1 Scientific Expertise in Hollywood: The Interactions between Scientific and Entertainment Cultures

Space may be the final frontier but it's made in a Hollywood basement.
—Red Hot Chili Peppers, "Californication," 1999

In 2009 the National Aeronautics and Space Administration (NASA) hired Hollywood filmmakers to digitally enhance footage of the *Apollo 11* Moon landings for the Apollo program's fortieth anniversary.[1] NASA had taped over the original video footage and alternative footage was grainy. To clean up the images NASA employed Lowry Digital, which had previously remastered copies of *Citizen Kane* (1941) and *Casablanca* (1942). Of course, the filmmakers' collaboration played into the claims of those who consider the Moon landing itself to be a hoax. This vocal minority believes that the pinnacle of humanity's scientific achievement *was* made in a Hollywood basement.

More accurately, many hoax proponents think that director Stanley Kubrick created the footage of Neil Armstrong and Buzz Aldrin walking on the Moon in Shepperton Studios of Surrey, England. Kubrick's vision of space travel in *2001: A Space Odyssey* (1968) was so impressive and the visuals were so realistic that hoax supporters have claimed that the film was the means by which NASA tested the cinematic techniques for creating the hoax films. Alternatively, they argue that NASA only lent its assistance in making *2001* to coerce Kubrick into staging the Moon landings on the same sets.[2] The televised images coming from the Moon bore too much resemblance to media images that the hoax supporters had previously seen in Kubrick's film and in other realistic space movies like *Destination Moon* (1950) and *Conquest of Space* (1955). *2001* can easily be called the most scientifically accurate film ever made for its time. Kubrick's film *felt* authentic and the scientific authenticity of this fictional text made it easy to see how some people believed filmmakers could fake the Moon landings.

Kubrick used cinematic language in *2001* as a means to explore complex ideas about the relationship between humanity and technology as well as humanity's place in the universe. For Kubrick, explorations of complex ideas did not emerge through simplification. Instead, they came about by displaying *every* detail of these complexities. Scientific verisimilitude was crucial for Kubrick not only in creating a visually rich film but also in putting the complexity of his questions into science, technology, and meaning on display. Kubrick's attention to detail was legendary, so it is not surprising that he went to great lengths to imbue his film with as much scientific accuracy as possible.

Influenced by both Italian neorealist films of the 1940s and the experimental style of the French New Wave movement of the 1960s, Kubrick's goal for *2001* was the transformation of science fiction movies from juvenile adventure stories into a medium of intellectual exploration comparable to science fiction literature.[3] To this end, the filmmaker hired former NASA space scientist Frederick Ordway as his primary science consultant to work on the film for almost three years (figure 1.1).

Ordway had founded an aerospace consultancy and thus had contacts with every major organization working on rocket development. A glance at the list of organizations contributing scientific and technical advice for *2001* dwarfs such input for any other film before or since. With Ordway's assistance the production staff consulted with over sixty-five private companies, government agencies, university groups, and research institutions.[4] In addition, Kubrick hired Ordway's business partner, aerospace engineer Harry Lange, as a production designer. Lange had previously worked for NASA illustrating advanced space vehicle concepts including propulsion systems, radar navigation, and docking techniques. Piers Bizony describes Lange's job at NASA as visualizing "as-yet-unborn vehicle concepts, so that NASA and its associated army of corporate collaborators could communicate their ideas for the future."[5] Essentially, Kubrick was asking Lange to do the same for his film.

Kubrick needed assistance in planning how to portray on film events that were not even remotely in the near future. A manned trip to the Moon was right around the corner, certainly, but Moon bases were not on the agenda in the 1960s, nor were orbiting space stations and manned trips to

Figure 1.1
This production photo shows *2001*'s primary consultant Frederick Ordway (left) next to statistician I. J. Good who provided Stanley Kubrick advice on supercomputers.
Source: I. J. Good Collection (VTA0002), Digital Library and Archives, University Libraries, Virginia Tech.

Jupiter. In order to speculate on future space missions Ordway and Lange not only had to come up with suitable technology based on current thinking in the space sciences, but also had to provide logical explanations for why this technology would exist, how it would fit into *2001*'s narrative, and how it would impact the film's visuals. Ordway had to use his experience within the space science industry—whose experts were just beginning to work out these details for themselves—to extrapolate from current trends to future realities. So, for example, the "Cavradyne engines" used for *2001*'s spaceships were based on an assumption that continuing advances in gaseous-core nuclear reactors and high-temperature ionized gases in the 1960s would make this technology feasible by the 1990s.[6] In this way, Ordway, Lange, and Kubrick developed comprehensive background information for the spaceships, space stations, and manned missions that was logical and narratively integrated.

