Science fiction in physics teaching: improvement of science education and History of Science *via* informal strategies of teaching

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Abstract: *The present work describes an alternative proposal to teach physics and history of science using science-fiction films. This proposal was developed to be improved in high schools, colleges and training courses for teachers-in-service. A videofilm (15 minutes duration) was produced in NTSC with several excepts from the classical science fiction films. The "physical phenomena" presented in science-fiction films are a powerful way to explore the common sense ideas of students and teachers about specific scientific contents and also to explore the development of conceptual frameworks in the history of science.*

Key words: *physics teaching, history of science, alternative conceptions, verbo-visual language*

Resumo: *O presente trabalho descreve uma proposta alternativa para o ensino de Física e da História da Ciência usando filmes de ficção científica. Esta proposta foi desenvolvida para o Ensino Médio, universitário e para cursos de atualização de professores-em-serviço. Um vídeofilme (de 15 minutos de duração) foi produzido no sistema NTSC com trechos de vários filmes clássicos de filmes de ficção científica. Os "fenômenos físicos" apresentados nesses filmes se constituem em uma forma poderosa para se explorar as idéias do senso comum de estudantes e professores sobre conteúdos e temas específicos e, também, para explorar o desenvolvimento de quadros conceituais na História da Ciência.*

Palavras-chave: *ensino de Física, história da Ciência, concepções alternativas, linguagem verbo-visual*

1 Introduction

Since 1990 we have been using the classic science-fiction films, like *Star Wars, 2001, A Space Odyssey, Star Trek*, etc., for college students and for teachers in specific training courses. These courses are extra curricular and they are not subject to evaluations so as to allow a great exchange of information and to create a very good informal atmosphere in the classrooms.

This kind of films, involving space battles (except *2001*), were chosen because they present a peculiar set of "phenomena", in most cases, very far from the behavior predicted by Galilean kinematics and by Newtonian dynamics.

Another characteristic of these films is that they present a very similar frame to that discovered by cognitive's researchers on "common sense knowledge" (mental representations) and on the several historical steps in the construction of scientific knowledge.

History of science reveals that the structuring of physical phenomena in a set of powerful laws came as the surpassing of common sense science presents in everyday experiences. The long historical development of mechanics, since Aristotle, Oresme and Buridan, up to the works of Galileo and Newton, was a conquest of a physics where idealized media were required to the occurrence of the phenomena (absence of friction, void, etc.).

Nevertheless, in the real world, idealized media cannot exist! In the experiences of everyday life, there is no void or frictionless surfaces. Our experiential world is full of phenomena where friction, and the presence of a material medium, determine the behavior of the bodies' motion.

In the following sections we will summarize our activity using the films as a powerful didactical tool, but, firstly, we will discuss the possible parallelism between science history, educational research and the most common mistakes present in standard science-fiction films.

2 The history of Mechanics: from Aristotle to Buridan

To understand the "physical dynamic" presents in science-fiction films it is necessary to recount a brief history of mechanics from the change of the Aristotelian view of "*omne quod movetur ab alio movetur*" ("all that is moved is moved by something else") to Buridan's impetus, before the foundation of classical mechanics by Galileo and Newton.

Unfortunately, in the science curriculum there is no space for ancient greek physics and the old medieval critiques of the Aristotelian physics. The way that physics is treated in schools is particularly a-historical and stuffed of "magical elements", in the sense that all the scientific discoveries or constructions seem to have been made in moments of geniality and completely detached from a rich previous historical context.

Aristotle of Stagira (384-322 B.C.) was the great name of physical science of the world. Perhaps, we are not exaggerating in attributing him the role of the greatest physicist, since all other theories were constructed on the basis of the Aristotelian thought. Without him the science of the Middle Ages and Galileo's *Dialogo* and *Discorsi* would not have been possible.

Aristotelian physics divides the natural world in two levels: a celestial one and a terrestrial one. Each of them is characterized by natural motions: in the celestial world, the natural motion was uniform circular motion; belonging to heavenly bodies; in the terrestrial world, the natural motion was linear, either straight up (fire and air) or straight down (earth and water). Only in these terrestrial motions an intervention can occur: using violence (*force*) natural motion could be changed or stopped. This last fact was never present in the heavenly motions.

