International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

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**To cite this article:** Philippe Colin , Franc¸oise Chauvet & Laurence Viennot (2002) Reading images in optics: Students' difficulties and teachers' views, International Journal of Science Education, 24:3, 313-332, DOI: 10.1080/09500690110078923

**To link to this article:** http://dx.doi.org/10.1080/09500690110078923

Published online: 26 Nov 2010.

INT. J. SCI. EDUC., 2002, VOL. 24, NO. 3, 313–332



# Reading images in optics: students' difficulties and teachers' views

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This paper focuses on difficulties students have in reading images, regarding the understanding of a particular domain, e.g. optics and colour. We concentrated upon what extent teachers were conscious of such difficulties and what they suggested doing to avoid possible pitfalls in this respect. A list of expected obstacles, set up to initiate the study, was shown to be appropriate. It shows that, when they predicted or observed a misunderstanding, the consulted teachers tended to add some elements to a misleading image rather than discussing the symbols that were used, their more or less realistic status and their possible ambiguity. Implications for teacher training and the design of innovative sequences are briefly discussed.

## Introduction

'We adopt a *transformative* view of the nature of communication and change. Communications are not simply ''received'' but are re-made, re-constituted, transformed by the receiver. Communication has to be seen as action; as minds acting on other minds which then act in response. Those acts of response are necessarily transformative, making new meanings relate to previous ones' (STTIS 1998). This viewpoint orientated the STTIS[1] research, which was devoted to the multiple factors that are likely to be significant when a teacher implements an innovative tool or strategy. Communication and transformation are involved at two levels: teachers or authors trying to lead learners towards new knowledge, on the one hand; and innovation designers trying to make teachers understand, appropriate and implement precise didactic intentions, on the other.

Among the multiple factors, images are a critical vehicle for (transformative) information transmission. To what extent and how do images fail to convey a given message? Do they raise unexpected difficulties? Do they reinforce learners' previous ideas? To what extent and how do the teachers consider these questions?

It seems essential, if innovative sequences are to be implemented in an effective and appropriate way, that teachers be aware of the aspects that are critical in the use of images, so that they may act suitably in this respect.

We chose to document these points in the specific domain of optics, including colour. After an investigation of students' difficulties, our research study focused on teachers' viewpoints and actions concerning five documents with images. The selection of these documents was done on the basis of a list of possible obstacles in reading images.

*International Journal of Science Education* ISSN 0950–0693 print/ISSN 1464–5289 online © 2002 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/09500690110078923

## Possible obstacles in communication through pictures

Drawing on previous research and on specific literature (Kress and van Leeuwen 1996), the STTIS group (1998) adopted a provisional grid of features which might raise obstacles in reading images and graphical representations. Drawing on this list, which was slightly modified afterwards (see introduction to this set of papers), we selected the following items.

- *Real-world objects versus schematic or symbolic entities* (*R/S*): When designing images, authors sometimes aim to present entities as real-world objects, and sometimes as schematized structures. For a given image, the student may misinterpret what is 'real' and what is symbolized.
- *Selection and salience* (*SEL*): Authors may regard it as impossible or unnecessary to represent certain aspects in an image. This selection may give rise to some misunderstanding. Similar difficulties may result from specific highlighting of certain aspects at the expense of others.
- *Similarity of symbols* (*SIM*): A given symbolic element may be used with a variety of meanings in one diagram. This is often the case for arrows. Thus, the reader is left with the responsibility of sorting out the different meanings to be ascribed to the specific occurrence of this symbolic element.
- *Reading compositional structures* (*CS*): A reader may attribute an inappropriate status to an element of an image because of its place on the page. Indeed, in Western culture, it is generally observed that left/right contrast corresponds to 'given/new' and up/down contrast corresponds to ideal or generalized versus real or particular (Kress and van Leeuwen 1996). This aspect of spatial arrangement may give rise to some misunderstanding.

Moreover, any image gets its meaning from being embedded within a tacit set of ideas. These may include conceptions or ways of reasoning that students have previously formed, some of which may be false but robust. Such a tacit model tells the student what to pay attention to in the image, and how to understand it. There may be a resonance between some of the preceding potential obstacles (R/S, SEL, SIM, CS) on the one hand, and some common trends in conceptualizing the topics at stake, on the other. In this case, previous ideas have a maximized chance of determining the reading of the image, and even of being reinforced.

## Images used in this investigation

In order to investigate students' difficulties in interpreting images, and then the difficulties teachers find in understanding students' difficulties and in using these images, we selected five documents found in textbooks that include images. Images cannot be considered separately but as part of what is supposed to be the conveyed message. The textual elements that accompany the pictorial and graphical ones provide access to the author's intentions, even if they do not sum up all these intentions. We will of course assume that none of these intentions is to foster misinterpretation or reinforcement of false ideas.

We selected these documents keeping in mind two sources:

(1) The types of difficulties expected (as listed above) are considered, paying special attention to the fact that learners may have specific 'glasses' according to their own conceptions and ways of reasoning. Optics and

colour, indeed are domains that have been extensively investigated as far as learners' common ideas are concerned (Andersson and Kärrqvist 1983; Guesne 1984; Fawaz and Viennot 1986; Goldberg and McDermott 1987; Olivieri *et al*. 1988; Kaminski 1989; Chauvet 1994, 1996a,b; Galili 1996). Strong resonance effects are to be expected between such ideas and the reading of some of the selected images.

(2) An estimation that such images are, at the worst, similar to those commonly found in teaching environments; in other words, they are not particularly misleading. We estimated this feature on the basis of previous studies (Chauvet 1994; Colin 1999, 2001; Hirn and Viennot 1999, 2000; Colin and Viennot 2000, 2001).