Although we most often associate *2001* with its groundbreaking displays of space and space travel, we forget that the film actually begins with the "Dawn of Man." Therefore, Kubrick also required scientific advice about the nature of early hominids. To get this advice Ordway brought in the famous anthropological father-and-son team of Louis and Richard Leakey.[7] Kubrick and Arthur C. Clarke, the screenplay's coauthor, also spoke with anthropologists about using anthropology to underscore one of the film's major themes concerning human evolution. Because Kubrick wanted the hominids' encounter with the alien black obelisk artifact to transform his hominid characters from vegetarians into omnivores, Clarke visited anthropologists Harry Shapiro and Ike Asimov to determine if such a biochemical change was possible in so short a time as a couple of weeks.[8] Ordway also helped Kubrick work out a logical explanation for the film's one truly fantastical element: the alien black obelisk.

Kubrick was balancing a desire for scientific verisimilitude and a need for plausibility with his artistic and technical judgments as to the viability of incorporating science: "I think there were two problems in the design of anything. One was, is there anything about it that would be logically inconsistent with what people felt would actually exist; and the other one was, would it be interesting? Would it look nice?"[9] Kubrick faced a series of choices. For example, should he incorporate a shiny, silver "look" for the interiors of his spacecraft because it was visually interesting and because audiences expected this depiction given the conventions of previous space

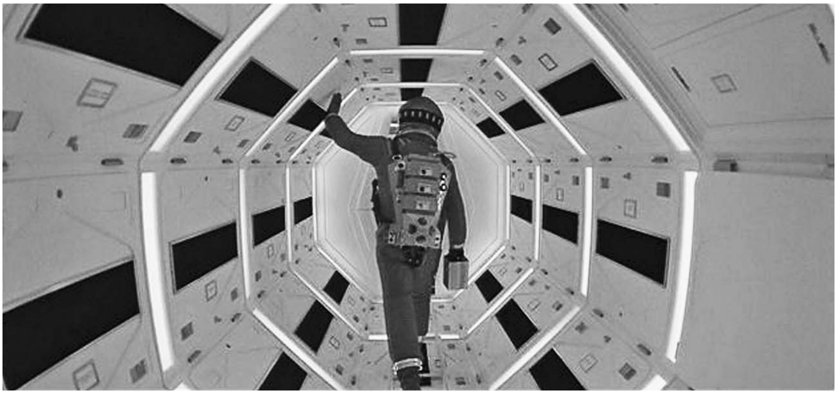

Figure 1.2
Kubrick employed a white, ceramic look inside the spacecraft designed for *2001*.

films? Or should he work with the white ceramic look that NASA acknowledged it was using for its real-world designs (figure 1.2)?[10] Should Kubrick ignore, as most filmmakers have done, the accepted fact that any long-term space voyage requires some means to generate artificial gravity? Or should he pay the Vickers Engineering Group $750,000 to spend six months building an actual working centrifuge (figure 1.3)?[11] On the one hand, Kubrick's obsessive pursuit of scientific authenticity in the face of the same filmmaking constraints found in every film production (budget, aesthetics, dramatic needs, filmability, technical capacity) is what separates *2001* from other films. With both the ship's interiors and the gravity wheel (as shown in figures 1.2 and 1.3, respectively) Kubrick decided that authenticity was worth overcoming these constraints.

On the other hand, even the detail-oriented Kubrick had to sacrifice scientific authenticity when it conflicted with his creative desires or his sense of commercial necessity. Arthur C. Clarke related a story in which scientists working on the recently declassified Project Orion passed on documents to Clarke and Kubrick. Orion was a theoretical propulsion system, based on the generation of thrust using a series of nuclear explosions that push against a drive plate, which many scientists saw as the only hope for long-distance space travel. As Clarke told it, no matter how excited scientists were about this propulsion system it was abandoned because Kubrick "decided that put-putting away from Earth at the rate of 20 atom bombs per minute was just a little too comic."[12] The Orion system