In the terrestrial motions, there was a non-inertial characteristic, *e.g.*, the velocity of a heavy body was determined by their nature (heavy bodies, like earth or water, and light bodies, as fire and air) and a constant action of a force was always necessary to sustain the motions. We could summarize this kinematics writing the mathematical expression (*never written by Aristotle, but that explains mathematically the essence of his thought!*):

$$v = k\,(F\,/\,R)$$

Where v is the velocity, k is a constant of proportionality, F is the force and R is the resistance of the medium.

This physics had a very important and fundamental consequence: the impossibility of the existence of a *void*, since it can provide no resistance to the speed of the fall of the heavy body. If R is equal to zero the velocity would be infinite, e.g., the phenomena would be instantaneous. As it was known, there are not instantaneous phenomena, therefore the existence of a void was impossible. So, in the region of the *quintessence* (supralunar region, beyond the limit of the Moon), the structure of the Aristotelian world required the presence of a material medium, the *ether*.

Another important characteristic of the Aristotelian physics was the fact supported by Plato: the *antiperistasis*. Aristotle wrote:

> "*Further, in point of fact, things that are thrown, move though that which gave them their impulse is not touching them, either by reason of mutual replacement, as some maintain, or because the air that has been pushed pushes them with a movement quicker than the natural locomotion of the projectile wherewith it moves to its proper place.*" (Aristotle quoted by Cohen & Drabkin, 1948, p. 204-205).

This physics remained without great critiques until the end of the fifth century A. D., when the last great Aristotle's commentator, John Philoponus, rejected the statement of the inexistence of the void and the antiperistasis. For him, in a void, the velocity of a body would be proportional to weight. We could summarize his thought writing:

$$v = k'\,(F - R)$$

The dynamics that maintains the motion after the projector is abandoned are not those provided by the air as "motive" power. The cause of the motion was:

> "*some incorporeal motive force (...) imparted by the projector to the projectile, and (...) the air set in motion contributes either nothing of all or else very little to this motion of the projectile.*" (Philoponus quoted by Cohen & Drabkin, 1948, p. 223).

Jean Buridan (1300-1358 A. D.), seven centuries after Philoponus and, perhaps, without knowing the statements of his great predecessor, stated the same things as Philoponus. The contribution of Jean Buridan did not appear in an empty context. There was, in his medieval predecessors, an intensive critique of the Aristotelian physics, which permitted him to write:

> "*... it seems to me that it ought to be said that the motor is moving a moving body impresses in it a certain impetus or a certain motive force of the moving body (which impetus acts) in the direction toward which the mover was moving the moving body, either up or down, or laterally or circularly.*" (Buridan quoted by CLAGETT, 1959, p. 534).

3 Science fiction films, the history of physics and mental representations of the scientific subjects in the didactical research

Science-fiction films, especially those on space battles, give a great opportunity to analyze, in a basic physics course or a history of science course, notions of mechanics, optics, astronomy, etc.

In these films, like *Star Wars* and *Star Trek*, where the space battles are numerous, we can distinguish some "physical phenomena":

- the engine of the space vehicles are always ignited, e.g., to maintain the movement the constant action of a force is necessary (the old Aristotelian frame "*omne quod movetur ab alio movetur*"?);
- the sounds of the explosions in space reveal the existence of a material medium, like an "Aristotelian ether" (this could not occur, in aristotelic physics because the terrestrial bodies, men and interstellar space vehicles, could never be in the supralunar region);
- the visualization of the light beams of lasers in space reinforces the existence of a material medium;
- the "flight" of the space vehicles (like terrestrial airplanes) in savage spatial battles, also reinforce the notion of the existence of an "ether";
- the inexistence of the inertial effects during the continuous acceleration or deceleration of the space vehicle's motions;

- the existence of an unexplained source of artificial gravity inside the space vehicles.

In contraposition with these films we worked also with the classical *2001, A Space Odyssey.* This film represents a break down from the star-wars-like films, because it is based on a relatively strong known physics. This film is characterized by:

- notions of referential systems;
- scenes involving "artificial gravity" provided by the well known scene of a space wheel in rotation relative to its own axis;
- "harmonic" space flights;
- no sounds in the external space;
- no velocities greater than light velocity.

This film, however, presents some few technical errors, like:

i) the centrifugal acceleration at the outer wall space wheel can be estimated as around 1/5 of the terrestrial gravity (BORGWALD & SCHREINER, 1993).

ii) The dramatic passage of the astronaut from spatial modulus to the great *Discovery* spaceship. This scene would be perfect, except for a great detail: the absence of a helmet (extravehicular visor assembly) on the head of the astronaut.

