HOLLY WEIRD

CHEMISTRY

Meet the Scientists Behind the Silver Screen

A selection of presentations from the symposium of the same name at the 253rd annual meeting of the American Chemical Society in San Francisco

ACS Chemistry for Life®

Organized by
Donna J. Nelson, PhD

Volume edited by
Erik Stengler, PhD

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Hollyweird Chemistry

A symposium at the 253rd meeting of the Amercian Chemical Society (April 2-6, 2017, San Francisco, USA)

Syposium organized by Donna J. Nelson

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Cover image: adapted from symposium poster by Mark Griep

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Why we should share science with the public through film and TV

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Frequently, we scientists enjoy spending time alone in our research activities, in our labs, offices, or homes. We are exceedingly comfortable immersed in exploring our relationship with our chemicals, our equipment, and/or our writing. Notice, the word "our" is the descriptor of these things which we care about so deeply. However, in almost all cases, we do not own these items, especially the tangible ones. In most cases, the items were purchased or acquired by universities or companies, or they were produced by employees of these entities. But even though universities, companies, government labs, etc. own these tangibles, it is the relationship with the public, which gives the greatest value to the tangibles.

In many cases, the items which we use or create are funded by tax dollars; in other cases, they are products which appeal to customers in the general public. Hence, in the long run, it is very important for scientists to have the support of the public in their work. Even with scientific work which is so esoteric that the public won't understand the significance of the results, it is important for the scientist(s) producing the results to make an effort to explain their value in layman's terms. From a self-serving perspective, we scientists want the public to value our work, so that the activities and equipment which we enjoy so much will continue to be funded, whether that is via tax dollars, gifts, or product purchases.

Those of us who serve as science advisors to television or movies must understand and work in multiple worlds – science, the public, and Hollywood production. Each requires a different way of working, and we must be able to use them all simultaneously and switch among them easily and instantly when needed. I'll detail my experiences below, knowing that the experiences of other science advisors have been similar in at least some ways.

Many of these points and considerations influenced my decision to be a science advisor for the Emmy award-winning AMC TV series Breaking Bad. I recognized the activity as an opportunity to help present correct science to the public and influence public opinion of science. When the opportunity presented itself, I also realized that I had no experience in illicit drug making, but it was unnecessary to have that, because Drug Enforcement Administration (DEA) agents were also helping the show. Breaking Bad portrays a high school organic chemistry teacher (Walter White), who has been diagnosed with terminal lung cancer and who is very concerned about the future financial welfare of his wife, their unborn child, and their current children. This builds on high school teachers not having particularly great salaries or health benefits, and his cancer treatment expenses have exhausted their savings. He decides to solve their financial crisis by using his chemistry talents – to synthesize methamphetamine.

After deciding to help the show, I had to read about the various ways to synthesize meth. One reason I decided to help the show was that after just a few episodes during its first season, I could tell they had a hit series which would play during prime-time television. Producer Vince Gilligan told me that he was very concerned about portraying science accurately, but he had no formal training in science. I decided to help increase the educational benefits of the show by helping him to insure accurate science. My activities ranged from drawing accurate chemical structures for Walt's blackboard during the high school classroom scenes, to calculating how much meth (in pounds) could be made from a 30-gallon drum of methylamine.

I didn't realize at the beginning that I also would indirectly influence the public opinion of scientists. The writers and most of the other employees didn't know any scientists. They had preconceived ideas about us – that we were all nerds. This is why, in our first meeting, the writers and Vince asked questions such as, "What makes a person become a scientist?" and "What kind of person is a scientist?" I was told many times, "You can't be a scientist." In the beginning, I heard that statement so frequently that I finally said emphatically, "I am a tenured professor of organic chemistry at a research university; I assure you I am a scientist." At the end of the show, when everyone associated with it went their own ways, I knew they would take with them a different idea of who could be a scientist, and this would impact how they portrayed scientists.

One Breaking Bad employee told me early on that a rumor in Hollywood advised that it was impossible to have a hit show and a science advisor. I asked for sufficient explanation that I realized that some past science advisors had emphatically blocked certain ideas, thereby stifling creativity. I vowed not to make that mistake. I aligned my goals with those of the producer, writers, cast, directors, etc. I understood that they knew how to have a hit show, and I was determined not to get in the way of their success. I was obviously successful, and we got along excellently. I believe that helped pave the way for future science advisors.

Another reason I agreed to be science advisor was because I knew how damaging illegal drug activities can be generally. In 1985, methamphetamine was synthesized in another professor's research lab in my department at the University of Oklahoma (OU). When a student was arrested for selling the illicitly-made drug to an undercover Oklahoma State Bureau of Investigation (OSBI) agent, it was embarrassing for the university and our department. The student went to court and then to jail. The newspaper stories brought disrepute to the organic chemistry professor who supervised the lab in which the compound had been synthesized. I am originally from Oklahoma, and I was asked by people in my home town how I liked working alongside "druggies" in my department. Even though I had nothing to do with the meth synthesis and no knowledge of it before the student's arrest, I was nevertheless embarrassed by it.

Breaking Bad reveals some similar consequences of life outside the law, and the mentality and personality characteristics of those involved. It does not glamorize that lifestyle; it shows Walt being shot at and beat up repeatedly. It shows a life of increasing deception which Walt must adopt in order to hide temporarily his dishonesty from everyone, even those closest to him. His chronic misunderstandings, forgetfulness, accidents, and changing stories will be recognized by viewers as characteristics of a smooth con-artist. Hopefully the extreme punishment and consequences which Walt experienced will dissuade others from emulating him. The initial episodes portray adverse working conditions for a chemist, such as Walt "cooks" meth in a sweaty recreational camper in the desert and runs around the desert wearing nothing but a chemistry lab apron and underwear. The show enlightened viewers who might think that illegal lifestyle is glamorous or admirable. But the show did portray Walt as a powerful and valued chemist.

Scientists, along with their science, are not generally appreciated by the public. High school teachers are not sufficiently appreciated, as shown by their low salary, poor treatment, and poor health benefits. These points were foci of Breaking Bad. The show also made other points which are beneficial for our society to recognize, such as that illicit drug manufacturers have an undesirable lifestyle; this is demonstrated by the Walt and Jesse characters being beat up constantly and becoming alienated from their families. The show also portrayed Jesse as being able to do great chemistry in the lab, even though he didn't succeed in his high school chemistry class; this signals that students who do not do well in chemistry courses can learn to do chemistry, provided they are motivated.

After the show started to gain popularity, I enjoyed listening to scientists at professional meetings discuss the science in Breaking Bad, without being recognized. One speaker at a symposium on science advising said "I don't know what Breaking Bad is doing, but it sure gets the science right. That made me feel good to know that other scientists noticed the products of my effort. I knew there were many errors in Season 1, before I came on board, but Breaking Bad fans soon forgot about those. I can think of only one instance of my advice not being heeded. On my first set visit, Vince asked me, "What do you think about making the meth blue?" I replied, "I wouldn't do it." He said, "Well, we are supposed to have pure meth, isn't there some reason why pure meth would be blue?" I said, "Pure meth would be white." He asked, "What if you had really, really pure meth?" I replied, "Really, really pure meth would be really, really white." However, they nevertheless made the meth blue. I never complained. I realized they needed a plot device; Walt needed a trademark for his product. In this case, the need to present a great story took precedence over the need to present accurate science. That happens sometimes. After all, no one claimed that Breaking Bad was going to be a documentary – it is fiction.

Finally, as real as Breaking Bad seemed to be, because it eventually achieved the pinnacle of storytelling and near-perfection in science, it is and always will be fiction.

How to Teach Chemistry Using Movie Wow!

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Introduction

Even though chemistry is the least popularized of the sciences (Masciangioli 2011), it finds its way into the narrative of feature films with reasonably high frequency because chemistry is an integral part of our social and economic activities. Since moviemakers work hard to create characters that people want to watch, these movies can be used to teach chemistry because they show actors interacting with chemicals or talking about them in engaging ways.

Movie Clip Presentations that Explore Themes

It all began with Elvis. We became aware of chemistry in movies when we happened to watch *Clambake* (1967) in the year 2000. In Elvis Presley's 35th movie, he plays a chemical engineer who develops a super-hard, super-fast-drying varnish called GOOP that he applies to his boat to win a race, the affections of his girl, and the respect of his father (Poliakoff, Salazar and Griep 2011). If you watch this film, you might be as astounded as we were when you hear Elvis sing a song about his varnish including its full name of glycooxytonic phosphate. A group of dancing girls and two male friends help him varnish his boat while he sings. In the weeks after watching the movie, Griep tried to decode the chemical structure based on this name but without success. Therefore, we watched the movie again a few months later for possible clues on the blackboards or other props that decorated the sets. During our second viewing, we were riveted when a different character earlier in the movie clearly annunciates the name of glycol oxyoctanoic phosphate. This name actually yields the acronym GOOP and can be used to generate a valid chemical structure by anyone who knows the organic and biochemical naming and bonding rules, agrees that oxy is short for epoxy, and agrees that this molecule is based on linseed oil varnish such that the octanoic acid part has an ω-3 double bond that is activated by the epoxy. The resulting molecule would probably crosslink much faster than linseed oil and, therefore, might be considered super-fast-drying. This experience was so enjoyable that we soon came up with a list of other movies we had seen that mentioned chemicals and/or that featured chemist characters. After we had a list of about 30 movies, we started a spreadsheet to keep track of all the emerging chemical themes. Other movies with similar themes were gathered from the Internet Movie Database and dozens of books about movies.