## Students' difficulties and teachers' views

### *Data collection and samples*

We present successively: (a) the five images used for this study and the corresponding difficulties, which are mainly estimated on the basis of previous research and checked by means of an investigation with a questionnaire (questionnaire S, see Appendix) at the end of secondary school; (b) an investigation with a questionnaire (questionnaire Ta, see Appendix), aimed at documenting the type of difficulty teachers expect will come up when pupils read these same five images; and (c) an investigation with a questionnaire (Questionnaire Tb, see Appendix) concerning other teachers, to see how they react when, for each of the five images, they are presented with some of the pupils' comments where typical reading difficulties appear. The corresponding samples are indicated in table 1.

**Table 1. Samples for the three questionnaires used in this investigation.**

| | *Pupils: upper secondary school* | | |
|---|---|---|---|
| | *Previously taught optics* | *Not previously taught optics* | *Teachers* |
| Questionnaire S* | | | |
| Doc: Diff | 17 (grade 10) | 15 (grade 12) | |
| Lens | 15 (grade 12) | 17 (grade 12) | |
| Young | 15 (grade 12) | 17 (grade 12) | |
| Jup | 17 (grade 10) | 17 (grade 12) | |
| Questionnaire Ta | | | |
| Doc: Diff, Lens, Young, Jup | | | 19 |
| Doc: Col | | | 14 |
| Questionnaire Tb | | | |
| Doc: Diff, Lens, Young, Jup | | | 19 |
| Doc: Col | | | 23 |

Note: * This investigation only aims at checking that some of the obstacles that previous research results led us to expect are present in the selected documents. Concerning colour, we only rely on previous results obtained with document 'Col' (see text).

*Selected documents and corresponding learners' difficulties*

In this section, we present the five documents on which we have based our investigation. For each of these, we specify which image-misinterpretation risks we have considered. We then provide some evidence of the extent to which such expectations are confirmed, by giving the results of a questionnaire put to students at the end of secondary school (questionnaire S, see Appendix, first 4 documents), and/or by previous research results (all documents).

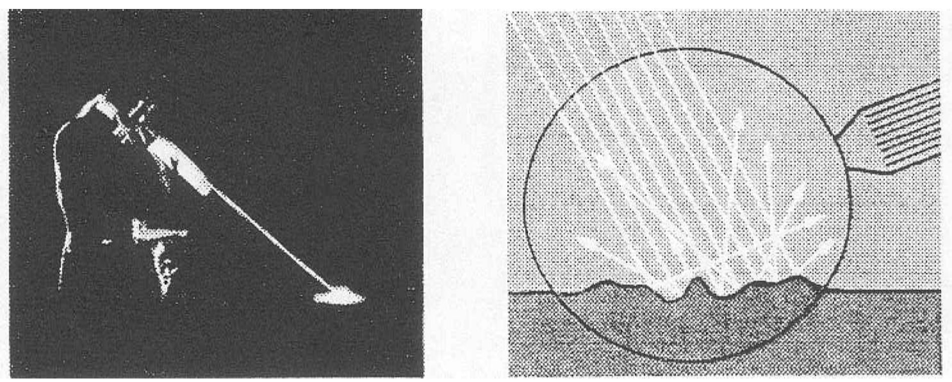
*(a) Document 'Diff'.* Document 'Diff' (figures 1a, b) concerns diffuse reflection. We think the risk here is that of reinforcing the idea that optical rays are not elements of a model but ordinary objects, visible from anywhere R/S), all the more so because of the metaphoric representation of a magnifying glass (figure 1b).

The idea that light is visible from anywhere as an ordinary object is very common. It very often appears, indeed, as underlying responses given by learners from grade 8 (Saltiel and Kamiski 1996) up to university level, and even by teachers (Kaminski 1991), to questions such as, 'What can you see from behind this hole [a hole punched in a screen at a position which is not in the axis of any beam of light]?'; or, more directly, 'Can you see a laser beam from the side?'

Asked to comment upon the type of document they were presented with (e.g. snapshot, schema, etc.), and to specify what element(s) of information they got from this document, pupils gave a variety of comments, often ambiguous ones and/or too short to decide what they had in mind. The following comment shows a type of difficulty linked with the observer wishing to see the light wherever there is any:

> 'The light is not seen as going in every direction. The impression is that there is no diffuse reflection of light.' (previously having been taught optics)

In such a comment, the realistic status ascribed to the represented rays, or at least the wish to see the light, seems to entail a question being raised by the limited number of rays (in figure 1b) (SEL), or at least by the limited part of figure 1a which is white (R/S). This link between two potential obstacles (realism versus



a) b)

**Figure 1. Document 'Diff'. Diffuse reflection: a) a beam of light strikes a white rough surface, b) a model for a rough surface which diffuses the light.**

symbolism – R/S – on the one hand, and selection – SEL – on the other hand) is worth pointing out and will be commented upon below.

Although this way of seeing things is not always incontestably present, many comments are compatible with a realistic perspective, as shown by the following excerpts:

> 'The figure shows us that the light ray propagates in a straight line (thanks to the white light that we can see).' (figure 1a) (previously taught optics)
>
> 'The magnifying glass is used to show the trajectory of the light rays that are infinitely small and that we cannot see.' (figure 1b) (previously taught optics)
>
> 'The magnifying glass is used to show that the rays are very small.' (figure 1b) (has not previously been taught optics)
>
> 'Figure 1a is seen from very far away, figure 1b is seen from very near.' (figure 1b) (has not previously been taught optics)

To sum up pupils' reactions to these pictures, with or without optics having previously been taught, we estimated the proportion of pupils reading this document with a realistic status ascribed to rays as being two-thirds of them (12/17 have previously been taught optics, 10/15 have not previously been taught optics).