After an interaction with some college students in the discussion and preparation of the best scenes to present in a training course for high school teachers-in-service, a videofilm was prepared (15 minutes duration, in NTSC system) using three brief sequences of science fiction films: *Star Wars, Dark Star* and *2001, a Space Odyssey.*

The main goal of this didactic videofilm is to use science-fiction as a tool to discover the mental representations of some physical conceptions present in the students and teachers, to compare, *a posteriori*, the aspects of the development of the scientific thought, with the nowadays accepted scientific principles and with the educational research in the area of scientific preconceptions (*common sense ideas*).

The interest of teachers and students in these films provided a curious, natural and ludical motivation for investigating the teaching level of scientific principles and history of science in the schools. After having shown the videofilm, teachers and students were left, with a great amount of time, to discuss the observed scenes and to compare them with their mental representations or scientific frameworks.

In the successive discussions, we analyzed that the most frequent errors found by teachers and students were those related to the behavior of the space vehicle's flight. The other ones, especially those relative to the inertial systems and the existence of a material medium in space, were not recognized by them. Our experience in these courses proved that a great charge of common sense physics based in the everyday experiences remains in the conceptual scheme of teachers and students, and that we find in the history of science frequent similarities. DIJKSTERHUIS (1969, p. 30) writes: "*... history repeats itself every year*".

We can hypothesize these results as being due to the traditional form of the physics teaching in high school and in the first years of undergraduate physics courses, where events and phenomena are relatively independent of mathematical background (WHITAKER, 1983), generating a deep gap between the physical world and the mathematical expression of this world. In this frame, the mathematics is memorized without an assimilation and accommodation.

Aristotelic and medieval physics can find an important role in the common sense physics to understand some of the historical development of the scientific concepts. We cannot forget that the similarities of the common sense physics are due to the intensive contact of people with the concrete world. Consequently, it is natural to think valid the old Aristotelian and medieval assertion: "*all that is moved is moved by something else*". J. Clement (1982) writes:

> "*In the real world, where friction is present, one must push on an object to keep it moving. Since friction is often not recognized as a force by the beginner, the student may believe that continuing motion implies the presence of a continuing force in the same direction, as a necessary cause of motion.*"

In this sense, the continuous force employed by space vehicles in films like *Star Wars* is a natural consequence. It is a "natural" transposition of the air flights in earth's atmosphere (full of friction) to another ideal medium: the space (void). But, in this transposition, the inertia and the absence of a material medium is not considered as a physical possibility. The notions of the instantaneous velocity and acceleration are mixed. The notion of the proportionality between force and velocity remains only as an "interpretative key".

Trowbridge & Mcdermot (1981) writes:

> "*A significant number of students from a wide variety of courses confused the concepts of velocity and acceleration. Students who succeeded in making the distinction could discriminate between the concepts of instantaneous velocity and change in velocity but often failed to take corresponding time interval into account.*"

During the exhibition of science-fiction films it is very interesting to analyze how common sense ideas are deeply linked in the conceptual frameworks of students and teachers, and, also, the presence of some "equivalences" with the dynamical process of the changing concepts of the history of science.

4 Instructional implications

Other didactical activities using science-fiction are being developed around the world, as we can see by the works of Barnes (1989), Pont & Lupiañez (1994), Dubeck, Moshier & Boss (1994) and Burgwald & Schreiner (1993). These works, however, have as principal aim the development of the physical contents taking the most frequent conceptual errors of the science-fiction films as tool.

Our didactical activities with teachers and students are very different from those authors quoted above. Our interest is based on a constructivistic epistemology, where it is possible to find the origin of the most frequent common sense representations to promote conceptual changes, using the history of science as powerful tool to clarify the spontaneous conceptions of a "non-idealized physics".

In this sense, we are elaborating the next steps of this didactical activity. Until now mechanics is used exclusively in the analysis of the observed "phenomena". To give a new dimension of discussions, we are now working on choosing other films including the following topics: voyages inside the earth, gravity (and weightlessness), and dimensions. These three "new themes" were extensively explored in the history of physics and in the research of physics teaching.