Our first movie clips presentation took place in 2002 as part of the University of Nebraska-Lincoln's (UNL) Chemistry Day (Table 1). Griep chaired the committee that created Chemistry Day the year before. Its purpose is to recruit high-performing high school students into the UNL Chemistry undergraduate program. Our program brings interested high school seniors, juniors, their teachers and parents to our building on a

Saturday and then takes them on lab tours, engages in several hands-on activities, gives them a quick lunch, and, of course, gives them a chemistry demonstration show interspersed with descriptions of our program. The first movie talk was developed to give our guests a unique experience at the end of the day that was entertaining and educational. The first talk was titled “Chemistry Themes in the Movies: Dr. Jekyll, Invisibility Chemists, and Industrial Chemists.” It summarized the three dominant themes we had identified up to that time. A new movie presentation was developed each year for Chemistry Day from 2002 to 2007 (Tables 1 & 2).

*Table 1: Movie Clip Presentations that Explore Chemical Themes**

Presentation Title	Presentation Years
Chemistry Themes in the Movies: Dr. Jekyll, Invisibility Chemists, and Industrial Chemists	2002, 2003
Bubbling Apparatus in the Movies	2003, 2004, 2008, 2010
Chemists Are from Mars, Chemists Are from Venus: A Look at Men and Women Chemists in the Movies	2004
Mandrake Elixirs and Other Spagyrical Preparations in the Movies	2012

*These presentations were created to discuss the content of the movie clips without rating the presenter’s explanation.

*Table 2: Movie Clip Presentations Designed for Chemical Instruction**

Presentation Title	Presentation Years
Drug Discovery in the Movies	2005, 2015, 2016, 2017
Everything I Know about Chemistry, I Learned at the Movies	2006, 2008, 2009, 2011, 2013, 2014
A Periodic Table of Elements in the Movies	2007, 2009, 2010
Elemental Composition of Aliens and Extraterrestrial Minerals	2011, 2012, 2013, 2014

*These presentations were created to include a component in which each clip and the presenter’s scientific explanations are rated by the audience.

The effectiveness of the movie presentations in Table 1 was determined from the surveys our guests completed at the end of their Chemistry Day visit. They were asked to rate each activity on a scale of 1 to 5, where 1 is low and 5 is high. Most activities earned an average of 4 or greater, indicating that they had a great time but it was hard to differentiate between the activities. The ratings are used by the planning team to decide which components needed improvement at next year’s event. Even though the average scores were high, the ranking orders did not change very much and the movie talks were consistently rated below the chemical demonstrations, hands-on activities, and lunch. On the other hand, the responses in the open-ended “Comments” field were very favorable about the movie clip presentations. To learn whether the movie clip talks were useful for teaching, however, a different assessment approach was needed.

Movie Clip Presentations Designed for Chemical Instruction

We developed a survey to help determine what sorts of movie clips and explanations resonate most strongly with the audience (Frey, Mikasen, and Griep, 2012; Griep and Mikasen, 2013, 2016). Before the talk begins, every person is given a pen with the departmental logo and a sheet of paper listing the movie names. During the talk, the audience is asked for two subjective responses: Wow! and Usefulness for teaching or learning. The viewers were asked to rate for Wow! (1 is low, 5 is high) immediately after watching each 2-5 minute clip. On the rating sheets, the factors contributing to Wow! were “famous actors, amazing special effects, memorable dialog, great movie sets, or other such things”. After hearing an explanation of the real chemistry related to the clip, viewers were asked to rate the explanation (1 is low, 5 is high) for “pedagogical utility” if they were teachers and “How much chemistry did you learn?” if they were students or outreach participants.

By 2017, over 2000 people during 51 separate events had answered surveys during at least one of the movie presentations (Table 2). The audiences included middle school students in the classroom, middle and high school students at science camps, high school students during UNL Chemistry Day, undergraduates at a wide range of institutions, summer undergraduate researchers at UNL, high school teachers participating in a professional development course, senior citizens as part of a continuing education course, and chemists at conferences. The survey results for “Everything I Know…” and “Elemental Composition of Aliens…” have been published (Frey, Mikasen, and Griep, 2012; Griep and Mikasen, 2013, 2016). The majority of clips in “Everything I Know…” were chosen because they were already being used in Griep’s introductory chemistry course for non-majors. The clips in “Elemental Composition of Aliens…” were chosen as a chemical complement to summer science camps in which underrepresented students clone green fluorescent protein into a bacterium.

The most impactful movies have high Wow! and high “Learning” or “Pedagogical Utility” because audience members are engaged by the story in the clip and then feel they’ve learned something from the explanation. The top three most impactful clips from the “Everything I Know…” presentation (Frey, Mikasen, and Griep, 2012; Griep and Mikasen, 2013) were from the movies *Apollo 13* (1995), *Harry Potter and the Chamber of Secrets* (2001), and *Fuller Brush Girl* (1950). The *Apollo 13* clip runs for five minutes from the moment the CO_2 light turns on inside the damaged space craft until the moment the CO_2 light goes off. Carbon dioxide scrubbers are the focus of the scene and the specific scrubbing agent, lithium hydroxide, is mentioned twice. The *Harry Potter* clip is the mandrake repotting scene that involves a discussion of extracts and physiological effects. The *Fuller Brush Girl* clip starts with the police chief on the phone saying he will come right over and ends after little Henry says, “No wonder she’s bald.” During the clip, Henry says he mixed the cream wave solution with the chemicals from his chemical set (visible in the background) and then names 24 elements and ions in about 30 seconds.

The most impactful clip from “Elemental Composition of Aliens…” (Griep and Mikasen 2016) was the scene from *Evolution* (2001) in which a periodic table T-shirt plays a critical role in sparking a hypothesis on how to defeat an enormous, carnivorous, and rapidly evolving alien life form that is based on nitrogen rather than carbon. *Evolution* is a good choice for students in a summer science camp because it allows the presenter to discuss the elemental composition of living beings. It also includes an absurd hypothesis that fosters creative thinking by connecting unrelated things in a new way to solve a problem. For this very same reason, however, it would probably not be effective in the classroom because the students are more averse to dealing with fictional hypotheticals.

Documentaries as Source Material for Student Compositions and Classroom Discussions

Our first paper about using movies to teach was related to source material for a General Chemistry writing assignment (Griep and Mikasen, 2005). When Griep taught the UNL General Chemistry 1 course in 2002-03, students were required to compose something that was evaluated by the instructor. Other instructors recommended having students write reports about the chemistry behind events reported in the news, an idea supported by the literature (Beall, 1993; Kovac and Sherwood, 1999; Shibley, Milakofsky and Nicotera 2001). Although students were given a set of guidelines on how to write the short paper, a disappointing 59% of the students completed the required 600-word report.

When Griep taught the course the next two semesters, he decided to draw upon the dozen movies and documentaries we had found that were based upon a true story (Griep and Mikasen, 2005). By 2003, our collection of useful movie clips was reasonably large and our literature research indicated movies might be most useful for science classroom engagement (Bell et al., 2009). We also found that others had pioneered the use of movies to teach scientific principles using specific feature films but that none of them had used movies in this way (Dubeck, Moshierand Boss, 1988, 2004; Borgwald, J. M. and Schreiner, 1994; Hollis, 1996; Goll and Woods, 1999; Wink, 2001). Two movies, *Dr. Ehrlich's Magic Bullet* (1940) and *Me & Isaac Newton* (1999), presented students with a balanced choice. Ehrlich was from the Golden Age of movies and was a biographical picture about Dr. Paul Ehrlich's development of the first chemotherapy, a treatment for syphilis. *Me & Isaac Newton* was a documentary that explored why seven scientists do what they do and featured Dr. Gertrude Elion's work on cancer chemotherapies. Neither movie names the compound associated with the chemist so one task for the students was to find and name the relevant compound. The student response to the exercise was overwhelmingly positive — 93% of the students completed the assignment and 90% of them earned a B or better.

More recently, we have demonstrated the resilient power of *An Inconvenient Truth* (2006) to get students to ask questions about global warming and climate change (Griep and Reimer 2016). Over the past decade, students have become less likely to have seen this documentary but, when they watch it in Griep's chemistry course for non-science majors, they enjoy watching the first half of the documentary to learn from this relatively jargon-free, broad overview. By the end, students want to know what has been done about this issue since the documentary was released and whether the trends have continued.

Chemistry in the Movies Boxes

A textbook editor working on "World of Chemistry" by Joesten, Castellion, & Hogg read our "Based on a True Story" paper (Griep and Mikasen 2005) and contracted Griep to write ten movie boxes for its fourth edition (Griep 2006). We had already begun our search for movie clips to use in the classroom so we accepted this timely opportunity. Each movie box describes the chemical scene, the movie's theme, the real chemistry related to the scene, and the scientific or technological impact of that real chemistry. This experience spurred our search for even more movie clips to use in the chemistry classroom. Some of the best examples are described in the presentation "Everything I Know about Chemistry, I Learned at the Movies" (Frey, Mikasen, and Griep, 2012; Griep and Mikasen, 2013).