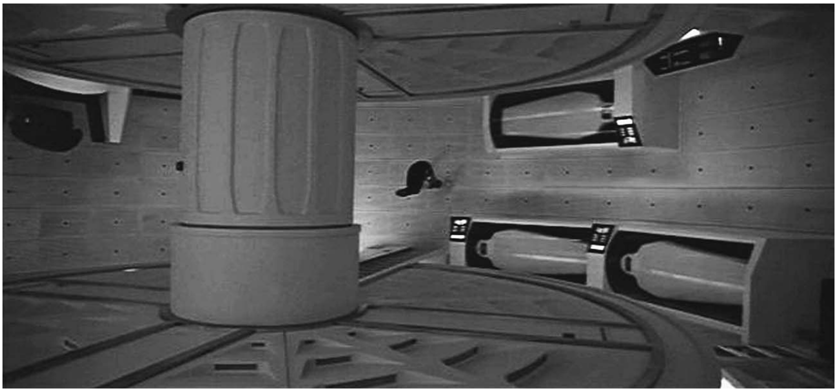

Figure 1.3
Kubrick built a full-scale rotating "gravity wheel" set for scenes in the *Discovery* spaceship for *2001*.

did not conform to Kubrick's sense of visual drama so it was not included no matter how authentic it was.

It is also the case that some aspects of *2001* look inaccurate today even though these same aspects were considered highly accurate at the time. This is not because the special effects look dated but, rather, because the "facts" Kubrick used at the time have themselves become out of date. In order to design the surface of the Moon, for example, Ordway secured pictures from Boris Polikarpov, the Soviet science attaché in London, and from astronomer Zdenek Kopal of the University of Manchester. As Ordway recalled, these images were soon to prove inaccurate after the Moon landing of 1969 but they were the best information available when those scenes were filmed in 1966.[13] This need to rely on science at the cutting edge also meant that several science consultants used the film's fictional nature to work through some of their own conjectural ideas. Ordway, for example, worked with several scientists on the film's astronaut hibernation scenario. One of the scientists, Ormond Mitchell of the New York College of Medicine, published an academic article based on the ideas that came out of his work on the film *2001*.[14]

Stanley Kubrick and MGM were not the only ones to profit from the large audiences for *2001* in 1968. Most of the consultants involved benefited from their association with the film's vision of the future and the space program. Kubrick traded screen time and publicity for access to dozens of organizations including IBM, Bell Telephone, Honeywell, RCA, Pan Am, and General Electric. They happily shared information on future technological developments and designs for free, just for the chance to have what I call "preproduct placements" that established their brand as "futuristic" in this high-profile film and to feature their film participation in their advertising. *2001* contextualized space travel for audiences in the same manner as Fritz Lang's *Frau im Mond* [*Woman in the Moon*] (1929) and George Pal's *Destination Moon* (1950) had done in previous eras. Unlike those two films, however, *2001* was not establishing the technological capabilities and societal necessity of space travel. Manned space flights had been taking place since 1961. What *2001* did was contextualize for audiences the cultural and social potential of space travel now that it was possible. Film scholar Robert Kolker contends that the power of *2001*'s images and narrative established the film as a modern myth: "2001 is not only a narrative of space travel but a way of seeing what space travel *should* look like" (emphasis in original).[15] *2001*'s vision of space travel with its space stations, transport shuttles to the Moon, and interplanetary space ships is still influential.[16]

It is tempting to view *2001* as an outlier regarding its utilization of science consultants. No other film can claim the amount and range of advice that *2001*'s filmmakers received during production. Despite Kubrick's obsession for details, however, *2001* only differs in degree, not in kind, from the other films I will discuss in this book. An examination of *2001* reveals the same features of science consulting found in other films with regard to both film production and cinema's impact on scientific culture. The exceptional feature of *2001* is that it demonstrates every facet of scientist/filmmaker and science/cinema interactions. Scientific experts were called upon to help filmmakers create scientific visuals, to check facts, to provide logical explanations for speculative and fantastical situations, and to help the cast act like scientists. At the same time Kubrick and his team exerted their creative control over these elements using their own expertise to decide how to incorporate science. By the same token *2001*'s science consultants had an opportunity to realistically visualize their conceptions of the natural world and technological possibilities in an extremely high-profile film that disseminated their ideas to a mass audience.

