Can we Evaluate the Impact of a Critical Detail? The Role of a Type of Diagram in Understanding Optical Imaging

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RESEARCH REPORT

Can we Evaluate the Impact of a Critical Detail? The Role of a Type of Diagram in Understanding Optical Imaging

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This paper describes an attempt at evaluating a potentially critical "detail" of teaching practice; that is, using a particular diagram to illustrate the imaging role of a converging lens. This "basic" diagram has been designed to contribute to help students overcome the well-known "travelling image" syndrome. We conducted a comparative study with 125 students in all, at three academic levels: end of secondary school, degree students, and teacher training. The groups compared had previously been taught elementary optical imaging in a classical, uncontrolled manner, and were presented with two classical questions, commonly used to demonstrate students' difficulties. In each group, one-half of the students had a classic introductory diagram and the other half had the "basic" one. A positive reaction of students to the evaluated diagram was observed at a relatively high academic level (trainee physics teachers and degree students), in contrast with an apparent lack of effect at the end of secondary school. The paper ends with a discussion of the evaluation of a detail of practice in isolation, with respect to the distance between students' actual and targeted levels of comprehension.

Introduction

Although not specific to this content domain, a striking fact concerning optical imagery is the resistance of some common ideas well after teaching. On the other hand, some studies about the role of images in learning (Pinto, 2002[1]; Pinto et al., 2000), and particularly in optics (Colin, Chauvet, & Viennot, 2002), call attention to the fact that using a given graphical document may constitute a "critical detail" of a teaching strategy. It has been argued (Viennot, 2001a, 2003a) that such details,

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although apparently “small”, might strongly affect students’ understanding, either in the desired direction or in an undesired one (see also Lijnse, 1994; Millar, 1989).

The investigation reported here is intended to evaluate the extent to which a given “detail”—in this case, one linked to a pictorial representation—appears “critical” or not in terms of the conceptual construction of students. Several authors (Leach & Scott, 2000, 2002; Méheut, 1998; Méheut & Psillos, 2004; Viennot & Rainson, 1999) have discussed the fact that we often do not know the part played by each specific aspect of a teaching–learning sequence in the final outcome. It is often the case, indeed, that a given researcher decides to try what might seem to him/her the “best possible method” to achieve a given teaching goal. In such instances, a coherent set of ingredients is brought to bear in the sequence experimented with. In cases where there is a noticeable difference in the students’ conceptual achievement, as compared with a classical sequence, it is difficult to ascertain which ingredient determined the outcome. By contrast, when someone tries to evidence the role of an isolated factor, there is often no significant difference in experimental samples with respect to control groups. The view taken here (Viennot, 2003b, p. 215) is that this is not simply a methodological problem. There might be non-linear effects, so to speak, in the “efficacy” of such factors, so that even if only one ingredient is added to a teaching strategy and brings about the “success” that had been missing before, this does not prove that particular factor was the only “effective” one.

This said, such a viewpoint is somewhat frustrating, because it might lead to a kind of paralysis, in terms of investigations. Should we wait until we find the miraculous cocktail, and totally renounce a detailed analysis of the role of each factor we have chosen to bring to bear in a research-based teaching sequence? The answer proposed here is unequivocally “no”. This paper is an attempt at characterising the impact of a *very limited* aspect of a teaching strategy, based on students’ responses to some classical tests. When the effect has been significant, the likelihood of that factor’s “criticality” will be suggested and considered in the light of this investigation. What this study definitely cannot prove is the impact that such a detail would have if it were inserted in a coherently designed sequence, bringing to bear a set of actions that are consistent with a specified teaching goal.

As has been stated earlier, the detail in question is a diagram used in optical imaging. After a reminder of the typical difficulties of learners and an analysis of common practice in this domain in the first section, the second section states the reasons why such diagrams should be used at the beginning of a sequence on optical imaging. Then, an investigation on this topic will be reported. After a small preliminary investigation at degree level, three groups of students were involved in this research. They were chosen at different academic levels—students at the end of secondary school (45), degree students in their third year at university (20), and trainee physics teachers who already have their degree in physics (60)—in order to appreciate a possible effect of this variable on our results. The three groups had been taught elementary optical imaging previously, in an uncontrolled and probably very classical manner. In order to isolate the “detail” under scrutiny, no innovative course, not even a short sequence, was planned in our research design. The intervention was limited to administering paper-and-pencil questionnaires with questions classically used in research about conceptions. These questions were illustrated with the diagram to be evaluated or a classic one and we compared the results for *a priori* equivalent subgroups. The goal was to see whether such a tenuous difference had an impact on the collected answers, or not, at different academic levels.