Griep uses some of the classroom movie clips as extra credit opportunities. He shows the movie clip, describes the chemistry, but doesn't give the answers to the two questions posed on the course's webpage. Typically, about one-third of the students submit answers to the extra credit questions. Students receive 3 points for one correct answer and 5 points for two correct answers.

ReAction! Chemistry in the Movies

By 2007, we had collected a large list of movies about chemistry, watched several hundred of them, and made the decision to write a book that summarized the major themes. This led to a grant from the Alfred P. Sloan Foundation in the area of the public understanding of science to do the research for a book titled ReAction! Chemistry in the Movies that was published by Oxford University Press in 2009 (Griep and Mikasen 2009). With these funds, we visited film archives in London and Los Angeles, where we found critical background information and learned about some rare films that were only briefly described in the literature. Information in hand, we wrote ten chapters that described the chemistry in 110 movies. The first five chapters develop themes that show the dark side of chemistry, such as Dr. Jekyll and Mr. Hyde, Invisibility Chemists, and Chemical Warfare. The second five chapters develop the bright side of chemistry, such as Inventor Chemists, Chemical Detectives, and Drug Discovery.

The book was favorably reviewed on the ScriptPhD blog (Fowler, 2010), the Science Fiction Biology Blog (Kolm, 2010), in Nature Chemistry (Morgan, 2010), Chemistry World (Batchelor, 2009), Education in Chemistry (Hollamby, 2010), Chemical Heritage Magazine (Mangravite, 2010), Journal of Chemical Education (De Groot, 2010), Bulletin of the History of Chemistry (Chastain, 2011), and Chemistry and Industry (Brake, 2009). A number of the reviews were especially taken by the entries in which a chemical structures was decoded from information taken from a movie's narrative, such as GOOP varnish in *Clambake* (1967) or the toxic green speck and black rock in *The Andromeda Strain* (1971).

The next innovations were supported by a UNL Kelly Fund grant in 2011 to improve undergraduate education. The result was the creation of a professional development course for science teachers, three webpages, and a Facebook page. The three webpages on Griep's website (http://chemweb.unl.edu/griep/) describe how he uses the best movie clips to teach chemistry, how those particular clips relate to Nebraska science standards, and the locations of relevant topics in the most used middle school and high school chemistry textbooks. More recently, the UNL Library purchased copies of most movies in our book and created a special website connecting each book entry with its library call number (http://unl.libguides.com/reactionchem).

Facebook and Feedback

In August 2013, we decided to use social media to quantify the level of the public's interest in the chemistry in the movies themes so we launched a Facebook page called "Reaction Chemistry in the Movies" (http://www.facebook.com/Reaction-Chemistry-in-the-Movies). As its "About" section says, it is "For chemists, chemistry students, teachers, and anyone who likes both chemistry and movies." Our goal is to raise awareness among chemists about the ways that chemistry is viewed by (non-chemist) moviemakers and to increase the public's awareness of chemistry by describing its presence in something as unexpected as movie narratives. For the first three years, we posted an average of two times a week (or 10 times a month) (Figure 1 lower panel). Specifically, the entries are pre-loaded to post on Monday and Thursday at 3 p.m. For the past six months, we've attempted to post thrice a week by adding a Wednesday post. Each post includes a link to an image or YouTube clip so that people will look at the post.

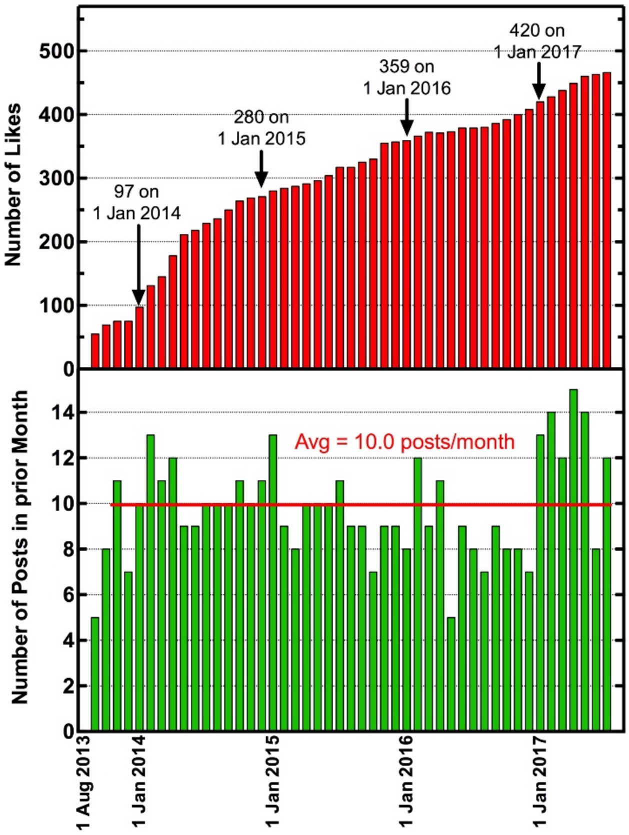

Figure 1: Number of Followers (Likes) and Posts on the "Reaction Chemistry in the Movies"Facebook page since 16 August 2013 when it was created. The Cumulative Likes are from the first day of each month and indicates the number of followers. The Number of Posts in the prior Month shows an average of 10 items per month.

From August 2013 until July 2017, the number of followers grew to almost 500. In the language of Facebook, all these followers are “organic” because we didn’t pay to advertise. Two thirds of the followers are from outside the United States and an examination of ten of them indicates that most are scientists, graduate students, or chemistry instructors. Starting in January 2014, we began posting themed series so that each individual post could be counted down as the movies progress from most recent to oldest. When each series ends, the evolution of the theme is summarized.

Facebook provides page managers with analytical tools to assess the effectiveness of posts. The simplest metric is “Reach,” the number of people who have seen your post. Although we’ve had about 400 followers since about January 2016, the average post was seen by 91±74 followers over this same time period. Apparently, about 75% of our followers have so many posts (and/or check their page infrequently enough) that our posts are too far down their wall that they don’t see them. The large standard deviation occurs because a few posts are highly viewed (Table 4). The three posts with greatest reach were “shared” by one or more followers on their own walls and were then seen by their followers. Each of the top three posts is about a well-known movie and was accompanied by a striking image. The Men in Black II image was a movie still of a collection of the aliens, most of whom played minor roles. The Casino Royal image shows the molecule on Bond’s glovebox instrument panel next to the actual structure of microcystin-LR, a cyanobacterial toxin. Unfortunately for the Bond franchise, microcystin is unrelated to digitalis extracts. The image accompanying The Martian post referenced the three movies in which Damon was rescued along with text indicating that the United States has spent a lot of money rescuing Matt Damon.

Table 4: Individual Posts with Greatest Reach

Post Date, Reach, Engagement, Theme: Entry
12/8/16, 488, 4%, Chem in Family Movies #9: Men in Black II, 2002
4/25/16, 470, 7%, Movie Chemical Structure Decoded #14: Casino Royale, 2006
1/6/16, 434, 5%, Matt Damon’s Chemistry in the Movies #4: The Martian, 2015

The second most important Facebook metric is “Engagement,” which is the number of “Likes, Clicks, and Shares” divided by “Reach.” A “click” is acquired when readers click on the link to the image or video. As indicated above, “shares” are desirable because they can greatly increase your “Reach.” Engagement is a tough metric and our average is a mere 3.5±3.0 %. Our most engaging post at 18% was “Chemical Music Video #5: The Elements Song, 1959” on 30 March 2017. This entry received a lot of clicks because the link brought the reader to a YouTube video of Daniel Radcliffe, of Harry Potter fame, singing “The Elements Song” during an appearance on a talk show in 2011. By March 2017, the video had already received 3.2 million views.

Since December 2013, we’ve posted 32 chemical themes in the movies with an average of 11 entries per theme. Between July 2015 and July 2017, there have been five themes with higher than average “Reach” and “Engagement” (Table 5).

Table 5: Themes with High Reach and High Engagment

First Post	*# Posts*	*Average Reach*	*Average Engagement*	*Theme*
June 2017	21	109	5.4%	Nutrition and Food Chemistry
October 2016	21	107	4.3%	Chemistry in Family Movies
April 2016	15	174	4.2%	Movie Chemical Structures Decoded
April 2017	12	121	3.8%	Documentary with Chemistry
July 2016	14	144	3.7%	Psychopharmaceuticals in the Movies since 2010

One feature shared by these popular themes (Table 5) is the use of chemical structures (Figure 2) rather than movie posters or trailer videos. The higher than average Facebook "Reach" and "Engagement" for movies accompanied by images of molecular structures is consistent with our observation that the majority of our followers are chemists rather than movie aficionados. In fact, the chemical structures posted with Prescription Thugs (2015) from the Psychopharmaceuticals series was the third most engaging post at 12%. This is a first-person, independently-produced documentary about prescription drug addiction, its causes and consequences. Near the start of the film, director, star, and narrator Chris Bell says that he wanted to make this documentary because his brother died of prescription drug addiction. Spoiler alert: the surprise near the end of the documentary is that Bell reveals he is similarly addicted.

