, and its theoretical flaws and technical limitations, is available in the nonfiction book *The Science of Jurassic Park and the Lost World, or How to Build a Dinosaur* (DeSalle and Lindley, 1997). Most importantly, this book underscores the real triumph of *Jurassic Park*, which is a plotline that raises questions and ideas from virtually all subdisciplines of modern biology.

Switching to human cloning, the 1978 thriller *The Boys from Brazil* depicts most people's worst-case scenario: cloning many new Hitlers using blood cells preserved from the original. Although unremarkable in most respects, the plot deserves attention here for a scene in which the protagonist seeks knowledge from a scientific authority, a professor who is neutral to the plot and whose only purpose in the film is to instruct him (and the audience) about the method and plausibility of cloning humans. This character answers questions over a cup of tea and shows a film clip on nuclear transplantation. The clip's narration clearly explains the steps of retrieving a recently ovulated egg cell from the mother, destroying its chromosomes, injecting a cell nucleus from the individual to be cloned, jolting the egg with electricity to start its development, and, once cell division has started, transferring the embryo back to the mother's reproductive tract, where it completes a normal gestation. The explanation is complete and, in the context of 1978 biology, accurate. Thus, one might wonder what is lacking in this explanation and what was discovered 20 years later to make Dolly possible. The professor hints at the difficulties of the microsurgery involved, which is one reason for the low success rate of real cloning. The rest of the story is 50 years of trial and error that started with the first successful nuclear transplantation experiments on frogs in the 1950s and culminated with the first successes on mammals six years ago (Di Berardino, 1999). The trials involved many different cell types from different stages of development and from different species, and even now, scientists do not fully understand why one cell type can be cloned and another cannot.

In addition to the accuracy and completeness of its scientific explanation, *The Boys from Brazil* deserves mention for its portrayal of a scientist as an unbiased and personable authority figure, one who is willing and able to communicate science to the public. Strangely enough, comments on this film's portrayal of scientists have addressed only the antagonist, a fictionalized version of the Nazi doctor, Josef Mengele (Ribalow, 1998). This character's sociopathic nature is already a matter of public knowledge, and thus his portrayal in films can hardly be considered a fair standard for how moviemakers choose to depict scientists.

Let us jump ahead to three years after Dolly, and examine how cloning is portrayed in the Arnold Schwarzenegger movie, *The Sixth Day*. Although the movie opens with headlines of Dolly and other recent advances in cloning technology, *Sixth Day* cloning bears no resemblance to nuclear transplantation. It involves infusing a generic human body with the DNA and electronically encoded memories of the person to be cloned. Movie-wise, this is a fantastic idea. That it takes only a few hours means immediate gratification to anyone needing a copy of him- or herself. Villains can now view their bodies as fully disposable, which makes them every bit the equal of their cartoon counterparts. Villains can also become the ultimate control freaks by genetically programming some built-in obsolescence into the clones of their underlings. Education-wise, however, the movie offers no explanation for its highly implausible concepts and provides only the opportunity to identify the many biological principles that it violates. For example, complete and intact human bodies can be created only by the natural processes of growth and development. These take a lot of time, require all cells to have their own DNA, and always produce individualized results. While it is theoretically possible to digitally encode all the information in our brains, the task of converting memories that are stored as three-dimensional patterns of chemicals and cell connections into a sequence of ones and zeros remains hopelessly complex. Also, a lot of who we are is the result of the many environments and experiences that we encounter during our lifetime, and this information is not stored in our DNA. Some obvious examples are Arnold's extra muscle mass and the creases on his face. *The Sixth Day* also buys wholeheartedly into genetic determinism, unlike *The Boys From Brazil*, which makes a subtle but powerful statement against this idea. The protagonist of that film eventually burns the list of names of the Hitler clones, confident that the role of the environment in defining a human personality is too complex to ever allow the exact duplication of megalomaniacs, geniuses, or other exceptional individuals.

4. How to appreciate movie science for what it is

In summary, of the four movies discussed above, three give fairly plausible depictions of breakthroughs in the science of resurrecting or recreating life. Two of these require some hindsight to pinpoint exactly why the movie science would not work, and the third provides a preview of, and commentary on, real science, the fruition of which is possibly around the corner. This brings us to whether one can expect movie science to be both plausible and accurate, and how movies should be critiqued for these elements. As long as profitability remains the strongest selective pressure in the evolution of Hollywood movies, the answer to the first question is obviously no. What sells is determined by a complex interplay between popular demand and the marketing of popular culture to condition and manipulate popular demand. Unless all members of the movie-going public suddenly opt to undergo regular scientific training, the need to enforce scientific accuracy in movies will remain secondary to the need for story lines that exploit science in exciting and innovative, but not necessarily real, ways. However, on the bright side, scientific plausibility is often a carryover from the real science that inspires a movie. Also, whereas scientific accuracy is often at odds with good storytelling (Crichton, 1999), scientific plausibility can only add to a movie's commercial success.

In evaluating scientific plausibility, I suggest that reviewers (and scientists) take a lesson from how movies about historical figures and political or cultural events are critiqued for their authenticity. Authenticity is usually interpreted in terms of the depiction of physical reality, meaning the chronology of events, the settings, appearances, etc. However, authenticity can also be meaningfully invoked on other levels, including the personalities and sensibilities of the characters, and the political atmosphere, moral tone, and emotional setting of a story. Likewise, scientific plausibility in movies comes in different forms, and appreciating it is more a matter of finding the connections and parallels (intended and otherwise) with real science than pointing out the inaccuracies and oversights.

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Author

Christopher Rose is an associate professor of biology at James Madison University, Virginia. As well as the general science course discussed in this article, he teaches developmental biology and comparative vertebrate anatomy. His main research interest is vertebrate metamorphosis, focusing on how the skulls of frogs, salamanders, and flatfish change during their metamorphoses and how this remodeling is controlled by hormones and other developmental mechanisms. Contact: Department of Biology, James Madison University, Burruss Hall 213, Harrisonburg, Virginia 22807, USA. Email: rosecs@jmu.edu