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REFLECTIONS ON REFLECTIONS –
FROM OPTICAL EVERYDAY LIFE PHENOMENA TO PHYSICAL AWARENESS

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Introduction

Physical education contributes in a special way to general education of young people. Therefore, physics lessons may not be restricted to pure physical topics but have to be combined with everyday life phenomena and problems. However, this is not as simple as it may appear at first sight, for the everyday life world does not contain the physical aspects for direct reading. As the pupils and students are not trained to look at the world from a physical point of view, they will not see what they should see, although their retinas might be exposed by physically interesting phenomena.
We will demonstrate and further explain this problem by discussing appropriate photographs and paintings. Some preliminary investigations show that teaching and learning physics within the context of everyday life phenomena may be very stimulating and successful.

On the situation of physics teaching

One important goal of teaching physics in schools of general education is that physics should help students to understand and cope with their everyday life. This implies that physical topics have to be related to questions and phenomena, which at first sight are not physical at all. But this is not as simple as it may appear. At least the following issues may be addressed (for a more thoroughly discussion, see: [1]):

1. The everyday life world is familiar and taken for granted.

As a consequence in their everyday life students are not confronted with open questions or problems which would invite them to have a closer look or even to make investigations. Therefore, a physical approach requires taking the most obvious into question, which means that the familiar has to be experienced as something unfamiliar.
As an illustration of this problem let's have a look at something common like the light spots under a tree while the sun is shining (Fig. 1) [2]. Normally the students do not find any striking at this mélange of light and shadow although they assume that the randomly formed openings between the leaves are the origin of the "sun talers". And even if you ask more specifically why the light spots are rounded, most of the answers are of the kind: How do you expect it should be? Even if you tell them, that the light spots are images of the sun the students sometimes think you were making fun.

Fig. 1: Normal images of the sun under the leaf roof of trees

Fig. 2: Images of the sun during an eclipse

But if one shows them a picture of the same situation during an eclipse of the sun (Fig. 2), where the light spots are crescent- shaped, the situation will change immediately: Even if, at first sight, the students would attribute the crescent form of the light spots to the moon (which could in principle

be true), the shift of perspective from the shape of the openings in the leaf roof of the trees to the shape of the light source is sufficient to finally identify the light spots as pictures of the sun.
Here the familiar sight is experienced in a seldom and therefore unfamiliar situation which attracts attention and leads to the want to understand what up to now was out of question, because “the strange challenges us and we demand the most simple of it” [3].

2. From the physical point of view the problems are complex.

At first sight, everyday life phenomena are simple in the sense that they do not suggest any question at all. One simply got accustomed to them as e.g. to a wallpaper of a familiar room. But if the students start to look at the phenomena with having physical questions in mind the phenomena suddenly become rather complex: On the one hand physical aspects have to be recognized within a nonphysical situation as such and on the other hand, there might be more than just one physical problem to be met. This turns out to be a rather demanding task and cannot be overcome without exercise and training. Normally students learn basic physical laws within an extremely simple, ideal and artificially designed context. Therefore, starting with everyday life phenomena requires another approach. One should start with the complex phenomena, then identify the physical problems, and finally work out the basic principles.
On this background, in the following it shall be shown by means of some optical phenomena how the “physical view” for everyday life phenomena can be sharpened and how the familiar can be turned into fascinating physical questions and investigations. Moreover, we expect that everyday occurrences may be revalued and experienced in a more intense way.

Reflections on Reflection

Concentrating on what we see when we look at something, and how we see it, we draw our attention to reflections which play an important role in the process of seeing and understanding, and enter into reflections on reflections.

Fig. 3: Normally, visual cliffs on glossy floors are ignored

Fig. 4: The „visual cliff“ by Gibbson and Walk

By reflection we mean the turning back of light rays encountering a surface. In general, not all the incident light is reflected. Part of it may be absorbed or – in the case of transparent media – transmitted. The reflected light determines the appearance of the surface (color, shape).
There are two different types of reflections. A totally matt surface reflects light in all directions, so that there is no memory of the light source(s) in this diffusely reflected or scattered light. A totally smooth surface, a mirror, reflects light in an ordered way according to the law of reflection. In this case, the incoming light is just returned without changing its properties so that things only seem to be at another place. Therefore, ideal mirrors are invisible.