*(b) Document 'Lens'*. Document 'Lens' (figure 2) concerns the respective positions of an object and its image given by a thin converging lens. The risks, according to us, are: first, to blur the idea that any pair of points and their images can be determined in the same way and that extreme points of the objects are not particular in this respect (Fawaz and Viennot 1986); and second, along the same lines, to put too much emphasis on the particular 'central' ray, at the expense of other rays (SEL), and thereby to miss the target of fostering a proper understanding of the principle of image formation. Restricted as it is, this representation of the correspondence between object and image may leave students with the idea of a global transportation from object to image (Feher and Rice 1987), with an inversion, thus being similar to common views on pinhole cameras and on image formation with a lens (Fawaz and Viennot 1986; Goldberg and McDermott 1987; Kaminski 1991; Galili 1996).

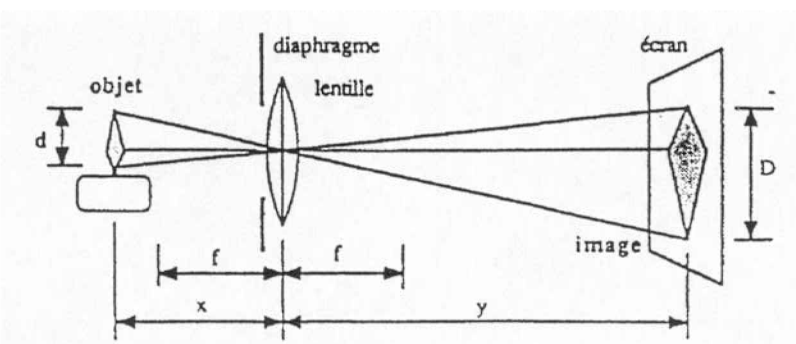



**Figure 2. Document 'Lens'. The essential elements of the device are shown on the figure, as well as the distances to be measured (with a tape measure). The focal length has been previously measured.**

The responses to our questionnaire (questionnaire S) are compatible with this hypothesis. Indeed, out of 15 students having previously been taught optics (grade 12), 14 answered that when the screen is moved away from the lens, an image still remains on this screen. Among these students, many added that this image is then larger (13 students), and blurred (12 students):

> 'On the screen, when it is pushed away from the lens, an image of the object, blurred, upside down and larger (larger than before, D'>D) can be seen.'

Only one student shows, although rather awkwardly, a clear understanding of the situation:

> 'If the screen is pushed away from the lens, the image on the screen will be blurred because it (understand: the optical image) is slightly to the front of the screen.'

Out of 17 students of similar age but not having previously been taught optics, no mention of sharpness or blurred image is made. The other features illustrated above are massively observed:

> '[T]he tilted and enlarged image of the object (is observed on the screen when this screen is pushed away from the lens).'
>
> 'It (the image) keeps getting larger.'

All these results suggest that the salient feature of this picture is the crossing of two extreme rays, which goes with the understanding of an optical image in terms of global transportation and inversion of a shape, as was expected. The classical left-to-right illustration (CS) of light transportation probably reinforces a story-like view of what happens to this shape, a global entity which can stop wherever a screen is placed.

*(c) Document 'Young'*. Document 'Young' (figure 3) concerns the principle of interferences with the Young experiment. Our expectations from previous research (Colin 1999, 2001; Colin and Viennot 2000, 2001) is that this document suggests the following ideas:

- Only two rays emerge (SEL), each from one hole, and these arrive at P. The representation shows only two selected paths of light among many other possible ones.
- What is represented on the right of the holes is the sole continuation (SIM) of the rays arriving at the holes (whereas any other path starting from a given hole might have been considered as well).

The responses to our questionnaire (questionnaire S), again, are compatible with this hypothesis.

Out of 15 students who had previously been taught optics, including diffraction, a third of them made comments showing proper understanding of this situation, such as, 'S1 and S2 (the holes) each emit a diverging beam, of which only one ray for each can be seen', whereas, as rather expected, still fewer students reached the same level of comprehension in the other group (2/17).

Within the two samples of pupils, whether they had previously been taught optics or not, nine pupils (out of 32) are far from clear, to say the least, about the basics of understanding diffraction, thus:

> 'Light is deviated.' (not previously taught optics)

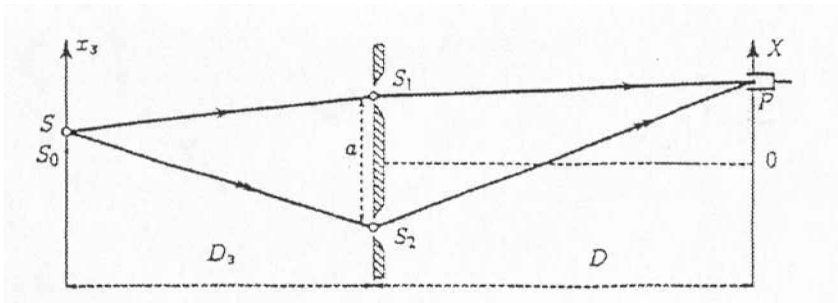



**Figure 3. Document 'Young'. The principle of Young's interferences. $S_0, S$: point $S$ of the monochromatic source of light. $S_1, S_2$: point holes punched into the first screen. At $P$: receiver.**

> 'Light can follow the path drawn only if (hole) $S_1$ is big enough to cause little diffraction and (hole) $S_2$ small enough to make the light diffracted a lot (. . .).' (previously taught optics)
>
> 'Light is deviated (scratched). Light cannot follow these trajectories. For two rays to converge towards the same point, it is needed that (. . .).' (previously taught optics)

For half of the regrouped sample, it is not possible to assess the pupils' understanding of the selective character of the drawing in Document Young.

