Materials Science and Optics in the Arts: Case Studies to Improve Physics Education

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Abstract

In the teching-learning process physics was often proposed in abstract way, reproducing in all levels and schools the same basic, propaedeutic module. Curricular research is working to offer it as a cultural context for interpreting the world, building the contents and analyzing conceptual knots in many field. In our contribution the investigations of the physical properties of paintings is the suggested approach for exploring optical phenomena in the art. Different pictures are discussed as case studies to learn the role of light and colour, of the surface and substrate in the diffusion, reflection, refraction and absorbtion processes. The last one give the opportunity to look to the new technological paints, which make use of light confinement [FDC1]by ordered nanoscopic-sized structures.

Introduction

Pisa project evidenced the lack of scientific culture in young generation [1]. This is accompanied by a worrying reduction in interest in physics by students already at the secondary school level. A vicious circle is being created, which has a negative effect on the idea which young people and society itself have of physics, in contrast with the cultural value, beauty and real importance of our discipline in the social and productive context [2]. One of the main reasons for this situation is the general lack of a basic scientific knowledge and the little attention devoted until now in planning the teaching/learning process, which is characterised by so many notions, too frequently repeated and not integrated in a progressive cognitive process. We taught physics in the same way in all the schools and at all levels. We gave precedence to results rather than to processes, to ideal models and laws rather than exploration of phenomena and developing formal thinking (developing). Thus physics was experienced as a school subject, talking of things which did not exist (the material point, the perfect gas, …), with difficult laws, which nobody knew when to use: the process of formalization was hardly ever made explicit, approximations and simplifications were declared, but not motivated. We must teach physics in a different way depending on the context where it is proposed, overcoming our lazy and anthropocentric habit of reproducing the same basic, propaedeutic module.

This implies a review of the contents and the methods in school activities realizing a strict correlation among the multiple dimensions of knowledge [3]. Physics must be integrated in the cultural world around us to stimulate curiosity and to be recognized as cultural knowledge able to interpret the emotions produced at sensorial level.

Though from morning till night our eyes incessantly send us images and information: we concentrate our attention on the message being conveyed, hardly ever do we stop to consider the physical origin of such images and information. We are enchanted by colours of spring, we marvel at the beauty of a butterfly's wings, we are carried away by the sight of a picture, but we ignore that all of that is the result of the interaction between the electromagnetic waves in the visible (which from now on we will call "light"), the material of the bodies' surface, and its structure. Such an attitude originates interpretations connected to perception aspects which tend to become rooted in our minds, such as colour being property of an object, light being a neutral entity which gives luminosity to things, the properties of the microscopic structure of matter being a small-scale reduction of those of the macroscopic structure.

Literature makes it clear that new teaching strategies are needed to produce the conceptual change from common sense to a scientific outlook on phenomena [4,5]. The missed connection between everyday experience and schoolwork in the scientific field has been identifed as the main cause of difficulties in learning [6,7]. The personal involvement is an important components for the construction of knowledge as an individual interpretation of the world [8]

Art is maybe the most suitable context to tackle this subject, as artists authors know well - at least from a practical point of view - that the final result of their work is given by the interaction of light with their paintings. Thus, they are very skilful at using the most varied materials in the most varied ways in order to give their paintings certain characteristics, and to convey sensations. In such a context, however, it is extremely difficult to speak in a scientific and rigorous way, as we are used to deal with art using proper terminology, language, and logic.

The colour of any object which must be illuminated in order to be seen is produced by a such a scientific approach to reality is hardly ever noticeable in the common way of looking at things.

This contribution to the curricular research proposes an approach based on the observation of paintings to approach the physics into the colour effects, completely absent in the general physics books:

complex whole of phenomena connected to the interaction between matter and electromagnetic waves.

The approach and the conceptual knots

The observation of a painting depends on three factors: the observer, light, and the nature of the painting itself.

As regards the first factor, we will not deal with the subject from the point of view of the observer's perception, as this would entail a detailed treatment of the physiological structure of the eye and of image formation and interpretation.