Real surfaces show a mixture of both kinds of reflection. According to the extent to which light is reflected in a diffuse or a specular way, and according to the colors of the light sources and its sizes the surface appears matt, dull, flaring, gleamy, lustrous, glittering, glossy, shiny etc. Normally, we are accustomed to the different ways light is reflected without paying attention to it. But sometimes one may get irritated by unfamiliar aspects of well known things.

Fig. 5: Looking from inside the cupola of the dome of Florence down to the floor, it suddenly seems to evolve into a third dimension.

When flat floors develop a third dimension

One day at an airport building, an elderly lady asked me to help her to cross the "cliffs" which she believed to see where other people saw a glossy floor. Looking at the polished tiles I suddenly became aware of what she meant: The reflections of rather unusual ceilings with different levels could be interpreted as stairs or depressions (Fig. 3).

After that incidence I encountered many similar situations where the gloss of smooth objects turned over in a totally new appearance. Sometimes the quality of the specular reflection is so perfect that only the non visual context helps us to distinguish reality from virtuality. This event may remind one of the experiments of Eleonor Gibbson and Richard Walk [4], in which a cat was made insecure by an optical cliff (Fig. 4).

That images can dupe men and animals is known since Xeuxis, who painted grapes so realistically that pigeons tried to pick them from the canvas. And the renaissance painters utilized linear perspective to create impressive virtual rooms (Fig. 5).

Fig. 6: Painting of the Delft School (1660-5). Look at all the different reflections.
(http://www.nationalgallery.org.uk/cgi-bin/WebObjects.dll/CollectionPublisher.woa/wa/largeImage?workNumber=NG2552&collectionPublisherSection=work

Glossy floors are not only typical for our time. The painting of the Delft School (Fig. 6) is an example where the painter presents many different reflecting surfaces. The silk dress shows a widely distributed sheen of white daylight coming through the window at the left. By this reflection the color of the dress is bleached but at the same time its crinkles are enhanced.

The dress itself is mirrored upside down in the polished black tiles, of which the original color can only be inferred from the context, because it is totally covered by a mirror image of the red dress. But only the black tiles show specular reflections, the color of the white tiles does not seem to be affected at all. Are they not smooth enough? A closer look especially on one white tiles lying in the shadow of a piece of furniture gives the clue to the answer: The diffuse reflection of white tiles totally outshines the specular reflection. Only if the diffuse reflection is eliminated by screening the daylight of the window the specular reflection is strong enough to provide a visible mirror image of the dress. Concerning the smoothness there is no difference between black and white tiles.

Fig. 7: Reflections of reflections. Detail from figure 6.

That black tiles are better mirrors becomes also apparent by the reflected highlights of the globular fire-iron, which can only be seen on black tiles (Fig. 7). This is a kind of reflection of the second order because the highlights themselves are specular reflections of the bright windows in the spherical parts of the fire-iron. Although the fire-iron is not a perfect mirror the specular reflection of the anamorphically deformed pattern of the floor can be recognized at least dimly in its spherical parts. This proves once more that there are really spheres and not just disks.

Finally, let's mention the reflections of the burnished leather tapestry on the back wall. Some vaulted parts of it are oriented such that the light of the window is specularly reflected into the eye of the observer (painter). At these places the color of the leather looks nearly white.

Anamorphic mirrors in the everyday life world

But one must not necessarily visit an art gallery to know the true promise of aesthetically appealing reflections. Our everyday life world provides many phenomena to be detected. A look at a window display of a household supply store may show many different reflections, of which some examples shall be mentioned here (see Fig. 8).

Fig. 8: window display of a household supply store with many specular reflections

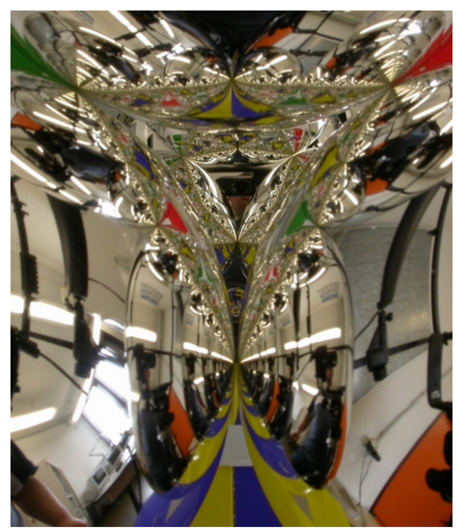

Fig. 9: Wada basins: reflections of reflections of … at the place where four Christmas tree baubles are facing each other