Thus, this picture is at least compatible with, and we suggest that it favours (via SEL and SIM), an understanding of diffraction in terms of a deviation of the incident ray. As for the preceding document, the classical left-to-right illustration (CS) of light transportation probably reinforces a story-like view of what happens to a ray, with the outcome that the hero has a unique fate: deviation.

*(d) Document 'Jup'.* Document 'Jup' (figure 4) concerns Jupiter and its satellite 'Io'. The aim is understanding what part and/or respective positions of these planetary objects are seen from Earth, this in relation with the Römer discovery of the fact that the speed of light is finite.

This image might give rise to a misunderstanding concerning the arrow going from Earth towards Jupiter. This arrow, indeed, is similar to another one that indicates the direction of solar rays from the Sun to Jupiter (SIM). This similarity of symbols might obscure the comprehension of the path of light in such a situation, a fact all the more regrettable here, the path travelled by light being the focus of the corresponding paragraph. The common left-to-right orientation of the two arrows might also be referred to the 'grammar of visual design' according to Kress and van Leeuwen's (1996) perspective (CS), and therefore be ascribed in both cases to a given/new orientation, or else seen as a story axis – story of light from the Sun to Jupiter and the story of the observer's visual intention.

The main features of response to our questionnaire (questionnaire S) are as follows. Out of 17 students having previously been taught optics, only four clearly showed that they understood the path of light from the Sun to the observer's eye. The difficulty that we expected is patent in some answers like these:

> 'For us on Earth, the part (of Jupiter) which is lit up is the part comprising points A, C, D. The shadow is red (on the drawing, this ''red'' is put on the part of Jupiter which is opposite the observer's direction, i.e. not the Sun's direction).'

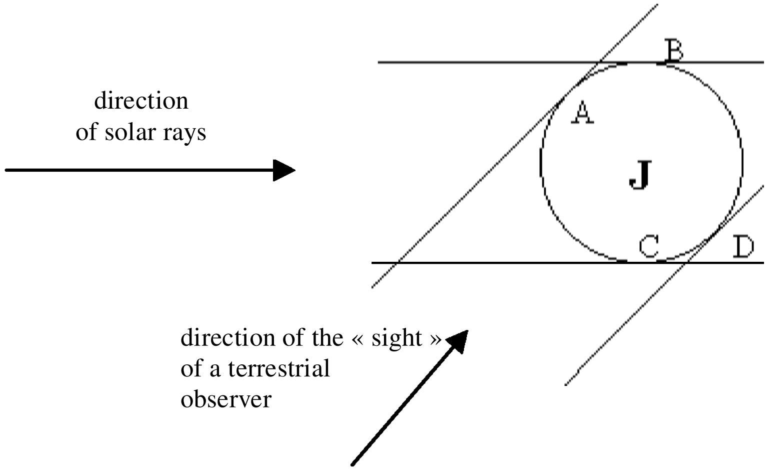



**Figure 4. Document 'Jup'. This document was presented to students after another one, more complicated, showing the Sun, the Earth, Jupiter and various position of the satellite 'Io'. This figure enlarges some elements of the preceding figure (Jupiter is represented without its satellite Io).**

'AB (actually lighted by the Sun, but invisible from Earth) is in a shadow area.'

In the other group, not previously taught optics, some comments show the same difficulty, for example, '[T]he terrestrial rays cross the solar rays', and 'CD is in the shadow but so is AB.'

Again, our hypotheses appear as being compatible with our data: in considering the aim of elucidating what the path of light is (be it the actual intention of the designer or not), this image is misleading, probably because of a similarity of symbols. At least, it is of no help to students in overcoming the well-known tendency to reason in terms of visual rays (Guesne 1984).

*(e) Document 'Col'.* Document 'Col' (figure 5a, b) concerns colours. In fact, in this document, the different areas inside the disks are coloured as indicated. In both cases, the external background is white.

In this domain, a realistic perspective sometimes goes with the well-known tendency of mistaking colours for paints, with the following attached difficulty: that of accepting that 'red plus green makes yellow', which is problematic if this is understood as concerning paints instead of lights. Considerable difficulty is therefore linked to the topics of additive and subtractive colour mixing. Understanding this point means being able to refer the two corresponding sets of rules to different practical contexts, i.e. respectively, to adding beams of light (or visual impressions due to separate coloured spots), and to superimposing filters or pigments.

Document 'Col' is prototypical of pictures used to teach additive and subtractive colour mixing and very commonly used by authors who deal with colour. However, it does not involve any indication of the experimental processes at stake in each case and therefore it is over-selective in this respect (SEL).

Moreover, the similarity of the symbols (SIM) used in figures 5a and 5b does not facilitate a differentiation between impacts of lights on a screen (as in figure 5a, but then the background should be black) and superimposed filters (figure 5b).

An investigation by Chauvet (1994, 1996a, b) shows that students know and willingly use these schemas. Chauvet also shows that students do not clearly differentiate on the one hand between a symbolic status indicating rules, and the realistic status of a description of an experimental set-up, on the other hand (R/S): for instance, are some circles in these pictures to be seen as superimposed filters or pigments? Such is the question raised by this comment (Chauvet 1994):

> 'The additive mixing consists of superimposing red, green and blue filters to give white at the place where they cross. The subtractive mixing consists of superimposing inks, filters or paints of yellow, magenta or cyan colour to give black at the place where they cross each other.'

