PHYSICAL SCIENCE
A revitalization of the traditional course
by avatars of Hollywood in the physics classroom

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1 Public Attitudes and Understanding of Science

It has been well-documented [1] that most Americans have very little understanding of science, are unable to distinguish between science and psuedoscience, and have no clear concept of the role of science in their daily lives. While about 90 percent if those surveyed by the National Science Foundation (NSF) since 1979 report being interested in science and more than 80 percent (in 2001) believe that federal government should finance scientific research, about 50 percent do not know that Earth takes one year to go around the sun, electrons are smaller than atoms, and early humans did not live at the same time as dinosaurs. Statistics concerning Americans lack of knowledge of such things receive frequent media attention.

Answering the question “Who is responsible?” is not an easy task since many factors, including social and economic conditions, have a direct impact on the science literacy of the public. However, scientists strongly believe that the media—ironically, exactly those that raise concern about the limited science literacy of the public—and, in particular, the entertainment industry, are at least partially responsible and are a significant source of the public’s misunderstanding and faulty knowledge of science. Unfortunately, the public who watch television shows and films with pseudoscientific or paraphysical themes does not always interpret them simply as entertainment based in pure fiction. Due to the lack of critical thinking skills, many people tend to perceive the events depicted as real or within the reaches of science. This unchallenged manner in which the entertainment industry portrays pseudoscientific and paraphysical phenomena should excite great concern in the scientific community. Not only does it amplify the public’s scientific illiteracy, but also puts at risk the public’s attitude towards science, raising the possibility that future influential figures in our society could inadvertently cause serious damage to mainstream physics simply through ignorance and misunderstanding.

The authors have embarked on an ambitious project to help improve public understanding of the basic principles of physical science. This paper reports the results of the initial phase of the program, which was begun with several large groups of non-science majors enrolled in the general education physical science course at the University of Central Florida (UCF), a course with a counterpart in nearly every college and university (and many high schools) in the nation.
2 On Our Course

2.1 The Course in Brief

At UCF the course is 3 semester-hours and is taken by about 3000 students annually. It has an independent 1 semester-hour laboratory elected by about 20 percent of those in the course. At this stage the lab is not a part of the project. During the academic year the class is taught in sections of 300 to 450 students; in the summer the class sections are limited to 90 enrollees. All sections are taught in multimedia-equipped classrooms.

In the authors’ sections, we teach the key concepts from all areas of physics, not only the standard core of classical physics that is presently physical science, but go beyond to introduce students to the captivating discoveries of relativity, quantum mechanics, astronomy, and cosmology. Augmenting the traditional lectures and live demonstrations, our new “weapon” in this effort to improve scientific literacy is the films themselves, often the same ones that perpetuate the incorrect understanding of science held by the students. Using a medium that is familiar to and universally enjoyed by the students, we employ short (5 to 8 minutes) clips from many films as the basis for discussions and calculations for the very broad range of topics covered in the course, including some decidedly non-typical topics, such as time travel, extraterrestrial civilizations, and black holes.

2.2 The Goals of the Course

Our goals for the course are these:

1. To motivate students to think critically about science information presented in films.
2. To help students learn to distinguish between physical laws and pseudo-science.
3. To encourage students to understand how science works and how any widely accepted theory has been verified using the scientific method.
4. To help students learn where the borderline between tested and untested physics ideas lies.

2.3 Other Similar Attempts

In years past forerunners of our approach have been tried in a few places with varying degrees of success. The most notable case is that of Professor L. Dubec of Temple University [2, 3]. Dubec has used science fiction films to teach scientific ideas to non-science majors. A real pioneer in this approach, but well ahead of his time, his course did not attract the attention it deserved. We only discovered it while in the process of developing our course for the Summer of 2002. His approach is qualitatively; on the contrary, our approach is mostly quantitative, although qualitative arguments are often given for various scenes. Moreover, we have made use of a broad array of genres, not just science fiction films.
Other efforts have focused at the high school level [16, 17, 18]. In particular, Dennis has recently advertised his success in an article published in Physics Teacher [17] about teaching mechanics with the aid of films. Motivated by this success, Dennis has published a book [18] with the hope of helping other teachers use films in their courses, too. Our approach carries many similarities in philosophy with that of Dennis; however, our course, taught at a college level is more advanced and covers by far more topics than mechanics.