Scientists working on entertainment productions certainly increase the chances that a film will contain a higher percentage of accurate science. It is important to note, however, that *2001* was successful, both critically and financially, not because of the volume of accurate science but because Kubrick used science as a creative tool to make the film visually remarkable and intellectually appealing, thereby increasing its box office potential. Kubrick's filmmaking genius was his understanding that for *this particular film* box office success could be achieved through an adherence to scientific authenticity as his consultants defined it within the confines of aesthetically interesting design.

Not every film can, or should, approach the level of accuracy found in *2001*. Kubrick's attention to detail and rigid notion of accuracy would pose financial and technical problems for most filmmakers and with the likelihood of minimal box office gains. In addition, such an approach to scientific accuracy can make a film tedious—the opinion of many people who watch *2001* today. At the time, however, Kubrick's choice to lean heavily toward verisimilitude paid dividends given the cultural context in which *2001* was released. What this book demonstrates is that the goal for science consultants is to let filmmakers negotiate scientific accuracy within their own context of narrative, genre, and audience. Scientific expertise is incredibly valuable in helping filmmakers create plausible and visually interesting films. Yet their advice is only useful in cinematic productions if it allows filmmakers to better use their own creative expertise.

The Nature of Scientific Expertise in Hollywood

Expertise is central to interactions between scientists and the entertainment industry. The concept of scientific expertise, however, is not a simple delineation between those who possess scientific knowledge and those who do not. This is especially true of scientific expertise in Hollywood where expertise is an extremely fluid concept. It is clear from *2001*'s production history that filmmakers look to science consultants to contribute to areas of expertise beyond knowledge of scientific facts. The same is true of many other films: What does the surface of Mars look like? What equipment does a molecular biology lab contain? What would a paleontologist do if confronted by a living dinosaur? How can the surface of a comet contribute to a film's drama? What goes on in a United Nations meeting on climate change? How could nanotechnology be used to create a monster? I have identified the following aspects of expertise that scientists bring to the fantastical realm of Hollywood cinema:

- Fact checking is not a consultant's only duty, but it is certainly a major one. As I will argue throughout this book the question of accuracy in film is actually open to debate. Rather than fixating on scientific *accuracy* I try to understand how scientists and filmmakers negotiate their perceptions of this term.
- Filmmakers expect consultants to help shape science's iconography. Visual elements are of primary concern for filmmakers. Thus, they will seek out expert advice concerning visual aspects such as the look of scientific spaces and technology before they even think about other scientific elements. Iconography also includes advising actors on how to "act" like a scientist on the screen.
- One of the most important functions of a science consultant is to enhance the plausibility of cinematic events. Scientists' contributions to the believability of a film's narrative, representations, and events—the text's "film logic"—are even more important than scientific verisimilitude. Plausibility directly relates to maintaining an audience's suspension of disbelief, and thus, affects filmmakers' ability to make money.
- Scientists' expertise helps position science into its cultural contexts, which contextualizes science's implications for society, its value as a human activity, the consequences of its use or misuse, and its ideological status. This expertise requires consultants to understand issues relating to political, economical, and social uses of science.
- Consultants are asked to use science in order to provide opportunities to create drama. Filmmakers look to scientists for help using science as a tool for drama and for tapping into the creative and speculative aspects of scientific thought.
- Studios prominently feature their consultants' scientific expertise in publicity material. By hiring scientists, studios borrow their expertise to claim legitimacy for the science on the screen.

Scientists offer more than just advice on particular aspects of scientific thought; their expertise can be used to examine film scenarios holistically. Scientific training develops an ability to parse through small details, but it also gives scientists a capacity for understanding and seeing the connections within complex systems, a skill that proves invaluable for screenwriters, producers, and directors as they flesh out the structural foundations of their film plots. It is important to keep in mind, however, that filmmakers have their own expertise. Therefore, the interactions between scientific and entertainment cultures are about prioritizing expertise or finding ways in which scientific expertise can complement filmmaking expertise. Scientific expertise provides both necessary constraints and flexibility that help filmmakers utilize their own expertise as creative and commercial artists.