The two metallised vases are almost spherical mirror mapping nearly all the surroundings. The oval, which in reality has a bluish appearance, represents the anamorphic deformed shop window, in which the street with the photographer and part of the blue sky are to be seen. Moreover, it shows that at the upper brim of the reflected interior there are some spotlights which come from halogen lamps illuminating the window display. They give also rise to light streaks on the metal stripes in

the foreground showing that the metal has tiny horizontal scratches coming from the production process [2]. Some of the light streaks are bluish, which apparently are caused by reflections of the blue skylight. Close inspection shows anamorphically deformed reflections of the ambient objects. Especially the feet of the vases being curved alternately in a concave and convex way show the ambient things alternately upside down and right side up.
The vases also reflect each other mutually, which – at a closer look – shows mirror images of mirror images and so forth to infinity producing a fractal structure (Wada basins [5]). This can be verified easily by putting four metallised Christmas tree balls together to form a tetrahedron. Figure 9 shows the parts where the balls are facing each other.

Deformed mirrors – coachwork of cars

Another example of an anamorphically deformed mirror in the everyday life world is worth being mentioned here: the coachwork of cars (Figs. 10 – 12). A closer look shows that the glossiness is nothing but mirror images of bright ambient objects. Again one has to switch one's view from a polished glossy surface to a deformed mirror. But this change of view is worthwhile because the observer is not only rewarded by aesthetically appealing phenomena but also by an insight into interesting physical aspects of non-physical objects.

Fig. 10: The color of the car is hidden under a specular reflection.

In some cases the quality of this fancy mirror is so good that, showing somebody only an appropriate section, it is difficult to recognize the original color of the car which in the case of Figure 10 seems to be blue. Nothing tells us that in reality it is black. The blue color is due to the specular reflection of the blue sky.
Once more it becomes apparent that shiny black surfaces are very good mirrors because in this case the diffuse reflection is minimal. The brighter the coachwork the more the specular reflections look washed-out.
Most of the coachwork produces anamorphic mirror images of the convex type. But sometimes one can detect mirror images which are upside down (Fig. 11).

Fig. 11: Coachwork as a concave mirror.

In the class this curious effect can help to give reasons for a discussion of spherical concave and convex mirrors as two principally different ideals of specularly reflecting surfaces. Those ideals can help to bring order to the different kinds of deformed reflecting surfaces met in everyday life. They permit to elaborate the essential principles of reflection without the need to discuss the many variants to be found in reality.
Whoever has watched children and young persons in science centers enjoying their own mirror image deformed both in a funny and interesting manner by a distorting mirror may perhaps wonder why they almost never meet somebody posing in front of a polished car. The reason is that they didn't adopt the special view to look at a car as a funny mirror. This special view could help to combine physics with everyday life experience thus grounding physics in a vast non physical area. For several reasons this is of great value for learning physics because at the one hand physical topics are detached from the spatial and temporal limita-

tions of physic lessons. On the other hand, physics learned within an affective positive atmosphere may contribute enormously to the learning success of the students.

Fig. 12: The deformation of the reflected traffic sign tells about the deformation of the car.

The deformations of specularly reflected objects are not only funny but may help to recognize the form of an object which for some reasons cannot be seen directly. The distorted reflection of a simple object like e.g. a straight traffic sign provides direct information about the form of the coachwork.
Of course, in the case of glossy cars this is not of much practical use (Fig. 12). But this example may be used to illustrate how physicists get information of an unknown structure by looking at the change the light or other radiation undergoes when being reflected. Physicists analyze reflections to deduce the structure of the reflecting object.

Fig. 13: Mirror image “under” the pavement.

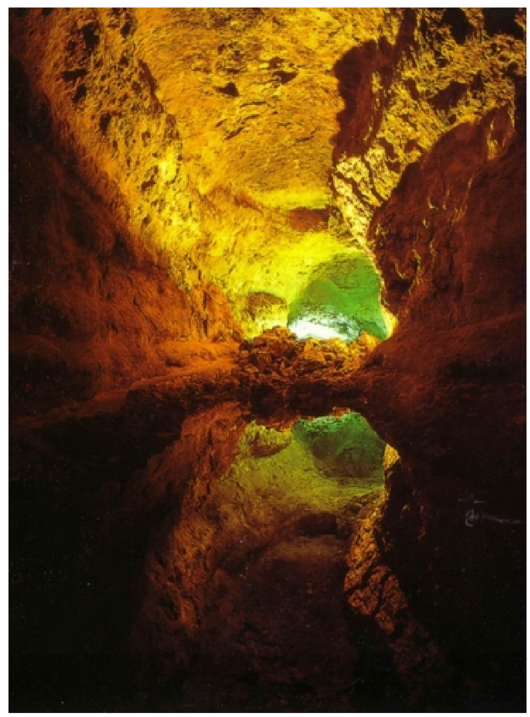

Fig. 14: A deep virtual abyss in a Grotto.