A serious challenge in each case has been to keep the course up-to-date—for example, this seems to be the most serious problem with the books [2, 3] as expressed by the students. This challenge we think our approach and careful planning will meet.

3 On Our Use of Films

The course syllabus outlines the topics to be covered during the term and also includes a schedule of films to be viewed as homework by the students. Each film contains scenes concerned with one or more (usually more) of the topics. For example, listed below are the films and topics used during the initial phase of the project:

1. Speed 2 [4]: speed and acceleration, collisions.
2. Armageddon [5]: momentum, energy, comets and asteroids.
3. Eraser [6]: momentum, free fall, electromagnetic radiation.
4. 2001: A Space Odyssey [7]: centripetal and centrifugal force, artificial gravity, zero gravity.
5. The Abyss [8]: hydrostatic and atmospheric pressure, effects of pressure on humans and objects.
6. Independence Day [9]: potential energy, conservation of energy, pressure, tidal forces.
7. Tango and Cash [10]: momentum, electricity, physiological effects on humans.
8. Frequency [11]: magnetism, motion of particles in magnetic fields, Aurora Borealis, solar wind, wormholes, time travel.
9. Contact [12]: relativity, space travel, wormholes, life beyond Earth, Drake’s formula.

The films assigned, about one per week, are popular ones available on DVDs or videotapes from stores or, in many cases, libraries [2]. Films are viewed at home as homework prior to discussion of the related topics in class; as mentioned, only short clips are used in class. We found that viewing the homework films quickly became occasions for student group or family pizza parties! This helped alleviate a potential problem of having enough copies

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1We are grateful to C. Dennis for sending us review copies of his book.
2The UCF library currently owns 10 DVDs from each movie used in the course.
of each film locally available. Sufficient available copies turned out not to be a problem as the numerous video stores tend to have many copies of the films we use.

In class integrated with the lecture, PowerPoint slides and demonstrations, we focus on analyzing the topic of the day using clips from films that have examples of that principle. For example, students might watch *The Abyss*. Then in class, using a couple of clips from the film to “set the scene”, we discuss pressure in a fluid as a function of depth, how deep an object (e.g., a person or submarine) can descend, and the propagation of sound in water. Following that discussion, a physics single-concept film may be shown to illustrate what the movie got right and what it got wrong. After class, the instructor’s analysis of each clip is placed on the course web site so that students may review the
discussion and calculations. An additional advantage of this approach is that the films we use can be varied each term to incorporate new releases and to focus attention on particular concepts. Below is an example of how we use particular clips from Armageddon in discussions of asteroids, momentum conservation and energy.

**EXAMPLE**: In Armageddon an asteroid of the size of Texas is on a collision course with Earth. In *Chapter 7: Training Begins* of Armageddon, the flight plan of NASA and the method for the destruction of the asteroid are described (see segment from 43:04 to 45:34): the team must land on the asteroid, drill a hole, plant a nuclear bomb, and then detonate it before the ‘zero barrier’. If the detonation happens after the ‘zero barrier’, then the asteroid fragments will collide with Earth. This segment is discussed twice in class, once when the concepts of momentum are presented (paragraph 1 below), and once when the concepts of energy are presented (paragraphs 3 and 4 below). In the second case, the calculation ends with an evaluation on the feasibility of the plan. Prior to the second time, another quick clip (*Chapter 4: NYC Hit Hard*, segment from 10:20 to 11:40) is shown in class which motivates a discussion on asteroids and the calculation of the mass of the asteroid seen in the film (paragraph 2 below). These discussions are repeated here in order to demonstrate our methods.