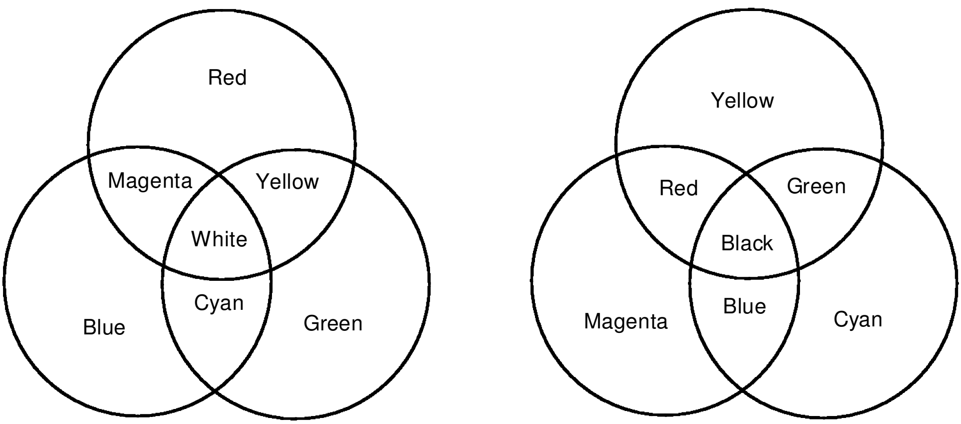
or else:

> 'The additive mixing holds for the mixing of pigments. Adding the three coloured primary pigments (B, R, G) in principle gives black. The subtractive mixing holds for lights.'

Thus, half of a university level group of students ($n = 50$, students in Arts) in Chauvet's investigation mistake the additive for the subtractive processes (concerning the set-up, not the rules) and show that they misunderstand this fundamental point: in any case, what is added or subtracted is light.

This account of the types of difficulty that students have in reading images obviously raises the question of what the main source of students' comments is: pictures or previous ideas? The images chosen were not particularly rare examples, but are rather common so we have to accept an indefinite answer: other similar images may have generated a type of reading, and contributed to these 'previous ideas' that we mentioned earlier. All this is likely to influence the way students react to a given document in our questionnaire. At least, what we can say is that the






a) Additive colour mixing

b) Subtractive colour mixing

**Figure 5. Document 'Col'. In fact, in this document, the different areas inside the disks are coloured as indicated. In both cases, the external background is white.**

document considered is not clear enough to clear up common ambiguities or misunderstandings.

The question now is to see to what extent teachers are aware of such possible limitations concerning documents involving images.

## Teachers' expectations and reactions concerning students' difficulties in reading images

Two types of data are available to document the question of how teachers take into account students' difficulties in reading images in optics, and consequently make certain decisions.

### *Procedure*

*Teachers' expectations.* The five documents already used for the investigation with students were presented to some teachers along with a written questionnaire and, for each of these documents, questions were asked as to students' expected difficulties (questionnaire Ta, see Appendix).

*The teachers' interpretation and suggestions.* Other teachers were presented with a second questionnaire (questionnaire Tb, see Appendix). This time, the same five documents were each accompanied with some typical students' comments which, according to us, show some of the difficulties they had in reading images. The questions bore on how teachers interpret these comments and what they suggested changing in each document in order to optimize correct reading.

For sake of brevity, we present in a single section, below, the results of these two questionnaires.



### *Teachers' viewpoints on students' difficulties: main results*

As in the previous section, we successively examine here the main results concerning each document.

*(a) Document 'Diff'.* Of the consulted teachers, none of them expressed any reservation concerning the bright and seemingly visible rays of light in figure 1b, or about the questionable status of the magnifying glass. As regards this, the only two suggestions made were quite compatible with a realistic view on these rays: 'Simply to indicate that b is a detail of snapshot a'; and 'There is continuity between what is inside and outside the field of the magnifying glass, which poorly accounts for the magnifying power.'

The teachers' main concern (6 out of 19 teachers) seemed to be related with the phenomenon of diffuse reflection itself: 'In fig b, there is a risk of mistaking (diffuse reflection) with (specular) reflection on a surface, . . .a risk that for them (the students) diffuse reflection and specular reflection be one and same thing'; 'Each beam and ray appears to be reflected and not diffused.'

The only suggestion of change for the picture itself follows the same lines: an incident ray is split into four reflected rays, instead of one as in figure 1b. Adding that four teachers explicitly expect no difficulty related to these figures (1a, b) and that six others answer in a non-relevant way as regards the points at stake here, globally this shows evidence of teachers' poor awareness concerning the obstacle pointed out above, i.e. briefly put: realism versus symbolism (R/S).

Let us now examine teachers' reactions when they are presented with a student's comment showing, according to us, a difficulty. The chosen comment was:

> '(a) The figure shows us that the light ray goes in a straight line (thanks to the white light that we see). (b) A magnifying glass has been used in order to show the trajectory of light rays that are infinitely small and that we cannot see.'

When asked to comment on this, on the possible difficulties that appeared and on the suspected origins of these difficulties, teachers were far from unanimous. Only seven of them (out of 19) mentioned more or less clearly the confusion between a realistic and a symbolic status for the drawn 'rays'.

> 'The impression you get is that it is possible to see the light rays with the magnifying glass.'
>
> '(There appears to be) confusion between a magnifying glass as a physical device and a magnifying glass as a symbol to schematise what happens.'
>
> 'Representing beams with lines is only a representation.'
>
> 'He has not understood that what is wanted is to see the details of the surface.'

Seven teachers did not allude to a realism-versus-symbolism problem at all and just said that students do not understand what the target of the schema is, i.e. diffuse reflection, while five others imperturbably passed over the problem: 'The magnifying glass gives a notion of the scale.'

The weak degree of awareness concerning a possible realistic reading of a symbolic element is confirmed by this investigation. Indeed, despite a students' comment showing, according to us, his/her misunderstanding, teachers' reactions are often (about two-thirds of the sample) in the best of cases limited to acknowledging the misunderstanding, with no comment on its possible origin. The teachers are not greatly concerned by the 'R/S' ambiguity.