Relative to the voyages inside the earth, Oresme (quoted by Franklin, 1976), considered the question of an object dropped into a hole in the earth:

> "*And this quality (impetus) can be called 'impetuosity'. And it is not weight properly (speaking) because if a passage were pierced from here to the center of the earth or still further, and something heavy were to descend in this passage or hole, when it arrived at the center it would pass on further and ascend by means of this accidental and acquired quality, and them it would descend again, going and coming several times in the way that a weight which hangs from a beam by a long cord (swings back and forth).*"

The notions about the "objects dropped into a hole in the earth" were well studied in educational research, like Nussbaum & Novak (1976), Nussbaum (1979), Mali & Howe (1979) and Dupré, Noce & Vicentini-Missoni (1981). This research pointed out an extreme confusion about the fall of the bodies linked with the notions of the gravitational force and inertia.

About the notions of gravity and weightlessness, Warren (1979) writes:

> "*The idea of weightlessness is further confused by certain errors in early works of science fiction. In a well known story of a journey to the moon (Julius Verne, 1865) the travellers are wrongly supposed to have normal terrestrial experience of weight throughout the flight except when passing through a small region where the gravitational field of the earth and moon cancel each other (the field of the sun is forgotten!).*"

Another conception that frequently appears in educational research about gravity is that related to the "causal notions": "if there is no air, there is no gravity" (RUGERIO *et al.*). Rugerio writes:

> "*[objects far away from the earth] will be taken into special consideration because it indicates a big difference in the experience which could be observed by man in the past compared with contemporary man. Before the*

*day on which television showed the landing of the first astronaut on the moon, but after Galileo's and Newton's time, scientists were able to predict the behavior of objects in space and it was this ability that actually led to the success of the space enterprises. What about non-scientists, however? It is possible that the problems which scientists were discussing in the Middle Ages are still problems for them? That is, is it possible that they may think, along with Roger Bacon, that's question on which there are different opinions among those who study the problems of nature, is the one concerned with the movement of heavy and light bodies in empty space (*PARODI*, 1981)? Or may they ask with Buridan: 'if the empty space exists, can a heavy object move in it?' (*PARODI*, 1981) and conclude with Aristotle (according Buridan) that either of the possibilities may occur: 'the heavy object will move or no heavy object will move' (*PARODI*, 1981). How can one decide which conclusion is more reasonable, since the adjective 'empty' which sometimes describes the space far from the earth where only astronauts go, (and that we can see on television), is the same adjective used to describe the space full of air in our everyday life? Is the empty space out there imagined space or real?*"

On the theme of dimensions, science-fiction films are very rich in giant monsters (as *King Kong* or *The Attack of the Woman of 50th* (PONT & LUPIAÑEZ, 1994)) and of small creatures (as *Land of Giants* or *The Incredible Schrinking Man*). Galileo Galilei, in his book *Dialogo Intorno a Due Nuove Scienze* (GALILEI, 1953) discussed the change of a bone's shape when it grows up three times its normal dimension. His conclusion was that the thickness of this great bone would increase proportionally. The new dimensions of this bone for a man's body, for example, would make him a very heavy creature and, consequently, unable to make any movement. On this fact, Barnes (1989) adds also the weight role of the skin and flesh:

"*One very obvious difference that occurs in scaling people or animals up by a factor of 10 is that it would cause grotesque changes in their appearance because of the weight of the skin and the flesh beneath it. Consider the face of a human. Much of the character of a person's face is caused by the flesh and fat beneath the skin. It varies considerably from person, but it can easily be 1 cm in thickness over an area of several square cm. Its density is about that of water, so, if we assume that on one cheek there is an area of fat and flesh at least 25 cm^2 by 1 cm, that represents a volume of 25 cm^3 and a mass of about 25 g. When scaled up ten times, that cheek has a volume of (...) 15,625 cm^3 or about 0,016 m^3 with a mass of 16 kg. Of course, the same thing is happening all over that scaled-up person's body. Every one knows the lack of rigidity of flesh, and specially of flat, so what does for the physical appearance of a Brobdingnagian doesn't correspond to what our society considers attractive.*"

These films about giant and small creatures are a rich source to investigate the notions of mass and energy conservation, biological behavior and animal's scale, resistance of materials, etc.

5 Conclusion

During years and years, physics is learned in school in a relatively dogmatic form. Students are seen as being owners of little empty brains (*tabula rasa*), which is necessary to fill with pre-defined topic of a scholar curriculum. It is not necessary to say that this kind of teaching produces a great educational damage in the student's life, forbidding him/her to the possibility to construct his/her knowledge.