**Figure 2**: Armageddon NASA simulations show that the successful detonation of the bomb before the zero barrier will result in splitting the asteroid in two fragments that will be deflected away from Earth.

**Figure 3**: NASA simulations show that detonation of the bomb after the zero barrier will result in splitting the asteroid in two fragments that will not be deflected enough to avoid collision with Earth.
§1. **Momentum Conservation:** Following the NASA simulation and to simplify the analysis, we assume that the asteroid splits in exactly two fragments. Moreover, we assume that the detonation of the nuclear bomb will force the two fragments to deflect perpendicular to the direction of the original motion at speeds that depend on the size of the bomb. (We shall indicate the direction of motion as $x$-direction and the perpendicular direction as $y$-direction.) The two fragments will still continue to move towards Earth with the $22,500 \text{ mi/h}$ speed of the asteroid. This is guaranteed by momentum conservation. The relation of the fragment speeds in the $y$-direction is also determined by momentum conservation. Assuming that the two fragments have equal mass, they will acquire equal speeds in the $y$-direction, such that the total momentum along this direction maintains the value zero that it had before the detonation.

§2. **Mass of the asteroid:** For a quantitative calculation on the *Armageddon* NASA plan, we shall need the mass of the asteroid. In the movie we are told that the asteroid is of the size of Texas. The area of Texas is $691,027 \text{ km}^2$ \[19\]. Assuming that Texas is a square, this would give a length of $831.3 \text{ km}$ for the side of the square. This gives an average length. In reality, Texas is stretching $1,244 \text{ Km}$ from east to west and $1,289 \text{ km}$ from north to south \[19\]. To be on the conservative side, we will adopt the average size $831.3 \text{ km}$ for our calculations. Even so, only one known asteroid is of such size; the largest asteroid, Ceres, has a diameter of about $940 \text{ km}$. In fact only two dozen asteroids have diameters $200 \text{ km}$ or greater. Even if we assemble all known asteroids to a unique big asteroid, its diameter will be no more than $1,500 \text{ km}$ and its mass less than $1/10$ that of Earth’s moon \[20\]. However, to give the director the benefit of doubt, we shall accept the existence of an asteroid of the size given on collision course with Earth.

If the asteroid is a cube, its volume is $5.7 \times 10^8 \text{ km}^3$. If it is a sphere, then its volume is $18 \times 10^8 \text{ km}^3$. Large asteroids have spherical shape; smaller asteroids have irregular shapes \[20\]. However, let’s assume that the volume of the asteroid in the film is somewhere in between the two values given above, say $10 \times 10^8 \text{ km}^3 = 10^{18} \text{ m}^3$.

Overall, about 15 percent of all asteroids are silicate (i.e. composed of rocky material), 75 percent are carbonaceous (i.e. contain carbon), and 10 percent are other types (such as those containing large fractions of iron). Stony asteroids look very much like terrestrial rocks. So, we might assume that the density of the asteroid is approximately equal to that of Earth: $5500 \text{ kg/m}^3$. However, we know from observations that asteroid Ida has a density of $2200$–$2900 \text{ kg/m}^3$ and asteroid Mathilde has a density of about $1400 \text{ kg/m}^3$. This especially low density of Mathilde might be due to a porous interior \[20\]. To be conservative, we shall assume a density of $2000 \text{ kg/m}^3$ for the film asteroid. In other words, ever cubic meter of the asteroid would have a mass of $2000 \text{ kg}$. The total mass of the movie asteroid would be $2000 \times 10^{18} \text{ kg}$ or $2 \times 10^{21} \text{ kg}$. We have assumed that, after the detonation of the nuclear bomb, the asteroid breaks in two pieces which have equal mass. This means that each piece would have a mass of $10^{21} \text{ kg}$.