*(b) Document 'Lens'.* In response to the first investigation (concerning expected difficulties), no allusion is made to the status of the rays (R/S), not a very surprising fact for this document, where rays are classically drawn in black by contrast with Document 'Diff'.

Concerning the problematic presence of only three 'rays' (SEL), only four teachers express any concern about the principle of image formation at a given place, three of them analysed what was missing in the schema: 'The rays which are drawn do not imply that the image will be formed at a distance y.' Only one teacher was very explicit in interpreting students' expected difficulties: 'Yes (there is a potential difficulty), pupils may mix up the fact of getting an image by constructing three rays and the global track of an object (shown) by the path of three rays.' All in all, this makes up only a quarter of our sample ($n = 19$) who anticipates a problem due to only these three rays.

The other comments stress possible difficulties in understanding the experimental device (5 teachers), the (non-)algebraic status of the measured distance (5 teachers), an illustration of image formation which is restricted to the case of real object and real image (2 teachers). These last comments refer to the usual teaching objectives in this domain: being able to manipulate, to calculate, to know all the cases. Finally, four teachers declared that they did not expect any particular difficulty.

Awareness of the point that we consider tricky here, i.e. a quasi projective structure of the schema, is not frequent in this sample of teachers.

The second round of investigation – in which teachers reacted to students' comments – gave a slightly higher rate of comments about this. The students' comments stipulated that if the screen was moved away from the lens, the image would still be seen on the screen but larger (and reversed). Five teachers previously confronted with these responses clearly incriminated an over-selection (SEL) of drawn rays, thus:

> 'On the schema, only the rays passing through the centre of the lens are represented. But they are not sufficient to define an image. There is confusion between an image and what is observed on any screen.'
>
> 'What disturbs the students is the represented light rays. Our impression is that, when pulling back the screen the rays can be extended and the image will be formed on the screen.'
>
> 'The rays do not only pass through the centre of the lens. Other rays have to be constructed so as to know where the image is formed.'

Five others, although not so clear about an over-selection, incriminate the schema: 'Image and screen are associated on this drawing.' In the other half of our sample, we found teachers' descriptions of what was not understood, without any analysis of a possible graphical origin: 'There is always something on the screen, the pupils do not bother to ask themselves whether the image is sharp or not.'

Therefore, when confronted with a response that, according to usual criteria – image position is indeed a classical topic – is clearly wrong, about half of our sample (10/19) seemed to react by incriminating the schema itself, beyond a mere acknowledgment of students' misunderstandings.

*(c) Document 'Young'.* When asked about the difficulties to be expected concerning Document 'Young', only one teacher pointed to the fact that two particular rays had been selected (SEL) on the figure, and that these rays correspond to a particular arrival point P. As stated by this teacher: 'Some particular diffracted rays have been chosen, but the secondary sources actually diffract in the whole half-space on the right (side of the holes).'

Moreover, two teachers in their own comments seemed to mirror a view of the situation in terms of two, and only two, rays which would each be identified as an entity starting from the primary source. This view, according to us, is fostered by the similarity of the arrows on a given path before and after the corresponding hole.

> 'Two light rays starting from S have been chosen.'
>
> 'One of the rays is almost in a straight line, it does not seem to be diffracted at all. (A suggestion then follows of representing two symmetrical rays arriving at the point of impact of the median of the holes on the screen).'

As for the preceding document, the rest of the comments concentrated on the description of the apparatus or on guidelines for calculation, three teachers responding that they expected no reading problem at all for this figure.

In the second version of our investigation, a confrontation with some students' comments seemed, this time, to be decisive. The two selected students' comments were:

> 'The light can follow the represented paths if $S_1$ is big enough so that it can be diffracted only a little and $S_2$ small enough so that it is diffracted a lot.'
>
> 'Light is deviated (principle of interferences).'

Three quarters (14/19) of teachers reacted by incriminating an over-selection of the represented rays:

> 'When schematising this experience, only the two rays that allow the problem to be put as an equation are represented, instead of specifying that the sources emit in every direction and that only two particular rays are represented.'
>
> 'The phenomenon of diffraction is well shown but the image is seen in a particular case, of a possible trajectory. This makes for confusion.'
>
> 'The schema is misleading because diffraction occurs in numerous directions, one only is privileged by the ray.'

Moreover, relevant remedying suggestions were made. One teacher suggested changing the position of the receptor for a symmetrical one ('P at -x') and to ask about changes, if any, occurring at $S_1$ and $S_2$. Another drew a small feather duster at $S_1$ and $S_2$, arguing that, 'otherwise, one gets the impression that it is the same ray with the same intensity which follows the path $SS_1P$ (resp. $SS_2P$).'

However, no teacher reached the point of denouncing the similarity of the arrows *(SIM)* which were placed on the two successive parts of a given path (for instance $SS_1$ and $S_1P$), despite the very different status of these lines.

To sum up, a large number of our sample of teachers (three-quarters of them) reacted and criticized Document 'Young' constructively, although this comprised a very classical schema. These reactions were not observed upon simple presentation of the corresponding schema and subsequent questioning about expected difficulties. In contrast to this, some students' striking comments were effective in triggering off critical analysis by these teachers. However, the subtle aspect of similar arrows (SIM) remained undetected.