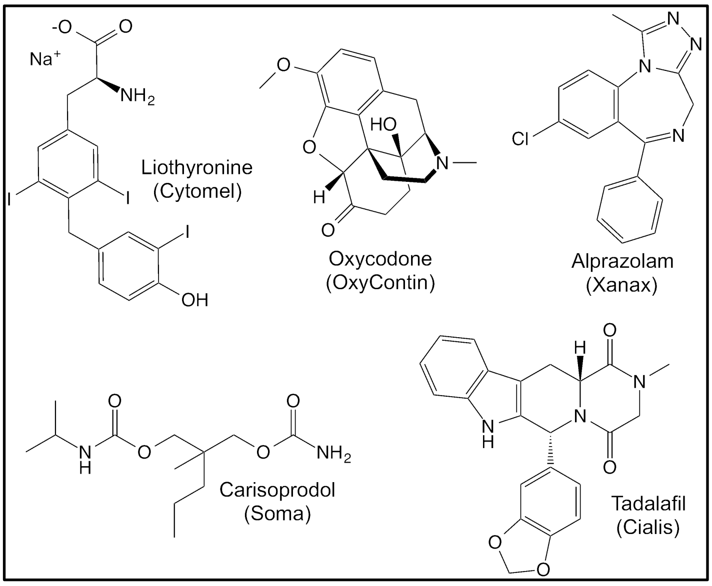

Figure 2: Drugs mentioned in the documentary "Prescription Thugs." This image was posted on the "Reaction Chemistry in the Movies" Facebook page on 20 April 2017.

Conclusion

Our journey through the history of chemistry in the movies have identified dozens of powerful themes and dozens of pedagogically useful ways to use movies. The chemical themes tell us what non-scientists think about chemistry and chemists. The most pedagogically useful movies or movie clips show us that chemistry can be represented in a highly engaging way. The bridge between the two paths is very likely to be the use of chemical structures as a representation of a movie. The chemical structure serves as a focus for the chemist to describe its structure and function while the movie shows actors talking about or responding to that same chemical.

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Science and Science Fiction: The Boundary Between Fantasy and Futurism

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Science fiction as futurism

In an increasingly technologically and scientifically complex world, our entertainment is filled with concepts and constructs that may be difficult to distinguish from reality. *Star Trek*'s communicators in the original TV series famously anticipated cell phones. Talking to our computers, and even getting location information on individuals from computer systems, once a fanciful feature of science fiction, is now commonplace. The "PADD" computers in *Star Trek: The Next Generation* now seem like quaint versions of ubiquitous tablet computers. On the other hand, warp drive and transporters remain the stuff of science fiction or, more accurately, science fantasy. This mix of fantasy and plausible future reality could conceivably be seen as a recipe for confusion. For the layperson in the 1960's watching Captain Kirk beam down to a planet, the distinction between transporter technology and the Enterprise's talking computer might seem like a trivial technicality. This then suggests the possibility that the portrayal of fantasy and futurism can blur the public's perception of what is grounded in science and what is not. Given the shear volume of science fiction and fantasy entertainment, young people in particular have a large exposure to scientific concepts and constructs in the context of these movies and television programs. Here I discuss the differences between fantasy and futurism in fiction and the role that the portrayal of science may have on scientific literacy.

Movie and TV producers, and the viewing public, pay attention to scientific accuracy in entertainment to varying degrees. The boundary between reasonable extrapolation of current technologies and physics-defying fantasy can be difficult to discern. In some cases science fact may even seem more preposterous than a fictional construct that defies the laws of nature. One of the most common conventions in space-based science fiction is the use of artificial gravity. Because it appears perfectly normal to see people walking around on the floor, this is unlikely to raise alarm bells in the viewers' minds (Figure 1). At the other extreme, it is now possible to remotely control mechanical devices simply through thought, with technology recording brain activity and transmitting the appropriate signals to receivers in the device. Manipulating the physical world through thought, without physical contact, certainly smacks of fantasy, but is far more realistic than, say, humans managing to survive the crushing accelerations that would be needed for the starship Enterprise to come to a full stop from superluminal velocities. But the latter seems perfectly normal, while the former seems fantastical. Does either extreme affect scientific literacy? While the combination of nonsense with a decoration of realism can be frustrating to the scientifically literate, there is not much evidence to suggest that it actually has a negative impact on the broader public's scientific literacy or attitudes towards science.

Figure 1: Images from the science fiction series Firefly (top, Fox Studios) and Star Trek (bottom, Paramount Pictures) that violate the fundamental laws of nature. Neither spacecraft rotates, nor do they accelerate at a constant 1g acceleration in a direction perpendicular to the floor. Every person and object should be floating. Everything in the futuristic Star Trek scene is realistic and plausible ***except*** *that everyone is firmly affixed to the floor or a seat.*

The movie *Alien* (1979) made famous the line “in space no one can hear you scream”, though there was plenty of screaming in that classic space pic, as well as plenty of ominous rumbling of spaceships. It became fashionable to poke fun at *Star Wars* and other space films for the noisy explosions and roar of engines, because in the vacuum of space no one can hear anything at all, screams or otherwise. Of course, there aren’t orchestras playing music floating in space either, but there are no complaints about John Williams epic soundtrack for *Star Wars*, nor are there movie cameras floating around to capture all the action. And anyway, who really wants all the spaceships in Star Wars to be silent? The movie would be a lot less engaging, and those sound effects are not likely to be causing any confusion in the public about the nature of sound waves. It is not as if sound in space is used as a plot device. Kirk does not ask everyone to be quiet so they can hear the Klingon ships approaching, nor are sound sensors ever deployed from the Enterprise. If they were, I would argue that that would sow a lot of confusion about the nature of sound waves and space. On the other hand, *2001: A Space Odyssey* (1968) famously used the silence of space to great dramatic effect (but still with orchestral accompaniment). And *2001* was set in our own, near future, while *Star Wars* takes place far, far away.

We can divide science fiction into two categories: one in which it is plainly fantasy adventure and not an extrapolation of our own society, and one that portrays events that could plausibly lie in our future. Getting science right in the former may be irrelevant, while egregious errors in science in the latter category could conceivably promulgate long-standing misconceptions about how the universe works in all areas, from biology to chemistry to physics and astronomy. The closer the work of fiction is to our own world or topics relevant to our current society, the greater the potential ill effects from “Hollyweird Science”. The more removed they are from the quotidien, I would argue, the smaller the impact on public scientific literacy.

Case Studies. The good, the bad, and the beautiful.

We begin with three big budget Hollywood movies from 1998: *Armageddon*, *Deep Impact*, and *Godzilla*. All three are nominally set in our world and the present day. The first two deal with the threat of an impending terrestrial impact by an astronomical object (an asteroid in *Armageddon*, and a comet in *Deep Impact*), while *Godzilla* deals with a giant mutant reptile. I was one of the science consultants to *Deep Impact*, and while the science topics in it and *Armageddon* are similar, the two movies took almost diametrically opposed approaches to realism. The overarching plot device in both movies – that a celestial object could impact the Earth, devastating life, and that it is technologically possible to do something to avert the threat – is realistic. In *Godzilla*, on the other hand, the creation of *Godzilla* from atomic fallout is pure fantasy (Figure 2). *Godzilla* deals with genetic mutations and results in predictable monster mayhem. While the event that leads to the creation of *Godzilla* is not a deliberate Jurassic Park style case of genetic engineering, both it and the *Jurassic Park* series, and others, touch on the real technology of genetic mutations and genetic engineering that are frequent topics of public debate and public policy. Genetically modified organisms (GMO) have strong negative connotations, even though these are plants that are bred with the same principles, but more precision, than splicing a lemon branch onto an orange tree.

Does a moviegoer to any of these movies, though, appreciate the differences between fantasy and futurism? Does the portrayal of scientific subject matter make a lasting or meaningful impact on that person’s understanding of science or attitudes towards science?

Both *Deep Impact* and *Armageddon* had technical advisors, but it seems that their advice was only taken on *Deep Impact*. Following extensive meetings with the creative crew of *Deep Impact*, including the producers, the director (Mimi Leder), screenwriters, special effects and other department heads, significant changes were made to the movie to make it more realistic.

Figure 2: Godzilla wreaks havoc in the 1998 film of the same name. Centropolis Film Productions/Fried Films/Independent Pictures/TriStar Pictures.

In *Deep Impact*, a comet roughly 10 km across is discovered more than a year prior to an anticipated impact on the Earth. A crew of astronauts is sent to deliver nuclear bombs to destroy the comet nucleus. This is the first and largest departure from realism: this could be done much easier without astronauts, and a deflection technique rather than a disruption technique would also be easier. But, of course, the astronauts are a big part of the story that the movie is really about. The director made the change to have the astronauts float not only in their spaceship, but also as they maneuvered above the surface of the comet, where the gravitational acceleration would be roughly one ten-thousandth what it is on the surface of the Earth. An astronaut would weigh about 10 grams and would fall to the ground in about 3 minutes. The movie got these elements right, including the depiction of the comet, the onset of its sublimation shortly after sunrise, the presence of jets of vapor on the sunlit side (Figure 3), and the rough scale and speed of the wave that results from its impact in the ocean (statistically the most likely spot for an impact on our watery world). In *Armageddon*, advance chunks of the asteroid seem to hit only major cities and world capitals, an implausible statistical anomaly.