§3. **Energy of nuclear weapons:** In the film a nuclear bomb is used to split the asteroid. The explosive TNT has become the standard means for showing the disastrous power of nuclear weapons. In particular, one ton (t) of TNT releases

$$4.2 \times 10^9 \text{ Joules}$$
of energy. Yet, one ton is a small quantity of TNT to describe modern bombs; kilotons (kt) or megatons (Mt) of TNT are units more appropriate:

\[ 1\text{kt} = 1000\, t, \quad 1\text{Mt} = 1,000,000\, t. \]

The Hiroshima bomb was equivalent to 12\text{kt} of TNT or

\[ 5 \times 10^{13} \text{ Joules}. \]

A modern nuclear bomb is equivalent to 20\text{Mt} of TNT. This is equal to 1667 Hiroshima bombs and releases about

\[ 8.4 \times 10^{16} \text{ Joules}. \]

Today the nations which have such weapons no longer spend effort to increase the destructive power of nuclear bombs as it is already immense. Instead, they focus on reducing the size of the weapons.

§4. Deflection of the fragments: Returning to the movie, let’s assume that the nuclear bomb that was carried to the asteroid was equivalent to 100,000 Hiroshima bombs. For the reasons we have already explained, this is a really generous assumption in favor of the director. As always, we want to be nice to him. Upon detonation, the energy released will be

\[ 5 \times 10^{18} \text{ Joules}. \]

Part of this energy will be used to break the asteroid into two pieces. However, once more, we will be generous to the director and we will ignore this fact, even though the energy needed to do so is significant. Therefore, we will assume that all the energy becomes kinetic energy of the two fragments; each fragment will be given an amount of

\[ 2.5 \times 10^{18} \text{ Joules}. \]

Moreover, as stated above, we assume that all energy becomes kinetic energy associated with motion in the \( y \)-direction and no amount is spent to push the fragments in the \( x \)-direction.

Knowing the mass of each fragment and the kinetic energy of its motion in the \( y \)-direction, we can find the speed of the fragment in this direction:

\[ KE = \frac{1}{2} m v^2 \Rightarrow v = \sqrt{\frac{2 KE}{m}}. \]

If we substitute the numbers and do the calculation we find that

\[ v = 0.07 \frac{m}{s}. \]

Therefore, each fragment moves in the \( y \)-direction \( \frac{7}{100} m \) (or 7cm) every second. In two hours or 7200s, the time to reach Earth, each fragment will move

\[ \frac{7}{100} \frac{m}{s} \times 7200s = 504 \, m. \]

Now compare this with the radius of the Earth:

\[ 6,500 \text{ km} = 6,500,000 \text{ m} \]
which is how far each fragment must move in the \( y \)-direction in order to just miss the solid Earth (but it would still go through the atmosphere and release a lot of energy).

So we see that applying momentum conservation and reasonable (and generous!) assumptions about the size of the nuclear bomb used, there is no way that this plan would save Earth. The two fragments of the asteroid would be barely few city blocks apart when they collided with Earth. Such proposals appear in the press from time to time, but now the students learnt how to critically analyze such suggestions made by well-meaning, but scientifically, illiterate contemporaries.

The above discussion, besides the explicitly made assumptions, ignores the gravitational attraction of the two fragments that will decrease further the deflection, the tidal effects on Earth, and the perturbation introduced by the asteroid in the motion of the Earth-moon system. These effects are discussed further in class, partly qualitatively and partly quantitatively.

As is obvious from our example, the quantitative analyses we use are often more sophisticated than what is expected from Physical Science students. However, we have discovered that, since the analysis is strongly correlated to the film, no complaints are generated. A similar attempt to solve such a problem in the traditional course would generate many unpleasant feelings and would make the course very unpopular.

Besides the films required to be previewed by the students at home, the instructors make use of clips from various other movies, IMAX films, and scientific documentaries. For example, a clip from Deep Impact is used to demonstrate the tsunamis after a collision of a comet with Earth, clips from the IMAX film Mission to Mir is shown in order to illustrate life under “zero gravity” conditions, and clips from the PBS documentary Life Beyond Earth are shown to discuss our quest for life in the Universe.