Is Science Entertaining? Interactions between Scientific and Entertainment Cultures

The scientific community refers to inaccurate science in entertainment texts as "bad science." Scientists external to the production process believe there is a tension in filmmaking between accuracy and entertainment. For filmmakers there is no tension. There is only entertainment. Accuracy is only important if filmmakers believe it generates entertainment value. Any science that detracts from an audience's enjoyment of a film is bad for a filmmaker whether it is accurate or not. I have sat in workshops with scientists and filmmakers and heard scientists ask variations on the question: "How can we make the science in entertainment products more accurate?" This is the wrong question. The more useful question is to ask filmmakers: "How can accurate science make your film better?" Science in cinema should never be obvious; instead it should be seamlessly integrated into the story and visuals. Science should conform to Lionel Trilling's notion of theatrical "sincerity": acting as the performance of not performing.[17] "Scientific sincerity" means taking scientific content as part of the film's natural landscape.

Technologist John Underkoffler of Oblong Industries, who has consulted on several films including *Minority Report* (2002), *Hulk* (2003), and *Iron Man* (2008), provides an apt metaphor for the ways in which science is often incorporated into cinematic texts: "Science in movies tends to be slapped on, like spackle, over a hole in a wall. No matter how much you paint over it that hole still shows."[18] To be effective, science in movies should be fully integrated; to continue Underkoffler's metaphor it should

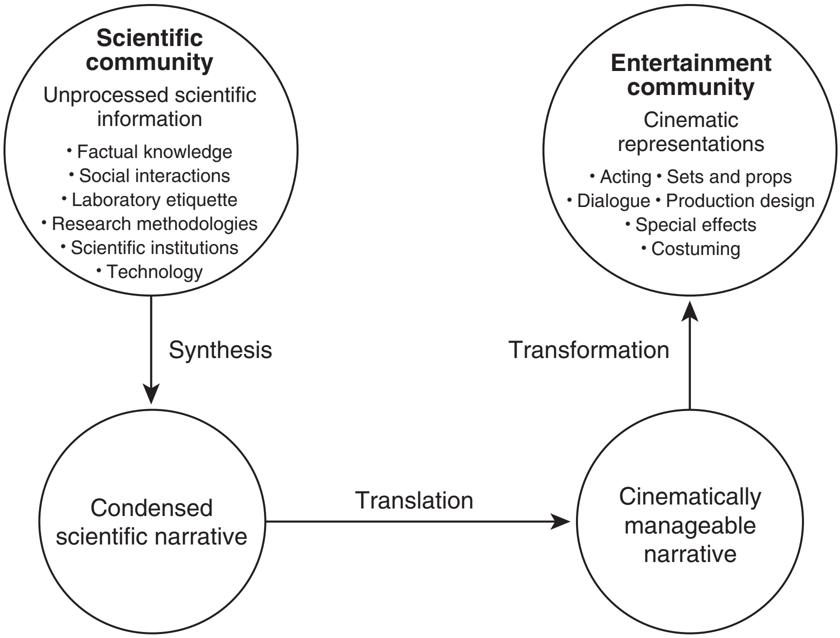

Figure 1.4
Schematic of the science consultant's process.

become part of the wall itself. The goal of filmmaking is to produce an entertaining story that may happen to have scientific content. This means that the process of science consulting is not a simple transfer of knowledge. The process involves the synthesis of information from the culture of science, the translation of that information into the culture of entertainment, and finally the transformation of the information into a finished cultural product (figure 1.4).

Even the smallest pieces of advice from a science consultant can impact a movie's dramatic and visual potential. Astronomer Carolyn Porco of the Space Science Institute was surprised when director J. J. Abrams asked her only a single question for her job as science consultant on *Star Trek* (2009): "I've got the *Enterprise* [U.S.S. *Enterprise* starship] coming back into the solar system and I want to hide it from the Romulans somewhere. Where should I hide it?"[19] She told him the *Enterprise* should come out of warp drive in the cloudy atmosphere of Saturn's moon Titan, then reemerge in a visually striking way—"submarine style," with Saturn's rings in the

Figure 1.5
Carolyn Porco's scientific advice led to this stunning visual in *Star Trek*.

background (figure 1.5). Although she later spoke with special effects technicians about how to visualize Titan and Saturn, this one answer was the extent of her input into the narrative. Yet it turned out to be a significant piece of advice. It gave filmmakers exactly what they wanted: a visually interesting *and* dramatic scene that had a logical explanation.