In contrast, *Armageddon* chose to use an asteroid the size of Texas discovered only 18 days before impact. All asteroids larger than a few km across in our vicinity of the solar system have been discovered, and the time for one to reach the Earth is roughly the orbital timescale of a year. Only tiny asteroids smaller than football stadium have the potential to sneak up on us with short warning.

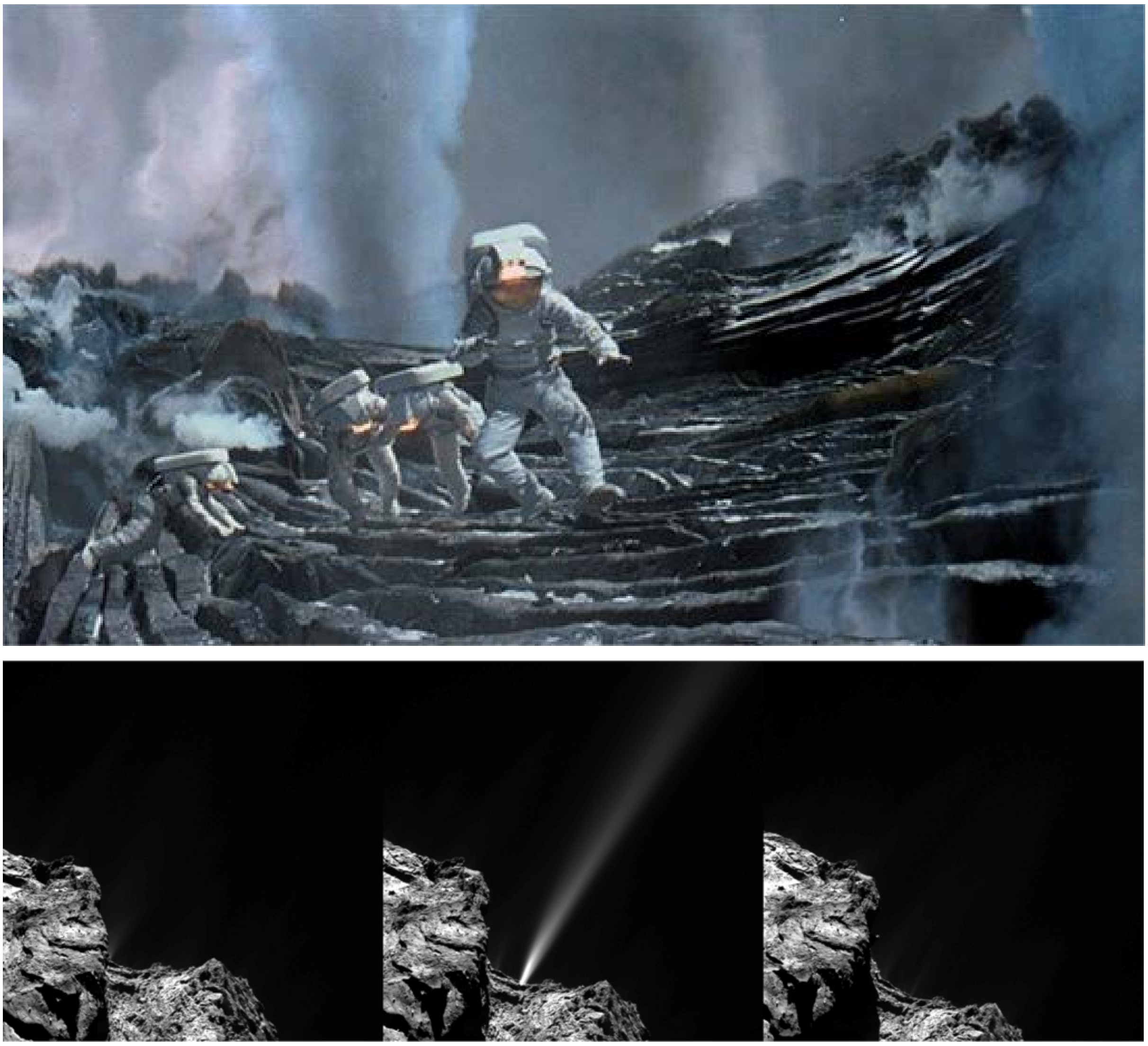

Figure 3: In the Dreamworks movie Deep Impact, astronauts face the hazard of erupting vents of water vapor after sunrise on the surface of a dark comet nucleus (top, Dreamworks/Paramount). Images of the comet Churiyomv-Gerasimenko/67P from the European Space Agency's Rosetta mission show the sudden onset of active outgassing (bottom, ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA).

Astronauts on this unrealistically mammoth asteroid would still have difficulty moving around by walking, weighing in at about a quarter of a pound and with a free-fall time of half a minute. That's a long time between foot-falls. In a peculiar dance around realism, the movie acknowledges the low gravity and then circumvents it by placing rocket thrusters (never actually seen, just referred to) on the shoulders of the astronauts to drive them into the ground with a force equal to their terrestrial weight. Set aside for a moment the hazards that this entails if one were to bend over by the slightest angle, changing the rocket's thrust vector to be anything other than straight into the ground. The reasoning behind this, given with a straight face in the movie, is that rather than using a very cheap and small rocket engine countering their tiny weight to enable the astronauts to skim over the surface of the asteroid, it would be better to affix rockets that are one thousand times as powerful to their shoulders and force them to trudge around with the equivalent of their terrestrial weight. In fact, with a 200 pound rocket on their shoulders and a net weight of a quarter pound, the astronauts would almost immediately end up getting reoriented by the thrust of the rocket and launched into space never to return.

In a similar vein, when docking with the Russian Mir space station, reference is made to spinning the space station so that there will be gravity making it easier to move around. This works if your space station is designed with a circular wheel around a central axis of rotation, but for the ungainly and decidedly non-axisymmetric Mir, moving around in it while it's spinning would be a disaster (Figure 4). I've not been to a space station, but after several flights on NASA's infamous "vomit comet" or Weightless Wonder airplane that provides 15-20 seconds of weightlessness, I can assure you that it is much easier to move around without gravity than with it, as long as you have something to push off.

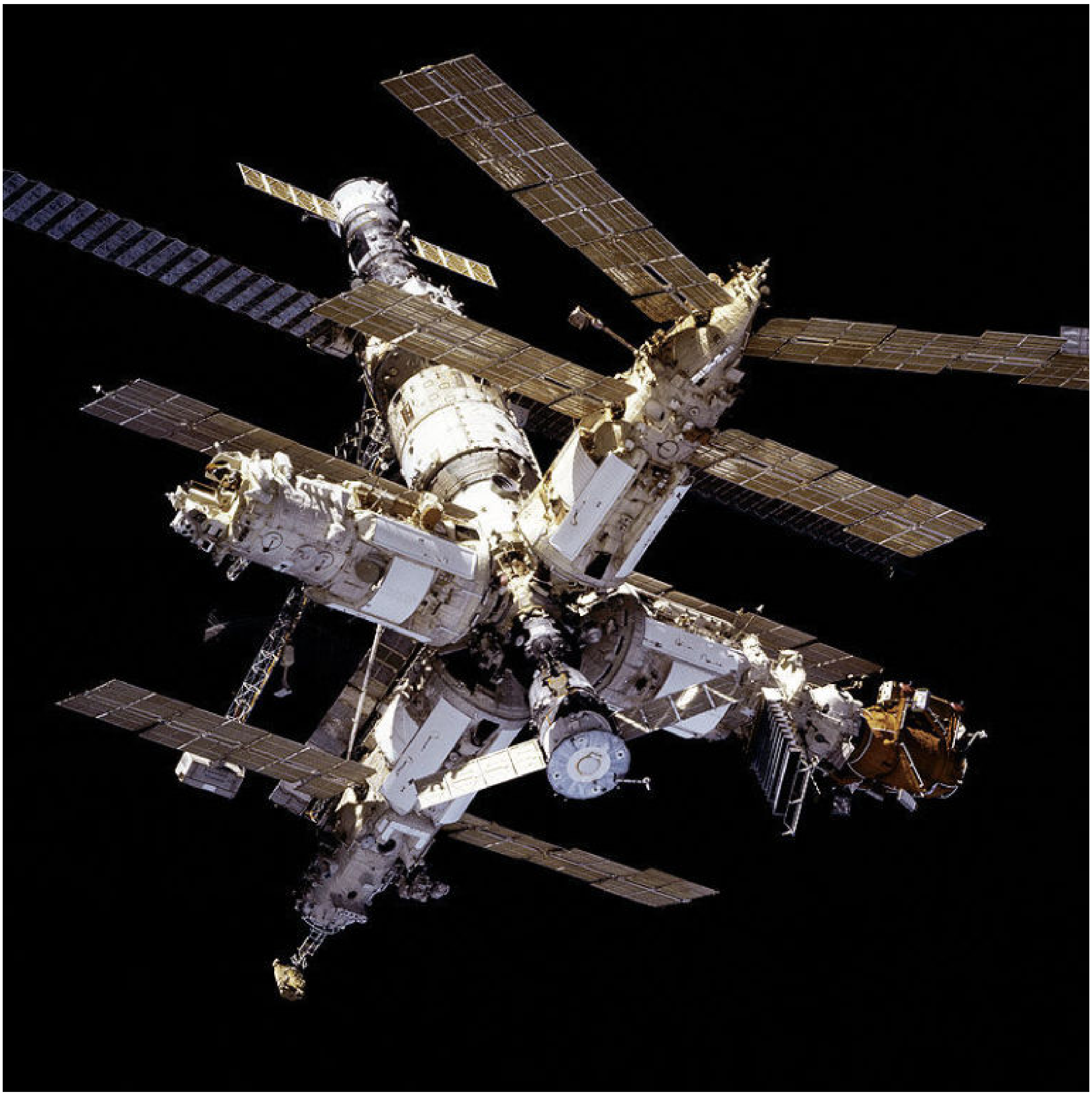

Figure 4: This image from the space shuttle Atlantis of the real Russian space station Mir shows living quarters arranged in three orthogonal axes. Space shuttles dock with Mir in the 1998 Touchstone picture Armageddon which was spun up to provide artificial gravity. Spinning Mir would have been disastrous for the station and everyone on board. Image credit: NASA.