### 4 Student Response and Performance Results

So, how do the students perceive the course? The instructors made use in class of an electronic personal response system whereby each student could respond immediately to questions posted by the instructors, their responses being automatically recorded and tabulated by an in-class computer. This system, besides its pedagogical value, was used to obtain data on the student’s feelings and reactions on the course and to record attendance. The results for several course-evaluation questions are shown in Tables 1 through 4.

Besides the data collected by the personal response system, students have expressed strong support through the standard end-of-term course evaluations and through — unsolicited — comments in their term papers.

Of course, even if the students embrace a new idea enthusiastically, it does not mean that their performance will be better than their performance in the traditional course (where the majority of them really struggle). The effect needs to documented. In Table 5, we list the performance of UCF Physical Science students in two almost identical classes, one taught in the traditional way and one taught using movies. The important parameters in both classes are identical: the classes have the same size, they were taught by the same instructor (C.E.) who used similar PowerPoint lectures, same demonstrations,
Table 1: Data on the question “The films were well-chosen to include a broad range of science ideas”.

|                | SUMMER 2002 | FALL 2002 |
|----------------|-------------|-----------|
| strongly agree | 38.16%      | 28.06%    |
| agree          | 52.63%      | 48.98%    |
| disagree       | 5.26%       | 13.27%    |
| strongly disagree | 3.95%   | 3.57%     |

Table 2: Data on the question “The topics selected from the movies for physics analysis were interesting”.

|                | SUMMER 2002 | FALL 2002 |
|----------------|-------------|-----------|
| strongly agree | 28.95%      | 19.72%    |
| agree          | 60.52%      | 53.99%    |
| disagree       | 9.21%       | 17.37%    |
| strongly disagree | 1.32%   | 6.10%     |

Table 3: Data on the question “The instructors should develop this course further since it is more interesting than the standard physical science course”.

|                | SUMMER 2002 | FALL 2002 |
|----------------|-------------|-----------|
| strongly agree | 77.92%      | 56.88%    |
| agree          | 10.39%      | 26.61%    |
| disagree       | 9.09%       | 6.88%     |
| strongly disagree | 2.60%   | 4.13%     |

The classes were even taught in the same auditorium. The classes also covered similar material with the same textbook [21] required in the traditional class and recommended in the Physics in Films class. The Physics in Films class used in addition a supplement [2]. The material of the Physics in Films class was almost identical. There were some differences in order to make the content of the course more exciting: a few topics of the traditional syllabus were omitted and they were substituted by topics that captivate the imagination of the students. Topics that were covered in the traditional course but omitted in the Physics in Films course were the extensive treatment of heat
and temperature and extensive discussion of elements and the periodic table. Instead, topics from astronomy (comets and asteroids, life and intelligent life beyond Earth), as well as some topics from modern science were added (elements of special and general relativity, space and time travel).

Table 4: Data on the question “I would recommend to my friends that they take this course”.

Table 5: Data on similar exams from two Physical Science classes of identical size taught by the same instructor. The material of the two classes was almost identical. (See discussion in article.) Exams are normalized to a maximum of 100 points. The differences are both dramatic and significant.

5 On the Drawing Board

The authors are currently writing a physical science textbook that incorporates the physics in films concept. It will be complete with an instructors CD containing analysis notes for every scene used in the book to discuss concepts in physical science and a tutorial on making your own analysis of scenes from favorite or new movies. In addition to physics, this approach to teaching basic concepts at the non-major introductory level can be applied in many other disciplines. Table 5 lists several possibilities with examples of films containing pertinent scenes.
Table 6: Use of films in other disciplines. We have listed three other areas besides Physics. However, the possibilities are really unlimited: Archaeology, Chemistry, Computer Science, Engineering, Forensic Science, History, Law, Philosophy, etc.

References

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