We could summarize the traditional physics teaching by the following problems:

- it is dogmatic, in the sense that all the things learned about phenomena must be "understood" by *memory* and in a context of "absolute truth";
- it is non-human, in the sense that the scientific dogma are seen as independent of human existence;
- it is mathematics, in the sense that the phenomena are only explained by an intricate mathematical language (there is no possibility of a phenomenological learning);
- it is non-symbolic, in the sense that the mathematical terms, presents in several formulas, are not understood in their real meaning;
- it is ethereal, in the sense that physics is "above the world", without a direct contact with real world.

These five problems on physics education are present in classrooms day-by-day from the early level of science teaching. Children are continuously demotivated to elaborate their own explanation of the sets of phenomena that constitute the real world.

The activities using science-fiction films constitute a great possibility to work with history of physics as we have seen in the previous section, and, mainly, to explore a constructivist view of learning, where it is not necessary the remove the intuitive ideas of students. This is possible because, in this kind of educational action, we recover the ability to communicate and the symbolic reconstruction of physical phenomena, using an informal strategy of teaching.

At the start, when this activity was being developed, we were not interested in "right answers" by students and teachers. A complete understanding of the "right physics" (practically non-existent in the films like *Star Wars*) was not necessary. We were interested in the comprehension of the logical mechanisms present in the common sense ideas and in the possibility of the comparison of these with the concepts developed along the very long history of physics.

Activities using these science-fiction films should be presented as early as possible, in junior high schools as well, so that the scientific domains of physical knowledge could be reinforced step by step in an amusing but rigorous teaching.

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References

BARNES, G. Physics and Size in Biological Systems, *Physics Teacher*, v. 27, n. 4, 1989, p. 234-253.

BURGWALD, J. M. and SCREINER, S. Classroom Analysis of Rotating Vehicles in '2001: A Space Odyssey', *Physics Teacher*, v. 31, n. 10, 1993, p. 406-409.

CLAGETT, M. *The Science of Mechanics in the Middle Ages*. Madison: University of Wisconsin, 1959.

CLEMENT, J. Students' Preconceptions in Introductory Mechanics, *American Journal of Physics*, v. 50, n. 1, 1982, p. 66-71.

COHEN, M. R. and DRABKIN, I. E. *A Source Book in Greek Science*. Cambridge: Harvard University, 1948.

DIJKSTERHUIS, E. J. *The Mechanization of the World Picture*. New York: Oxford University, 1969.

DUBECK, L. M., MOSHIER, S. E. and BOSS, J. E. *Fantastic Voyages: Learning Science Through Science Fiction Films.* New York: American Institute of Physics Press, 1994.

DUPRÉ, F., NOCE, G. and VICENTINI-MISSONI, M. Modelli Fisici Pre-Newtoniani nelle Conoscenze degli Adulti, *La Nuova Scuola*, v. 2, 1981, p. 53-64.

FRANKLIN, A. Principle of Inertia in the Middle Ages, *American Journal of Physics*, v. 4, n. 6, 1976, p. 529-545.

GALILEI, G. *Opere*, Milano: Ricciardi, 1953.

MALI, G. and HOWE, A. Development of Earth and Gravity along Nepali Children, *Science Education*, v. 63, 1979, p. 685-691.

NUSSBAUM, J. and NOVAK, J. An Assessment of Children's Concepts of the Earth Utilizing Structured Interviews, *Science Education*, v. 60, 1976, p. 535-550.

NUSSBAUM, J. Israeli Children's Conceptions of Earth, *Science Education,* v. 63, 1979, p. 83-93.

PARODI, M. Spazio e Tempo nel Medioevo. Torino: Loescher, 1981.

PONT, J. J. and LUPIAÑEZ, M. M. Física i Ciéncia Ficció. Barcelona: Edicions UPC, 1994.

RUGERIO, S., CARTELLIi, A., DUPRÉ, F. and VICENTINI-MISSONI, M. Weight, Gravity and Air Pressure: Mental Representations by Italian Middle School Pupils, *European Journal of Science Education*, v. 7, n. 2, 1985, p. 181-194.

TROWBRIDGE, D. and McDERMOT, L. C. Investigation of Student Understanding of the Concept of Acceleration in One Dimension, *American Journal of Physics*, v. 49, n. 3, 1981, p. 242-253.

WARREN, J. W.: *Understanding Force*. London: Martin Printing Works, 1979.

WHITAKER, R. J. Aristotle is not Dead: Student Understanding of Trajectory Motion, *American Journal of Physics*, v. 51, n. 4, 1983, p. 352-357.