As regards light, paintings appear in a completely new perspective if they are illuminated by a light having a different spectrum than the natural solar one. For example, it is of common knowledge that the colour shades, intensity and contrasts of a painting will look completely distorted if we illuminate it monochromatic, say red, light. Different interaction are produced for example by infrared light and X-rays with pigments and chemical elements used in the picture, selecting what is possible to see. Goya's Dona Isabel de Porcel by infrared light it would appear as black and white painture and we can see an eye near the woman's[FDC3] chin, belonging to a previous portrait painted underneath, because the eye was painted with pigments which interact with infrared radiations. The triumph of Henry IV by Deruet reveals by X-rays the portrait of a woman in a formal dress hidden underneath Henry IV's chariot.

Students can realize how the same painting may look different depending on the wavelength of the incident ray and on the kind of detector used. This helps them to overcome the misconception of light as a neutral entity.

The third factor - the nature of the painting - is worth a more complex treatment.

As far as natural visible light is concerned, the physical phenomena underlying interaction with matter are reflection, refraction, and absorption, and it is the interplay among these three phenomena which originates the sensations of colour, light and shade that we feel when we look at a painting.

The Panza modern art collection "Monochromatic Light" are particularly suitable for our aims. They are monochromatic paintings exhibited in seven rooms of the Sassuolo "Ducal Palace"[FDC4] (Modena, Italy).

The five paintings by the artist Phil Sims represent five colours: red, green, yellow, blue, and purple. The paintings are homogeneous, uniform, still. If one observes them from different points of view and by different lighting conditions, their appearance does not change.

On the contrary, the ten blue paintings by Anne Appleby are luminous and lively: it seems as if the author has copied the sky in a clear, cloudless day.The difference between the two examples is that the first ones are oil-painted on a linen substrate which gives surface roughness to the picture, so that light is diffused, and therefore its intensity, reflected in every direction, is nearly uniform and unchanged. The paintings of the second group, on the contrary, are painted in oils and polished wax on canvas. In this case, light is reflected very effectively, and this gives animation to the painting and causes a higher percentage of light to reach the observer.

The luminosity of an object depends on how much light it conveys to the point of observation: if light is not reflected by the surface of an object, the object itself cannot be seen. This problem was well-known to Jan van Eyck, who is considered to be a great developer of oil-painting. The brightness and liveliness of its Annunciation painting is particular. . The artist made good use of the optical properties of enamels and used to apply several coloured transparent layers on a white background so that light could penetrate into them, strike the background and be reflected towards the observer.

Light is reflected and transmitted by the painting surface and by the substrate: the binders in which the colour pigments are suspended act as light propagation media in order to facilitate interaction with the pigment particles. For example, oil colours can be very intense owing to the binder which is left after exsiccation.

In the Rubens's Holy Women at the Sepulchre light appear to come from the sepulchre in a dark background. This effect was obtained deposing on the painting a translucent layer with an intermediate refractive index between the refractive index of air and of paint, thus leading more light to penetrate into the painting and enhancing the intensity of the colours. The same result can be obtained by covering a casein paint with a transparent varnish layer. The maximum efficiency in transmitting light into the paint layer occurs when the varnish refractive index is equal to the square-root of the refractive index of the paint.

The last factor can be highlighted by observing the effects of illumination by white, red, and blue light. White light and red light illuminate the red Phil Sims's picture, or on any pure red saturated surface, unlike blue light which seems to make it even darker. In the first two cases light is reflected, whereas in the third case it is absorbed by the coloured surface. What appears of an illuminated surface is light which is not absorbed, and that is the origin of colour. An interesting hint is given by David Simpson's works in the Panza collection. They are four monochromatic paintings of a pinkish colour. The artist created colours which had never been seen before, through the interplay created by absorption of light by metal nanoparticles suspended in a binder. These are the new technological paints, which make use of the light confinement [FDC5]by ordered nanoscopic-sized structures.

The same phenomenon was exploited in the Renaissance period to produce the golden and red colours of the Gubbio and Deruda (Italy) lusters. These last aspects may contribute to open a discussion on

what colour is and which properties of matter cause its determination.

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