I do not want to ascribe too much influence to science consultants. For one, a film's content is influenced by factors external to the filmmakers themselves such as marketing priorities and studio politics.[20] Science consultants do have an influence—sometimes significant—on a text but it would be a naïve view to believe that scientists have as much control over the science in a film as the director or the production designer. Filmmaking is a complex and chaotic process that involves hundreds of people who have a limited amount of time and money to bring a film to its completion. In addition, film cultures are not egalitarian communities. Instead they have a very rigid hierarchy of superiors and subordinates. Donna Cline works as both a professional science consultant and as a storyboard artist.[21] As a storyboard artist Cline knows exactly where she fits into the hierarchy: she is in the art department. If she needs to bring something to the attention of the director or production designer she goes through her superior, the art director. As a science consultant, however, she does not have a fixed place within this well-established hierarchy. Therefore, she has to understand the rules for interacting with any individual within this hierarchy. As she tells it, she needs to know how to "toe a political line" with every individual.

In addition, several consultants told me that they had to be very careful about the ways in which they phrased their advice to filmmakers. They said that filmmakers as a group are sensitive to criticism and take offense if they are told they are “wrong.” In scientific or academic culture, such a critique is a valued social norm because scientists understand that their colleagues are just “telling it the way it is.” In filmmaking culture, however, the perception is that scientists are overtly demonstrating their superiority and undervaluing filmmakers’ own knowledge. Not only were consultants wary of straight-out telling filmmakers their fictional science was wrong, the consultants also had to provide realistic alternatives to replace any cinematic elements they were critiquing.

Barnard College mathematician Dave Bayer experienced the vagaries of the consultant’s place in the filmmaking hierarchy while working on *A Beautiful Mind* (2001): “There’s a lot to take in, to be an active participant in a film, more than simply knowing one’s subject matter and being flexible about adapting it for dramatic purposes. A film is a far more socially charged environment than academics are accustomed to.”[22] Bayer had established a good level of trust with screenwriter Akiva Goldsman, but this did not automatically extend to other members of the production crew. In one instance the art department made some mistakes copying coordinates on the panels that actor Russell Crowe’s character uses when cracking an encryption code. Instead of “busting their chops” Bayer decided to allow the coordinates to stand and he had Goldsman modify the script.

Unfortunately for Bayer, a graphic designer made another replacement panel showing the initial coordinates and this panel was incorporated into the set. Rather than asking Crowe to memorize new lines Bayer attempted to fix the problem by substituting in the original panel, which put him in conflict with another filmmaker. Recalled Bayer, “It turned out that the production designer Wynn Thomas had spent many hours using the various panel tones to turn this set into a work of art, and I was not to touch the panels. . . . He proceeded to give me a withering dressing down about my place in the production, in front of the assembled crew.” In the end, Bayer convinced Thomas that the original panel better served the interests of the production and Thomas rearranged the set. Bayer, however, realized that even though he had direct access to filmmakers at the highest production levels, such as director Ron Howard, he was still an outsider in this community and those on the inside had no qualms about letting him know this. His "authority" on the set only extended as far as anyone in a position of power was willing to grant him.

A consultant's influence over the science in a film depends to a large extent on when they become involved in a production. This can occur at any point from informal discussions with a scriptwriter before preproduction to discussions with special effects technicians days before a film's release. Several consultants made the point to me that the earlier you get involved the more influence you have over the final product. According to *Minority Report*'s production designer Alex McDowell, "the story drives many of the most significant decisions, so the early integration of a science advisor on a film allows the story and the design logic to become inextricably entwined, and to minimize the potential conflict."[23] Sometimes a director will make a decision to incorporate a science consultant's suggestion during production even if it costs time, money, or resources. This occurred when Jet Propulsion Laboratory scientist Richard Terrile came on board as consultant for *2010* (1984) and told director Peter Hyams that his rotating set for the *Discovery* spaceship was flawed.[24] As Terrile tells it, "The first day I was there I cost [Hyams] a lot of money but if he had hired me a week earlier it would have saved him fifty thousand dollars." Hyams did not have to act upon Terrile's suggestion, especially at such a substantial cost. In this case Hyams believed that an accurate set was worth the time and cost to make this change.

For the most part, however, advice that could easily be changed at the script stage is more likely to be disregarded in the middle of production if it conflicts with work that has already been undertaken. This is not to say that scientists coming into a production later cannot have an impact on a film, rather, it is to say that the momentum of a film production makes it harder for filmmakers to accommodate a consultant's recommendations in later stages. Regardless, Terrile's suggestions for *2010* and Porco's advice for *Star Trek* would have been meaningless if their respective employers had not taken them seriously. Successful science consultants, then, are those who are best able to convince filmmakers that their advice represents what's best for a film.