*(d) Document 'Jup'.* As for this fourth document, our main concern was the similarity of the symbols (SIM) used for the direction of the light coming from the Sun to Jupiter and the direction of a terrestrial observer's sighting towards Jupiter. In the first part of this investigation (questionnaire Ta), our result was very simple: not a single teacher even alluded to this potential problem. In a first version of this document, the figure was completed by different positions of the satellite 'Io' and this may have distracted their attention: 14 (out of 19) teachers commented upon the complexity of the figure, a fact which prompted us to simplify the document for the other parts of our investigation (questionnaire S, questionnaire Tb). The fact remains that out of the teachers consulted, none of them denounced the similarity of the two arrows. It therefore seems that the understanding of the path of light from the Sun to the observers' eye was not considered as a conceptual key for the reading of this image.

With questionnaire Tb, teachers were confronted with the pupils' comment: 'CD is in the shadow, but so is AB.' This statement shows that the two areas mentioned (CD and AB) are envisaged similarly by the pupil, whereas one is lighted by the Sun and the other is not. A noticeable awareness is raised by this comment. Six teachers (a third) point more or less explicitly to the similarity of the two arrows involved:

> 'As the nature of the two directions is mixed, they are not distinguishable on the drawing (the light ray from the Sun: primary source/ Jupiter: secondary source).'

> 'The student mistakes the shadow area (area which is not reached by the Sun light) for the area that the terrestrial observer cannot see. This is due to the fact that the rays are represented by *1* (sic) arrow.'

> 'I think that the origin of the difficulty lies in the arrows: the one corresponding to the Sun's rays is correct; the other should have been reversed so as to underline the diffuse reflection of light by the planet.'

> '(slightly less explicit:) I think that the pupils get the impression that the terrestrial observer is lighting Jupiter.'

> 'The picture does not show us the diffuse reflection, therefore the pupil has not in fact understood why the AB area that is lit up by the solar rays cannot be seen.'

So, a confrontation with a striking comment by one of the students is partly effective in fostering a better awareness of potential reading difficulties. This effect is, however, limited to a third of our sample, which seems to confirm that teachers are not very vigilant about the similarity of symbols (SIM).



*(e) Document 'Col'*. Out of 14 teachers questioned about reading difficulties expected (questionnaire Ta), very few responded in terms that directly put Document 'Col' into doubt. One only pointed out the similarity of the codings (SIM) for two situations which are of a different type. Four pleaded for representing the experimental settings which are associated to each schema (television set, mixing of paints), and, out of those, only one fully developed his argument to the point of denouncing a potential inconsistency:

> '(suggestion:) indicate that the additive synthesis is obtained, for instance, with spotlights on a white screen, the surrounding background is then black, indicate that subtractive synthesis is obtained with paints for instance.'

Two other teachers questioned the very nature of colour: 'What is colour? A radiation, an impression?'; or commented on students' difficulties: '(having said that students mistake colour for paint) Black would be the sum of all the colours'. But although these remarks might have led to further questioning on the schemas, this was not the case. Among other remarks, some (4 out of 14) recommended the use and the explanation of terms such as 'primary', 'secondary', 'complementary' colours, thus referring to classical terms.

This investigation about expected difficulties showed, once again, how weak teachers' sensitivity may be concerning the difficulties raised or left unsolved by a picture: fewer than a third of the teachers consulted provided any critical analysis.

The confrontation with a students' comment (Tb) focused the teachers' attention on the idea of a filter, which was expressed by this student *a propos* of additive colour mixing (schema a): 'the additive mixing consists of superimposing red, green and blue filters to have white at the zone where the colours cross.' Teachers take up the word 'filter' or 'disk' which trace a realistic interpretation of the circles (R/S; 14/23):

> 'It is clear that three colours have been superimposed and that each colour is obtained with a filter.'

'The filters are represented by three disks.'

This realistic register of interpretation links up with the common ideas about colour which are shared by a quarter of the teachers consulted, this without the slightest criticism concerning the schema (6/23): 'At the place where the three circles cross one other, white can be seen well.'

Nearly half of the teachers (10/23) did not incriminate the schema, and considered that the students' comment was incomplete or ambiguous, but not false: 'The pupil does not explain the physical reality of the phenomena and is satisfied with talking of white. One (the pupil) does not specify where the filters are situated.' On the contrary, other teachers (9/23) detected the ambiguous or incomplete character of the schema itself, and thus suggested that the schema was over-selective (SEL):

> 'The schemas do not say if it is on a screen or if filters are superimposed: it is necessary to add that what we are talking about are beams that are being projected on the screen.'
>
> 'The schemas seem to represent a superposition of filters and not of coloured lighting. Moreover, the additive colour mixing is not entirely described.'

These teachers suggest modifying schema (a), by adding some elements, realistic (spots) or symbolic (the limits of beams of light), or a more precise caption: 'mixing of coloured lights'. By doing so, three quarters of these teachers propose only to modify this first schema (a), to foster realistic reading. The teachers' vigilance concerning the similarity of the two schemas (a and b) is therefore particularly slight.

Concerning colour in general, and these figures in particular, substantial training seems to be needed if a noticeable change is to be observed (Chauvet 1994, 1996a, b).



## Concluding remarks

A more general view of our results suggests some provisional conclusions. First of all, the list of previously defined obstacles seems relevant to our research questions. The images selected according to this list actually cause students to misunderstand, and their comments more or less directly confirmed the nature of the obstacles involved. Although pupils having had no previous teaching in optics did not show an appropriate understanding of the images as often as the others, the rates of occurrence of expected reading difficulties were comparable in both types of group.

Still, it is worth noting that these predefined categories of obstacle are not to be considered as strictly separated. For pupils, for instance, a realistic view about a 'ray' does not favour an awareness about the change in the status of the corresponding line after each 'Young's hole', nor a view of this ray as splitting in four by diffused reflection, instead of continuing unaffected. Correspondingly, we may criticize the similarity of symbols or the over-selectivity in an image, whereas an underlying factor in the corresponding difficulty is a realistic approach to the considered paths of light. In such cases, pairs of obstacles may reinforce each other mutually, even if, strictly speaking, only one of these obstacles is clearly shown in a pupil's comment. Along the same lines, over-selectivity can be diagnosed in a case where this drawback is aggravated by similarity of symbols which contributes strongly to blurring the message, as in the case of colour mixing.