Changing Deformations

Reflections are not only caused by solid surfaces, liquid surfaces, especially water surfaces, may provide impressive reflection phenomena which in most cases are as well overlooked.
If a flat water surface has developed (e.g. after a rainfall) or objects are covered by a thin film of water especially bright objects may bring out a mirror world behind, respectively below, the mirroring surface (Fig. 13). Due to the flat surface reflections in a puddle provide an undistorted view. Though, according to the angle of incidence, the water only reflects a more or less small portion of the light, the mirror images often look rather distinct and clear because the light entering into the

water is absorbed to a great extent, so that there is only little diffuse reflected light disturbing the specular reflections.
In similar cases, e.g. if cobble-stones are covered by a thin film of water we get distorted mirror images, where in extreme cases only the color refers to the reflected objects. The shine and intensity of watery stones are also due to reflections. But this shall only be mentioned here [7].

Fig. 15: A water surface – a permanently changing mirror.

Fig. 16: Transparent wine glasses visible by reflections.

In spite of the – sometimes perfect – quality of the mirror images produced by water puddles it is almost always obvious, that it is about an image and not a real object. In rare cases, if the reflections are observed in non familiar situations, the appreciation may be different. For instance, visitors of a grotto (as shown in figure 14) believed to stand directly in front of a steep cliff, though they looked only at thin layer of water reflecting the vault. This optical illusion is favored by the fact that both the upper and the lower parts of the grotto looked so similar that only a careful comparison could unmask the reflection.
Not only flat water surfaces may transform to mirrors, slightly wavy water may produce deformed reflections of the ambiance reminding of a dynamically variation of glossy coachwork, kaleidoscopically changing without rest (Fig. 15). Due to the motion of the water the deformed mirror images are no longer seen beneath the water surface as in the case of a flat surface. Instead the colorless water[1] seems to take on the colors of the surroundings thus loosing its transparency.
This observation may lead to the discovery that transparent media like water and glass get visible essentially by reflections of the bright ambiance. Examples are wine glasses which can only be seen because the reflections reduce the transparency (Fig. 16). If the reflections are not strong enough pronounced transparent objects may be ignored: Many a person ran into a glass door because the reflections were too faint or it was not noticed. This shows that illusions – mirror images can be regarded as illusions – may help to better recognize reality.
On the other hand it can be very dangerous if illusions are taken for reality. Many a bird became a victim of a window pane because either the reflections were too weak, so that they were overlooked, or too perfect, so that they suggested a real world behind the pane.

Window panes – transparent mirrors

When looking at the display behind a shop window pane on a bright day the view may be disturbed by specular reflections of the ambient objects in the window pane itself.
Window panes are waterproof, airtight and impermeable for thermal radiation but are nearly totally transparent for daylight. "Nearly" means that it is absorbed to a negligible extent and reflected by

[1] Bigger volumes of water show its proper faint blue color.

only 4% at each boundary of the pane. This would not be worth to be mentioned if this small effect of reflection was not of great importance in many situations.

On a sunny day when everything is reflecting the sunlight, a window pane may become a nearly perfect mirror of the surrounding things. How does this observation go with the small fraction of reflection?

Fig. 17: The mountain landscape is reflected perfectly. Only in the shadow of the photographer there is a hole in the mirror and one may recognize the floor of the room behind.

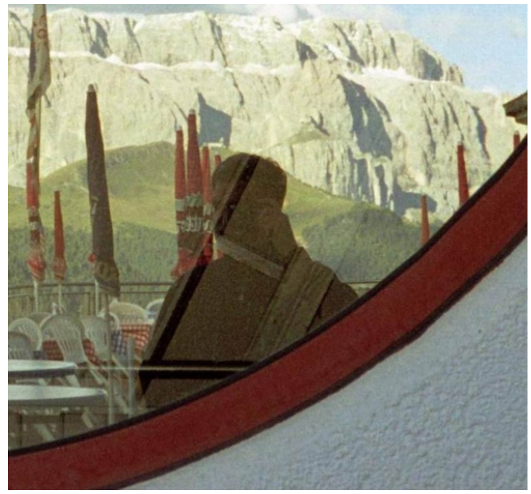

Fig. 18: Detail from figure 16. The shadow of the photographer tears a hole into the specular reflection of the pane.