One of the greatest misconceptions people have about space is the relative scale of planets, stars, and the distances between them. (Others include the cause of seasons, and the relationship between gravity, weightlessness and space.) The distances between planets are annoyingly large, but have frequently been treated reasonably accurately in science fiction. Movies dealing with the exploration of Mars, for example, usually have the appropriate months-long journey from Earth to Mars. But the distances between stars do not lend themselves to realistic storytelling. Either the travellers are put to sleep as in *Alien* and *Interstellar* (2014), or the ship is given a miraculous capability to travel faster than light (*Star Wars*, *Star Trek*, *Battlestar Galactica*, and on and on). In *Star Wars*, every corner of that galaxy far, far away seems to be reachable in a few hours. In the latest *Star Trek* movies, everything seems to be right next door. The Klingon Empire is only a one-hour warp away from Earth, a meaningless separation for supposedly warring civilizations. Spock even sees the planet Vulcan, shining brightly in the sky like our own Moon, from a planet in an entirely different system in the 2009 *Star Trek* movie (Figure 5).

Figure 5: Spock sees a planet around a distant star explode from a planet in a different system, violating physics, common sense, and everyday experience for anyone who has ever looked at the sky. Paramount Pictures.

There are several questions related to scientific literacy and public policy that are raised by these movies and their different approaches to science. (1) Do the many incorrect portrayals of physics and astronomy in a movie that ostensibly takes place in our world have a measurable negative impact on scientific literacy? (2) Does poor science in a movie taint the serious and important issue of the threat of a major asteroid or comet impact, thus rendering it as apparently silly in the minds of the public and policy-makers as the many liberties taken with the science? (3) Conversely, do realistic representations of basic science improve public literacy, and do they help legitimize an otherwise poorly known and exotic real-world threat? (4) Do people develop negative associations with real science (genetic engineering, nuclear energy, medical radiation) based on horrifying portrayals of related science, even if they are fantastical rather than realistic?

Does realism matter?

It is tempting to look at the poor performance of American students in standardized science assessments and search for an easy explanation. The ubiquitous misrepresentation of basic principles of physics in the popular culture is a natural place to look for the difficulty students have in grasping the basics of Newton's laws of motion, for example. Even though I may lecture passionately and convincingly with physical demonstrations in every class, by the time they reach me students have spent countless hours experiencing the physics models of video games, *Star Wars*, and *Stargate*. Perhaps, the beleaguered professor might wonder, if the movies and television programs would get the science right, then our overall science literacy would be much higher. If you'd hate to see Darth Vader floating around the Death Star, the news is good: the data that we have do not indicate any link between realistic science in movies and science literacy in students.

The Programme for International Student Assessment (PISA) measures reading, mathematics and science literacy in 15-year-old students in 72 countries every three years. The 2015 study had science as its focal subject. This study does not ask students to track their movie-watching habits or attitudes. However, the global nature of the entertainment industry can help us look for links between cultural products (Hollyweird science, if you will) and scientific literacy. While the PISA data show relatively poor performance of American students, particularly in math, other countries whose children are likely seeing the same popular representations of science and science fiction, fare much better.

In the science category, for example, the U.S. score is 496, ranked 25th. Singapore had the highest score at 556. But Canada, arguably as close both geographically and culturally to the United States as possible, ranked 6th in science (528), while the United Kingdom also bested the U.S. students with a score of 509, tying Germany. *Armageddon* was probably as popular in Canada as it was in the United States. So while there might be some unknown benefit that would occur if we could impose totalitarian scientific order on all movies to require them to be accurate, the lesson of Canada is that there is plenty of gain to be made in science literacy without worrying about changing our movies and television programs.

Data from Science and Engineering Indicators: 2010, an aggregate of studies by the National Science Foundation and National Center for Science and Engineering Statistics, suggest though, that popular culture can play an important role in public scientific literacy through the attitudes that shows foster toward scientists as people and science as an enterprise. Although these data are a few years old, they did not show significant changes when compared with earlier studies. In the U.S., 79% of adults say that science has made life easier for most people, and a majority is positive about the impact of science on the quality of health care, food, and the environment. And while both the general public and scientists in the American Academy for the Advancement of Science (AAAS) believe that U.S. scientific achievements are either the best in the world or above average, both groups recognize that U.S. education in STEM fields (science, technology, engineering and mathematics) lag behind the best in the world. Almost half of AAAS scientists and 29% of the public rank U.S. K-12 STEM education “below average”. Three-quarters of AAAS scientists point the finger at U.S. STEM education as a major factor in the public's limited knowledge of science.

But while the public professes an admiration for scientific achievement and simultaneously recognizes the poor state of American scientific education, individually they are unlikely to agree with scientists on various charged issues. Almost 90% of AAAS scientists, for example, agree that it is safe to eat genetically modified foods, but only 37% of U.S. adults say it is safe (Pew Research Center 2015). Similarly large gaps between the public and scientists were found for questions about evolution and vaccines. More recent polling from Yale University and George Mason University found 58% of Americans think global warming is caused mostly by human activities (Leiserowitz et al. 2017), compared to 97% of climate scientists (Cook et al. 2013). The most productive and promising thing popular cultural vehicles such as television shows and movies can do, perhaps, is to portray scientists as believable, realistic people who know what they are talking about (Weitekamp 2017).

While *Star Trek*'s Mr. Spock may have walked around in a starship when he should have been floating, and used a tricorder to detect things using no known physics, he was a scientist who was admirable in every sense. Hollywood can help with scientific literacy by making things realistic when possible without sacrificing the story, acknowledging the liberties taken in story-telling, and above all by depicting scientists as the real people we are, in all races, nationalities, genders and personality types so that children will be motivated to find out just how that spaceship or tricorder works, or how to cure a disease through genetic engineering, or how to make a cleaner environment.

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Science as a Human Story

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Introduction

NOVA's *Hunting the Elements* and my series, *The Mystery of Matter: Search for the Elements*, are both about Periodic Table and the elements. But they approached those subjects in very different ways. NOVA set out to present lots of interesting information about the elements in an entertaining package, and they did that very effectively. We set out with the goal of telling a story – a story about a series of people whose discoveries had revealed the elements and led to the Periodic Table.

Origins of the Project

My interest in chemistry started about a decade ago, when I was one of the producers of a NOVA program called "Forgotten Genius" – a two-hour biography of the African American chemist Percy Julian. One of the things I realized in doing that project was that there was very little chemistry programming on television and, as a result, very few good chemistry videos for teachers to use in the classroom. That's changed as a result of the programs Chris has been making for NOVA since then, though chemistry is still way behind other fields like biology, physics, astronomy and archaeology.

Julian's story – especially his lifelong fight to overcome the racial obstacles he faced as a scientist – was compelling stuff. But he was a synthetic organic chemist, so his science wasn't a good fit with the subjects high school chemistry teachers are expected to teach. So I wondered if there were interesting stories about the people who had discovered more basic thing like atoms and elements and the Periodic Table – the things that chemistry teachers are supposed to teach. I started looking into it and discovered there was a fascinating human story that would make both entertaining television and a great resource for teachers. The result was *The Mystery of Matter*.

Limiting the cast to seven

Now, the history of chemistry is a huge subject, and we knew that if we tried to cover the hundreds of people who had made significant discoveries, the result would be an unwatchable mess. So we made a very deliberate decision to limit the number of people we focused on, so that each one of them would have enough time to emerge as a memorable human character. We ended up with a cast of seven:

Joseph Priestley and Antoine Lavoisier. The series begins with a two-person story about the discovery of oxygen. Joseph Priestley, a British clergyman, found this new gas, but it was Antoine Lavoisier, a French tax administrator, who understood what it meant. In Lavoisier's hands, the discovery of oxygen completely overturned the existing science of chemistry. One of the things he realized was that oxygen was bound up with almost everything, and you could discover new elements just by separating them from oxygen. This triggered a worldwide race for new elements.

Humphry Davy. One of the people caught up in the hunt was a precocious English chemist named Humphry Davy. Davy realized he could use a battery to discover new elements by prying substances apart with electricity. More about Davy later.