Cinema's Impact on Science and Technology

Ultimately, my interest as a science studies scholar is to understand how representations and narratives in entertainment media impact scientific culture. The cinematic apparatus actually emerged out of the animal movement studies of Eadweard Muybridge and Etienne-Jules Marey in the late nineteenth century. Since that time, moving pictures have remained an integral part of scientific research.[25] But cinema impacts science beyond being a research tool. Popular films impact scientific culture by effecting public controversies, enhancing funding opportunities, promoting research agendas, and stimulating the public into political action. Several recent studies of science popularization demonstrate that the *meanings* of science, not public knowledge, may be the most significant element contributing to public perceptions of, and attitudes toward, science.[26] According to Alan Irwin, the public makes sense of science—constructs its "science citizenship"—in the context of people's everyday lives, preexisting knowledge, experience, and belief structures.[27] Entertainment texts, like popular films, significantly influence people's belief structures by shaping, cultivating, or reinforcing the "cultural meanings" of science.

Moreover, entertainment texts can influence scientific thought by foregrounding specific scientific ideas and providing narrative reasons to accept them as representing reality. Lily Kay offers the useful notion of "technoscientific imaginary" to account for shared representational practices both within science and in the broader culture.[28] The technoscientific imaginary represents a "master" narrative that encompasses all the narratives, both scientific and public, that frame an issue and give the issue its cultural value. Science consultants can significantly impact the technoscientific imaginary by assisting in the creation of cinematic depictions.

Beyond its impact on public discourse, dissemination of scientific ideas through entertainment media has the potential of impacting scientific knowledge production. Numerous studies of science in public, from the spectacle of nineteenth-century electrical displays to the twentieth-century news coverage of the cold fusion affair, show that scientific popularization is not just a "sharing" of scientific knowledge with the public, but is also a component in the making of that knowledge.[29] Such social, cultural, and historical studies of science show a destabilization of the boundaries between activities that constitute science's "inside" and "outside." Sir Richard Owen jumped at the opportunity to serve as advisor to sculptor Benjamin Waterhouse Hawkins in the creation of concrete, life-size dinosaur models for exhibit at the Crystal Palace in 1853 after his scientific rival Gideon Mantell turned down the offer. As such, audiences in the mid-nineteenth century saw enormous sculptures that matched Owen's notions of "rhinocerine" quadruped *Iguanodons* instead of Mandell's conceptions of bipedal animals with short forearms. These sculptures became representations that were important in Owen's ideological battles over evolutionary thought.[30] Just as Owen's opportunity to advise on these influential statues helped promulgate his ideas, consultants working on cinematic texts can disseminate their ideas through the visual medium of cinema. Any time a scientist discusses, or portrays, scientific information it is an act of persuasive communication, and as such it can have an impact on scientific practice.

Entertainment Experts, Authenticity, and Scientific Culture

The overwhelming financial success of *Jurassic Park* (1993) has led contemporary filmmakers to believe that "realism" is a necessary component in producing a highly profitable movie blockbuster. Film realism, however, has three distinct components incorporating naturalism (visual realism), narrative integration (dramatic realism), and authenticity (scientific realism). Science consultants have an influence on all three categories. Chapter 2 fleshes out some of the theoretical issues encompassing the understudied relationships between visual and narrative realism and scientific verisimilitude. Media representations can be a strong determinant in the production of technoscientific knowledge. Film's reality effect renders scientific representations plausible because it naturalizes images and events within the fictionalized world. Films act as virtual witnessing technologies by permitting large sections of the public to observe objects and events without the need to directly witness these phenomena. Popular films are particularly effective virtual witnessing technologies because their financial success is tied to how well they convey a sense of realism. Cinema's status as a virtual witnessing technology, then, is both a boon and a bane for popularized science since it naturalizes all scientific images whether they are accurate or inaccurate.

Chapter 3 examines the motivations the disparate communities of entertainment and science have for entering into a relationship. On the one hand, the need for realism is clearly a significant incentive for studios to hire science consultants, but their value as a publicity investment makes them even more desirable. On the other hand, the best way for scientific institutions or scientists to control their media image is to become involved in the production of media texts. The various forms of compensation scientists receive for consulting reflects a tension inherent in contemporary scientific culture between an obligation to science advocacy and a belief in the value of scientists' specialized knowledge.