Globally, teachers are hardly sensitive to the possible outcome of the specific characters of images that are, still, classically used in teaching. It has been observed that students' striking comments may noticeably foster teachers' awareness in this respect. Their reaction is striking, even if it does not go as far as one might wish. The fact that these teachers become then more sensitive to the problems raised by some images suggest that they had never realized before that a pictorial message might be misleading in a domain such as elementary optics.

When asked to predict or comment students' possible difficulties, teachers, in their critical analysis, give preference to emphasizing the over-selectivity of images, i.e. what should be added to illustrate a phenomenon properly. Teachers seem less aware of ambiguities linked to a realistic reading of symbols or to a similarity of graphical elements. Finally, although we suspect an influence of spatial arrangement (such as left-to-right) of graphical elements, we do not have any direct evidence as to this.

Concerning possible resonances between previous ideas and misunderstandings in reading images, our results do not invalidate this (not very risky) hypothesis, but we also observe misunderstandings concerning a very academic topic, Young's experiment, in which previous ideas cannot be considered as being brought into play directly.

These first conclusions are quite preliminary and deserve further investigation. In particular, an extension to other domains of physics is needed. Anyhow, our work and parallel STTIS studies (in this issue; dee also Chauvet *et al.* 1999a, b, Pinto *et al.* 2000) strongly suggest that it is crucial for the teaching–learning process to document these points: how a given message supposedly conveyed by an image can be transformed by the reader, and how to take this into account when implementing an innovative sequence.

According to us, the results of this and other similar studies should inspire corresponding teacher-training objectives. Specific material used in research could help in this direction, a point investigated by one of us (Chauvet *et al.* 1999c). Training about colour, which, in order to foster an approach more 'reasoning oriented' than usual, integrates coherently a global rationale and the specification of critical details, seemed to improve noticeably teachers' sensitivity to the difficulties relating to the reading of images. Needless to say, such awareness might have transferable effects. This possible transferability might be a very relevant topic to document after the present (STTIS) investigations.

Moreover, the designers of innovative teaching sequences might use this type of information to optimize the design of their materials, avoiding in particular reinforcing the observed difficulties with excessively ambiguous symbols or compositional structures, and using carefully the captions as a means to positively clarify the message and not only as a casual label.

**Acknowledgements**

We gratefully acknowledge the contribution of Gérard Rebmann and Colette Hirn to the selection and discussion of the images used in this investigation.

## Note

1. STTIS is a research project founded by EU D.G. XII within the frame of the TSER programme (co-ordinator: R. Pinto): see the introduction to this set of papers (pp. 227–234).

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## Appendix

### *Questionnaire S*

*Document 'Diff'*

(a) Can you specify what kind of figure (snapshot, schema, . . . ) document (a) is?
(b) Can you obtain any information from document (a) about the phenomenon of diffusion?
(a) Can you specify what kind of figure (snapshot, schema, . . . ) document (b) is?
(b) Which connection is there between documents (a) and (b)?
(c) Why is a magnifying glass represented in document (b)?
(d) Does the document (b) provide you more information than document (a)?
(e) According to you, is there too much information in document (b)? Some information you cannot manage? Not enough information?

*Document 'Lens'*

(a) What do you see on the screen when it is moved away from the lens?
(b) Is the image always formed on the screen?
(c) If so, does the image remain the same or are some of its features modified? In the second case, which ones?

*Document 'Young'*

(a) According to you, how can the light follow the paths represented on this document between S and P?
(b) Do you have any difficulty for giving an explanation?

*Document 'Jup'*

Using these two documents, explain why one cannot see the parts AB and CD of Jupiter from the Earth. You can, if you want, complete the documents.

*Questionnaire Ta*

For each document, it is asked to answer to the following questions:

(a) Do you expect any difficulties as regards the use of this document with students?
(b) If so, have you any idea of the possible origin for each of these difficulties?
(c) If you have to explain the meaning of this document to students, would you add or change any element: (a) in the graphic? (b) in the caption?

*Questionnaire Tb*

The following students' comments have been selected and presented to teachers, as such, along with the corresponding document:

*Doc 'Diff'*

(a) 'The figure shows us that the light ray goes in straight line (thanks to the white light we see).'
(b) 'One has utilized a magnifying glass to show the trajectory of light rays that are infinitely small and that we cannot see.'

*Doc 'Lens'*
Comment 1

(a) 'The image which is reproduced on the screen gets larger (but it looses however luminosity) upside down.'
(b) 'Yes, it is still formed on the screen.'
(c) 'When the image gets closer to the lens, it narrows.'

Comment 2

(a) 'It is a converging lens, therefore the image gets larger and turns upside down.'
(b) 'Yes, it is still formed on the screen.'
(c) 'I have already answered.'

*Doc 'Young'*
Comment 1
'The light can follow the represented paths if $S_1$ is big enough so that it can be diffracted only a little and $S_2$ small enough so that it is diffracted a lot.'

Comment 2
'Light is deviated (principle of interferences).'

*Doc 'Jup'*
'CD is in the shadow, but so is AB'

*Doc 'Col'*
'The additive mixing consists of superimposing red, green and blue filters to have white at the place where the colours cross each others.'

For each selected comment of student, it is asked to answer to the following questions:

(a) Comment this answer, specifying to what extent, according to you, it is correct or reveals difficulties.
(b) In the second case, for which reasons, according to you, do these difficulties appear? Underline in particular all that might stem from a misreading of the image.