Dmitri Mendeleev. The battery, and later the spectroscope, led to an explosion of new elements in the 1800s – and left a lot of chemists scratching their heads. Until a Russian chemistry professor named Dmitri Mendeleev brought order to the elements by arranging them by increasing atomic weight in the periodic table.

Marie Curie. But just when the chemists thought they had everything in order, Marie Curie came along to upset the applecart. Her work on radioactivity revealed that atoms weren't the indivisible units of matter chemists thought they were. They could fall apart, which meant they had undiscovered parts inside them. And worse, with changes to those parts, one element could turn into another.

Harry Moseley. English physicist Harry Moseley was one of the people who helped discover the atom's parts. Working in Manchester under Ernest Rutherford, who had just discovered the atomic nucleus, Moseley used newly discovered X-rays to reveal that each element was defined not by its atomic weight, as Mendeleev had thought, but by its atomic number – the number of protons in its nucleus.

Glenn Seaborg. The discovery of the final piece of the atom, the neutron, in 1932, quickly led to the discovery of nuclear fission. And American chemist Glenn Seaborg built on that discovery to create new elements, starting with plutonium, opening up a whole new realm of discovery and leading to the creation of all those man-made elements in the upper reaches of the table.

Six stories make one big story

So the three-hour series includes six distinct stories, each about a half-hour long, and each with the kinds of things you like to see in stories – a main character (or characters), a story arc, antagonists, inciting incidents, twists and turns, setbacks and triumphs.

And together, the six stories, stitched together by scenes with host Michael Emerson, tell one big story about how a long chain of people going back hundreds of years set out to solve the mystery of matter. They began with a simple question: What is the world made of? And in the process of answering it, they discovered elements, invented new instruments and techniques for finding them, created the Periodic Table and laid the foundation for the modern understanding of matter.

Precocious Davy

To give you a sense of the series, I'm going to play a bit of the Davy section, but first a little background: Davy was a self-taught prodigy from Cornwall, which one of our scholars described as the Wild West of England, about a week from London by stagecoach. By 1798, he'd made it about halfway to London and was working in Bristol. His notebooks from this period reveal that he'd set a goal of becoming the Isaac Newton of chemistry. And at the age of 19 he'd already been named director of the Pneumatic Institution, where his job was to test the physiological effects of the new gases that had been discovered by Priestley and others. His favorite guinea pig was ... himself. (To watch the clips I played at this point in the talk, click on the links below.)

https://vimeo.com/143375821 Davy discovers laughing gas

https://vimeo.com/143377263 Volta's discovery of the battery intrigues Davy

https://vimeo.com/143399431 Davy becomes a star lecturer at the Royal Institution

https://vimeo.com/143377266 Davy discovers potassium and sodium with the battery

The program goes on to show how Davy discovered five more elements using the same technique. More important, he realized that electricity was somehow part of matter, though it would take almost a century for the discovery of the electron to begin to explain electricity's role.

Letting scientists tell their own stories

A few observations:

- First, as you saw, one of the techniques we used was to shoot the main character – and others – delivering lines directly to camera in period costume. My co-director, Muffie Meyer, developed this technique for her earlier award-winning series like *Liberty!* and *Benjamin Franklin.* I thought it was tremendously effective, and that's why I asked her to work with me on this series.

- Second, we didn't make up the words delivered by the actors in these scenes. The words are drawn from the writings of the historical figures, modified only slightly to make them easier to deliver out loud. In deciding which characters to focus on, one of the factors we considered was: Did they leave enough writing for us to use in this way?

All seven of the people we chose left behind a wealth of writings in the form of letters, speeches, lectures, autobiographies or other books. By putting their words into the mouths of wonderful actors, we allowed the historical figures to come alive and help tell their own stories.

Revealing the process of science

One of the advantages of presenting chemistry in this way, as a story, is that it reveals many things about the process of science.

- **Serendipity**. Davy happened to land a job at the Pneumatic Institution, where new gases were being tested. That put him in a position to discover the effects of laughing gas, which made him famous and led to his opportunity at the Royal Institution in London.

- **Courage**. There's a long history of self-experimentation in science, and Davy is an early example of it.

- **Drive**. Davy could have settled for fame and fortune on the strength of his popular lectures, but he'd set a goal of becoming the Isaac Newton of chemistry, so as soon as he'd made himself indispensable, he started using the resources of the Royal Institution to do original research – something his bosses had never envisioned.
- **Importance of instruments**. It was the invention of the battery by Alessandro Volta that allowed Davy to make his discoveries of new elements. This is often the way things work in science. A new instrument comes along, and suddenly there's a burst of progress. The invention of the spectroscope, 60 years later, was another example of it.
- **Trial and error**. Davy didn't succeed in finding potassium the first time out. He tried one way and failed, tried another way and failed, and finally succeeded when he tried a third way. Failure is not only an option, it's an unavoidable, essential part of science.
- **Excitement of discovery.** When you finally do make that breakthrough, as we saw in Davy's case, it's tremendously exciting. That high is one of the things that motivates scientists to keep going.

When you present science as a story, these kinds of insights into how science works naturally fall out – they're revealed in an entertaining package that also lets viewers learn some basic chemistry along the way.

Does science storytelling work?

We don't really know if presenting science as a story works better than other ways, because no one has ever set out to study this question in a systematic way. But we do have some anecdotal evidence that it works:

Even though PBS scheduled all three hours of *The Mystery of Matter* on a single night in the middle of August, it did very well.

- It was one of the top three series of the week for PBS.
- The total U.S audience of the series is three million … and climbing with each repeat broadcast.
- The worldwide audience will eventually be much bigger, because our international distributor has sold the series for broadcast in 184 countries.
- And the Facebook comments and viewer reviews have been overwhelmingly positive, with positive comments outnumbering negative ones about 50-1.

As expected, we got lots of positive comments from chemistry teachers. Here's one example:

- *As a chemistry teacher, it's hard to find videos that are educational, accurate and interesting. So many are narrated by monotone-voiced scientists who put my students (and me) straight to sleep. This video is so well produced that it appeals to a wide range of people - scientifically inclined or not. I showed a few clips from the series in class to highlight some of the topics we were discussing, and many of my students actually sought out the full episodes so that they could watch them all.*

More surprisingly, we also heard from many people who knew little or nothing about chemistry:

- *I just saw the COOLEST show on CH 11, in NH (NHPTV)! It's "The Mystery of Matter", and it's all about chemistry! I'd looked forward to Chemistry in high school, but my class's Chemistry teacher had a mental breakdown and disappeared mid-year. Her replacement quickly told us that we'd been taught nothing, and taught poorly, at that. Half a year, wasted. This new teacher proceeded to deride and berate us for something that was not our doing. It was awful. Something I could have loved was ruined and left completely opaque to my mind. But THIS SHOW, in an HOUR, helped me understand more about chemistry and the people behind it than an entire year of that torturous high school mess! It was just so freaking great!*
- *I've never taken a chemistry class but I loved learning about it from this wonderful series. I didn't know what I was missing!*
- *This was fabulous! And now I know what the Periodic Table is and means! A great feat, since I've been wondering about it ever since it keeps coming up in questions on Jeopardy.*

One viewer, channeling his inner Jesse Pinkman, said simply:

- *Effin science, yo!*

Viewers responded to the re-enactments

All media projects funded by the National Science Foundation have to be evaluated after the fact. Our evaluator gave a test to a group of people who had watched the series, and the viewers averaged about a 90 – much higher than the control subjects who took the test without watching the series. So the content stuck.

One reason, apparently, is that presenting the information in story form, and including the re-enactments of the scientists' discoveries, helped viewers understand and retain the science:

- *The re-enactments helped me relate to the chemists on a more personal level. When I have a face to connect a memory with, it is far easier for me to remember the information.*
- *Including re-enactments of the scientists' upbringing and personal histories really added a great deal of interest for me. Without them it would've been just another boring chemistry video.*

More than 60 percent of the evaluation respondents said the re-enactments were their favorite thing about the series. That's a credit to our production designer, Katha Seidman, and cinematographer, Gary Henoch, who shared an Emmy Award for their work in creating these scenes.

In summary, the evaluator found that viewers "strongly agreed" that the series' focus on the "real lives" of chemists increased interest in chemistry as a human endeavor. The dramatic scenes enhanced their understanding of the people and processes that led to the development of the periodic table, and helped them understand basic chemical concepts such as atoms, elements and atomic numbers. As a result, they came away with a more positive impression of chemistry and chemists.

Many ways to tell stories

We chose to make a history of science series because it seemed like the best fit for the subject matter. Taking a historical approach is a good way to shine a light on the more difficult, neglected corners of science – not just chemistry but math, geology and others – because by focusing on people and their discoveries, it's possible to make almost any scientific subject into interesting TV.

But making history of science films isn't the only way to achieve these things. Twenty years ago, NOVA broadcast a program called "The Proof," which chronicled mathematician Andrew Wiles' successful effort to solve Fermat's Last Theorem. The math Wiles was doing was so complex that only a few people in the world understood it. But by making the film about his personal struggle to tackle a problem that had gone unsolved for 300 years, director John Lynch made an incredibly exciting and moving film. The fact that Wiles was still alive to describe his quest made it even better.