In order to be able to see objects behind a window pane they must radiate visible light to the eyes of the observer. This requires that the objects inside the room receive daylight traveling through the glass and reflect it again towards the window. But as the light received by the objects is partly absorbed and partly reflected in all directions only a more or less small amount is leaving the room through the window. This amount is the smaller the darker the objects are, i.e. the more they absorb. If the fraction of light leaving the room by the window is small compared to the specularly reflected light the disturbance is not very important and the pane behaves like a mirror (Fig. 17). In such a case an open window would look like a black hole because only the light from inside scattered in the direction of the window is seen (Fig. 19).

Fig. 19: On a bright day the interior of a room seen through an open window looks dark.

Curtains of a bright color can disturb the specular reflections because they are situated directly behind the window so that a significant amount of light is reradiated back through the window thus superposing the specularly reflected light. As a consequence the mirror images are bleached accordingly.

Dark objects (e.g. those lying in the shadow or casting a shadow themselves on the window) may tear holes into the mirror image and permit a look through this hole into the room behind the window (Fig. 18). In this case the intensity of the light falling on the pane from outside can be so small that the light coming from inside will be dominant. Therefore, in order to look through the reflections of a window one can intensify the own shadow by approaching the pane and putting the hands at both sides of the eyes, thus screening the light arriving from the sides.

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Somebody who is looking from inside a room through the window at the bright world outside will have a good view. He profits from the light emitted by the bright objects and will not be disturbed by reflections at the inner surface of the pane, because as we just mentioned only little light is reflected to the window from inside the room. Moreover in this case, the light reflected specularly at the outer surface and providing excellent mirror images for the observer looking from outside, is of no importance for a person looking from inside.

Fig. 20: Windows reflect windows which reflect windows.

Fig. 21: View into a shop window. Only the context tells us what is inside and what is outside.

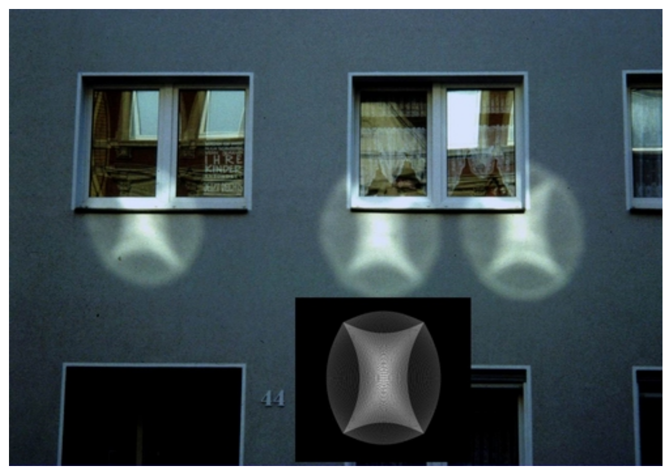

Fig. 22: Light spots of sunlight focused by deformed double glazed window on the wall of the facing house. The lower figure in the black square is a result of a calculation of the observed reflection [8].

At darkness, when the homes are illuminated by artificial light the relations reverse: Now the specular reflections at the inside of the pane become so strong that they outshine the poor light entering from the dark outside. Conversely, passer-bys in the dark streets can observe the events inside the bright homes as if they happened on stage – unless the curtains or Venetian blinds are drawn.

Church windows display their colorful splendor only inside the church. From outside they look rather unspectacular. In most cases a layer of dust only permits diffuse reflection.

Mirror images in window panes can themselves be object of specular reflection in other panes. In those cases one is looking in a window seeing reflections of reflections etc. giving rise to images which more easily remind of modern art than of familiar sights (Fig. 20).

If the intensity of light specularly reflected from a window pane is of the same order of magnitude as the light coming from objects inside the room, there may result a funny superposition of outside and inside views. Sometimes only the context can help to decide what is where (Fig. 21).

Double glazed windows

Nowadays, simple glass panes are more and more replaced by double glazed panes, which from the viewpoint of heating a house is of course advantageous. Aesthetically regarded the mirror images suffer a loss of quality because the two different reflections do not coincide very well. On the other hand this disadvantage is compensated at least by some new physical phenomena.