Chapter 4 concerns science consultants' contributions to two of the most crucial cinematic elements: acting and visuals. Audiences have become more sophisticated and no longer accept obvious stereotypes so willingly. Filmmakers' recent emphasis on scientific realism has extended to actors' performances, and so producers hire scientists to teach actors how to act like a "real" scientist. Filmmakers also look for scientists to help them with the "look" of scientific spaces and technologies. Ultimately, filmmakers ask consultants to provide the symbolic cues that convey to audiences that "science" is on display.

A large proportion of fact checking for film productions involves scientific knowledge for which there is a strong consensus within the scientific community as to what represents natural law. Chapter 5 explores the variety of constraints (budget, drama, production schedule, etc.) filmmakers face when incorporating established facts into fictional texts. The notion of *flexibility* plays a central role in how scientific facts are negotiated in film production, meaning flexibility on the part of filmmakers and science consultants, but also flexibility as to what represents an "accurate" depiction. It is clear that filmmakers' treatment of facts depends to a large extent on the public's familiarity with a given scientific fact. The more well known that fact is, the less likely it is to be compromised. This flexibility with facts can be problematic regarding public discourses about science, especially for those facts that significantly impact the cultural meanings of science.

During "science in the making" several competing visions of nature have valid claims to representing "fact." Chapter 6 investigates how filmmakers and scientists grapple with scientific knowledge in flux. Scientific uncertainty provides flexibility since multiple sides of a scientific dispute can stake a claim to representing natural law. No matter which side filmmakers incorporate, they can honestly maintain they are adhering to scientific verisimilitude. Consultants generally welcome this flexibility, but they become rigid defenders of what they believe to be the "correct" side if they have a significant stake in a debate. Cinematic images can be a powerful force in knowledge production and it is highly advantageous for a scientist to have their position "naturalized" on the screen. This naturalization of disputed science troubles scientists who do not agree and who find other public outlets—news media, popular magazines, the Internet, and so on—to promote their own conceptions about what represents a "true" scientific representation.

For Hollywood films to be successful, audiences need to believe that the extraordinary events behind increasingly perceptually realistic cinematic spectacles are *possible*. This need for plausibility presents a dilemma for filmmakers: how can they make movies both believable *and* sensational? Chapter 7 explores how scientific explanation for fantastic and extraordinary events became the default position for filmmakers. Because scientific work involves logical deduction filmmakers perceive that scientists have an expertise in "thinking" that I refer to as an "expertise of logic." Filmmakers combine scientists' expertise of logic with their own creative expertise to construct stories that are both believable and spectacular.

Consultants have found the popular medium of film to be an effective means of convincing the public that a scientific issue needs more attention. This is especially true for areas where scientists believe inaction will lead to disaster. Chapter 8 considers scientists' belief that plausible "scientific disasters" in popular films will lead to the prevention of these disasters by arousing public fear. For science consultants, the key is to help make the film plausible enough to become an asset and not a liability. Consultants believe that the more realistically a scientific disaster is visualized in a fictional world, the more motivated the public will be to fund scientific research in order to prevent the event from occurring in the real world. Regardless, a basic level of scientific authenticity is essential to stave off the worst critical attacks by scientific and political opponents.

Consultants can also utilize cinematic representation to reduce anxiety and stimulate a desire in audiences to see potential technologies become realities, as discussed in Chapter 9. Cinematic depictions of future technologies are what I call "diegetic prototypes." These technologies only exist in the fictional world—what film scholars call the diegesis—but they exist as fully functioning objects in that world. Diegetic prototypes foster public support for potential or emerging technologies by establishing the need, benevolence, and viability of these technologies.

Chapter 10 concludes that the scientific community and the entertainment industry both benefit from their collaborations. These collaborations provide members of the scientific community the means to disseminate their visions of science as an activity and an institution, and their conceptions of the natural world through a culturally powerful visual medium. Entertainment industry practitioners clearly benefit through their interactions with scientific culture. Science adds to a story's plausibility and visual splendor and, thus, to the audience's enjoyment. Consultants' costs are minimal at worst and free at best. The challenge now facing both communities is in maximizing the full potential of scientific thought in the arena of entertainment. Ultimately, science consultants challenge our understanding about the place of science in entertainment, conceptions of expertise, and the role of informal communication in scientific practice.