A few years earlier, Lynch had made another great NOVA episode called "Race to Catch a Buckyball." It revealed how two teams of scientists, including Richard Smalley and Harry Kroto, had raced to create the first carbon-60, or Buckyball, for which they won the Nobel Prize. Unlike "The Proof," which focused on a single person, "Buckyball" captured the collective and competitive aspects of science.

A more recent example is "Particle Fever," which followed a huge team of scientists over a four-year period as they worked at the Large Hadron Collider in Switzerland to prove the existence of the Higgs Boson. The filmmakers were there in 2012 to capture the jubilation of the scientists as they saw the first evidence of the so-called God Particle. This film has won a bunch of awards, and deservedly so. It's a wonderful illustration of the power of telling science as a human story.

So it doesn't matter if you do it through a history series or a film about a single scientist's quest, a race between teams or a massive collective effort – all these approaches work.

Science is a human story

In the course of the Percy Julian project, I read many of Julian's speeches, looking for lines we could have the actor who played him deliver on camera. This was one of my favorites:

Science is not a compendium of facts. It is a human story, a story of men and women of faith and courage, of a thirst for knowledge and suffering to achieve it.

I think too often, especially in schools, science is presented as a compendium of facts – a body of knowledge you're expected to learn, never mind where it came from. But this approach drains science of much of its excitement. By presenting science as a story, with all the faith and courage and thirst and suffering Julian mentions, filmmakers and television producers can put the excitement back in … and make interesting programs about even the most challenging fields of science.

Film and TV as part of an on-going dialogue between science and society

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The presence of science in movies can take many forms and fortunately we are seeing an increase in scientific themes being part of growing number of stories. More importantly, science is being presented more and more often as part of the solution of conflicts than as their origin. It is important, though, to note that we are not advocating for an overrepresentation of science in film nor for science and scientists to be always depicted in a positive light or as the archetypal heroes. This would be completely unrealistic and does not happen with other types of knowledge areas or professions either.

However, it is equally true that the scientific community has often expressed unease and concern about science being mainly represented as a negative force in the battles shown on screen. It is felt that stereotypes like the mad, white, male, old scientist in a lab coat, or science as the origin of man-made large-scale natural disasters does not help promoting science as part of culture or as a career option for students. It is noteworthy that much of what I have just mentioned represents a feeling in the scientific community, and that it remains to be supported by evidence. For example, at this very symposium Stephen Cass showed with data that it is a myth to think that there are not enough graduates to cover the available jobs in science and that this is putting scientific and technological progress in peril.

In any case, regardless of whether such perceptions are based on facts or not, the reality shows that in response to them there has been a huge effort to “normalize” the depiction of science in film, with individual initiatives by scientists to contribute to filmmaking as advisors, often with a generous use of their own time, or collective initiatives like the by now well-known Science and Entertainment Exchange (http://scienceandentertainmentexchange.org/). This has facilitated the collaboration of numerous scientists and filmmakers, always bearing in mind that the common objective has necessarily to be to make a better film rather than vindicating the role of science or nitpicking factual errors. My favourite example of such a collaboration is the film *Dolores Claiborne* (1995), which is not about science at all, but includes a solar eclipse that works masterfully as a metaphor of the main character’s life as an abused wife. I will not enter into further details in order to avoid spoilers, but the metaphor, and the mood of the film at a crucial point of its plot, work all the better because the eclipse is represented in a very accurate way, following a huge effort in time and resources by the director as never seen before with eclipses in movies.

Science is present in film in many ways. Many films are “based on true events” and tell the stories of specific historical moments or characters from science. Films like *Longitude* (2000), *Apollo XIII* (1995), *The Dish* (2000) and many others bring us closer to important milestones in the history of science, and are therefore quite educational and unproblematic in terms of the image of science they project.

Slightly less unproblematic are the “biopics” that focus on specific figures, like *A Beautiful Mind* (2001), *The Boys from Brazil* (1978), *Creation* (2009), *Einstein* (2008) etc., not so much in terms of the way science is portrayed, but because the choice of characters can present a skewed image of science: if only conflictive and tormented figures are picked, or only the most controversial side of the scientists is shown, the image of scientists in society will certainly be not representative. Also, the choice of historical figures could end up replicating gender and racial unbalance in science and technology and therefore inadvertently contribute to it through a lack of female or black scientist role models. Fortunately, there has been a movement to counteract this with films like *Agora* (2009), *Gorillas in the Mist* (1988), *Hidden Figures* (2016) and *Marie Curie* (2016) and the prominent female scientist characters in TV series like *Bones* (2005-2017), *CSI* in its various variants (*CSI* (2000-2015); *CSI Miami* (2002-2012) *CSI:NY* (2004-2013)), including the short-lived *CSI:Cyber* (2015-16), in which the leading forensic scientist was finally female.

Films about science can also be part of other “campaigns”, some very obvious, like the numerous disaster movies directly linking the destructive natural phenomena to climate change (*Waterworld* (1995), *The Day After Tomorrow* (2004), *A.I.* (2001) and numerous B-movies); other less obvious like films about missions to Mars like *Mission to Mars* (2000), *Red Planet* (2000), *The Martian* (2015) which many have regarded as deliberately timed to promote public support when funding for NASA was due for renewal.

There is of course the whole world of Science-Fiction, where many of the issues mentioned above are also present, but which opens up the creative process to more speculative approaches. In many case the speculation is purely scientific, in terms of exploring the “what ifs” of advances in specific areas of research, as in *Star Trek* (1966-), *Life* (2017), and so many others in between. Often, however, science is “just” a backdrop or an instrument to explore other issues, like power relations in society or what it means to be human, as for example in most films about robots (*Chappie* (2015), *ExMachina* (2014). In either case, and given the enormous popularity of science-fiction as a genre, it is an ample arena for the “normalization” efforts mentioned above, with a huge potential impact in public perception of science

The important consequences of these efforts in terms of science communication have been thoroughly discussed by Jovana Grbic and David Kirby at this symposium. Dr. Grbic highlighted various practical uses of science in film in public engagement with science and Dr Kirby showed in detail how the way science is depicted in film has broad and deep implications in public attitudes towards scientific progress and technological advances, to the extent of influencing society’s response to and influence on policy and funding.

This responsive influence is increasingly being incorporated into the process of science communication, which has undergone journey through various stages, starting from a focus on conveying information to the public, to promoting public understanding of science, then public awareness of science and later public engagement with science, in which “dialogue” became a buzzword that had to be part of every interaction between science and society. This later evolved into the current push towards public participation in science, in which “dialogue” gave way to “co-creation” and which led to the latest chapters in the controversy around “expertise” (e.g. Collins 2014). (Incidentally, this controversy began already many years ago with what was called the “Science Wars”, in direct allusion to the “Star Wars” franchise, but this is another story...).

On the surface, by its very nature, science in film remained on the margins of these developments, as embedding dialogue and participation in a clearly unidirectional format of science communication seemed an impossibility. However, here I would like to point out that it is actually possible to regard science in film as part of that dialogue between science and society.

While Physics and Mathematics include “thought experiments” include as part of their accepted methods of enquiry, as for example the famous *Gedankenexperiment* by Einstein, Podolsky and Rosen and the counterargument by John Bell in the debate about the interpretation of Quantum Mechanics, in the social sciences such an approach seems to be scarce. Using fiction films to explore realistic social situations could offer an opportunity to do so[1]. A recent and on-going example is the work by Compagna et al. (2016), who are using fiction films to study how the public would react to real autonomous robots, since for safety reasons this could not be done in realty. The reliability of such an approach relies heavily on the assumption that the filmmakers strive to be realistic and have carried out a thorough background research. In other words, it relies on a careful selection of films to be used.

If this can be done in the context of social robotics, there is nothing stopping us from considering carefully selected films as a valid representation of societal responses to other areas of research. As such, the representation of science in films can be considered as part of a slow dialogue between science and society, in which the filmmaker becomes the voice of the public in response to particular issues that are subject to debate for their ethical, moral or otherwise societal implication.

Analysing the representation of science in films thus acquires a new and highly relevant dimension, and many films that are dismissed by the scientific community for their lack of accuracy or highly critical attitude towards science and technology need to be revisited and taken into consideration in this context. Realism does not play an important role in this context, except when the lack of it shows that the critical response on a specific issue may be explained by a misunderstanding of the topic. But regardless of the accuracy of the science, the depiction of science and scientists in films and TV series, like *Godsend* (2004), *The Andromeda Strain* (2008), *Westworld* (2017), to name but a few, needs to be takes seriously as part of an on-going dialogue between science and society. We need to “look who’s talking”!

References

Collins, H. (2014) *Are we all scientific experts now?* Cambridge, UK: Politi Press, 2014.

Compagna, D. (2016). ‘”At Least There is Something Human in You” The provocation of Social Robots for Modern Societies’ https://conference.aau.at/event/46/material/2/50.pdf (visited on 28 August 2017)

Note: At the conference I took the opportunity to officially launch:

http://www.scienceinmovies.com/

[1] This idea was formulated in these terms by Marc Audétat at the STS Italia 2018 Conference “Technoscience from below” as part of the discussion in the track *Science Fictions*.

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