Fig. 23: The deformation of the double-glazed window can be deduced from the deformations of the specular reflections of facing windows.

The double glazed panes are manufactured by gluing two panes together so that there is an airtight space between them enclosing a fixed portion of gas or just air, determined by the conditions (temperature, pressure) which prevailed at the day of fabrication. Now, if the state of the atmosphere is changing the temperature and pressure inside may change accordingly and thus deform the elastic glass walls. If the pressure of the atmosphere is decreasing or increasing the panes are arching to the inside or outside thus changing the optical properties accordingly. As far as specular reflections are concerned one of the panes becomes a concave and the other a convex mirror.

One very obvious but normally overlooked effect of this deformation of the panes is that the concave "mirror" may focus direct sunlight to a bright light spot on the wall of the opposite building (Fig. 22). The reflections have been calculated by means of a simple thermodynamic- optical model. The result of such a calculation is enclosed in the black square in figure 22.

Moreover, the specular reflections of bright ambient objects by double glazed panes show characteristic doublings and distortions, which are not only interesting from a physical point of view but also aesthetically appealing.

In figure 23 a double glazed window reflects windows of the opposite house. One easily can recognize that the windows are reflected in each of both panes. The different sizes of the mirror images indicate that one of the panes (which of them?) gives rise to a smaller and the other to a greater image. The latter behaves like a huge cosmetic mirror producing an enlarged picture of the object lying within the focal length. Therefore, the focal length must at least be as long as the distance between the two facing windows reflecting each other. This conclusion is in good agreement with the observation that the sunlight very often is focused on the wall of the opposite building [8].

Moreover, the oppositely curved frames of the reflected windows are a direct indication for the curvature radii of the panes being oriented opposite to each other and being smaller at the edges than in the middle of the windows. The deformation of the double glazed pane which may be deduced from this observation is in accordance with the results gained by the evaluation of the focused sun light [8].

The straight parts of the windows reflected as represented in figure 23 show in a rather direct way the curvature of the reflecting window. If a whole lattice of windows is reflected by a lattice of the same kind the result is a pattern of horizontally and vertically straight lines bent by the numerous deformed window panes (Fig. 24 and 25). The reflected checked pattern individually bent by each window in a slightly different way and embedded in a large repetitive structure gives rise to a qualitatively new view and reminds of an installation of modern art.

The impressive effect of the deformed reflections is mainly due to the contrast between the bright sunlight and the dark lattice-shaped façades of the opposing buildings. The striking similarity of groups of adjacent reflection patterns has a physical reason. It indicates that these windows were produced at the same place under the same conditions.

Fig . 24: Array of equally looking windows at a sky scraper in New York

Fig. 25: Detail of figure 24 showing a pattern of similar but individually deformed reflections of the facing window array.

Summary

Normally, the everyday life world is accepted without question. Like a familiar tapestry, from which we probably could not describe the pattern in detail we experience our ambiance for the most part in a more or less implicit way: Although our retinas are impressed by objects we look at. But as long as nobody is standing behind them to interpret what is seen, there will be no contribution to insight or cognition.

Looking at the world from an unfamiliar – in the present case physical – perspective the well known can become a new reality. We tried to demonstrate such a change of perspective by selected examples and to illustrate them by appropriate photographs.

In particular we wanted to show that though mirror images of the ambiance cover parts of the reflecting object, thus destroying information, the visual perception is improved (perception of shape, gloss of transparent objects etc.). For if specular reflections are seen as gloss they are not seen as mirror images even if they are visually dominating. Normally, one does not become aware of the fact that gloss is nothing more than more or less distinct specular reflections of the surroundings.

In order to arrive at the physical perspective, by which e.g. a glossy object is regarded as a mirror, training is needed. One has to learn to adopt the “physical view” – in the present case for optical phenomena – and may be greatly recompensed by experiencing unexpected and even exciting aspects of every day life.

This is not necessarily restricted to just physical experiences. The physically intensified view may give access to an aesthetical, perhaps even artistic dimension of the daily occurrences.

In this manner there may be established connections between school physics and every day life in an affectively positive atmosphere. This is of great importance from an educational point of view because the restriction of physics to subjects and phenomena which only occur within physics courses and which do not provide any possibility to be encountered in the daily world are committed to oblivion.

To come to a conclusion one might say: The examples of optical reflection within the everyday life world demonstrate that physics shows us not only what we don't know but also what we know how we don't know it.

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