Our final remarks will bear on the general question of *evaluating* the impact of potentially critical details. This point will be discussed in relation with the—smaller or larger—gap existing between two factors: on the one hand, the comprehension of the topic that the students with whom the investigation was conducted may have; and, on the other hand, the conceptual goal that is supposedly backed up by the evaluated diagram.

Problems in Understanding Elementary Optics

Students' common ideas, whether "holistic" (Feher & Rice, 1987) or "projective" (Galili & Hazan, 2000), are similar as regards one aspect. They are not compatible with the idea that each point of a source sends some light into all of space—or, in practice, a large part of it—with light propagating rectilinearly and isotropically until it meets a medium with a different index. In familiar language, light is diluted in space, and an imaging device captures a part of this light and reorganises it differently. In the language of geometrical optics, all of the rays associated with the light that is emitted by a point source and transformed by the lens share another single—image—point (to put it briefly). If this is not understood, the way is paved for all of the misunderstandings commonly observed; that is, "holes in the image" that supposedly result from a mask put on the lens, or even "images" that travel alone to a nearby wall in the absence of a lens—images that are "erect, this time" or "not distorted".

The type of diagram that is classically used in the academic treatment of imaging, with a converging lens, for example, is shown in Figure 1.

An exclusive focusing on the "central ray" is highly compatible with what Galili calls the "image projection model"—in which the point-to-point correspondence is ensured by one ray only, and the image is not localised. Considering the two rays

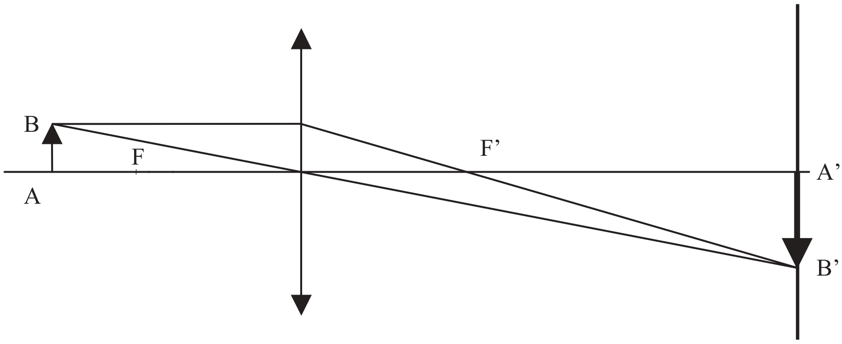


Figure 1. A classic diagram concerning optical imagery with a convex lens

represented in Figure 1 as constitutive of the image leads students to the often-observed answers (Fawaz & Viennot, 1986; Goldberg & McDermott, 1987), according to which if these rays are blocked the image disappears totally. The global horizontal dynamic suggested by such a diagram also encourages the idea of a “travelling image” or its variants.

Moreover, the classical experimental device—an optical bench—may also convey the idea that the horizontal direction is somewhat privileged in this domain, the source being—at first glance—not unlike a gun launching a luminous letter towards the screen. Some common expressions, such as “the image is received on a screen”, are more than compatible with the idea that an image is a kind of copy that travels in space like an ordinary object, possibly undergoing some limited transformations. This is an instance of a much more general trend towards materialising the concepts of physics (Viennot, 2001b). In brief, trying to prevail against so many opposing factors seems to be a lost cause.

As mentioned earlier, we chose to envisage the role of one of these aspects only: one that is linked to the graphical representation of what a converging lens does to light.

Why Use a Specific Type of Diagram to Introduce Students to Optical Imaging?

It is often said that a picture is worth a thousand words, but in teaching the role of images is far from being so clearly positive. A part of the European STTIS project focused on the difficulties concerning the reading of images, and one of the topics investigated was elementary optics. Concerning this domain, it has been observed that some images that are *a priori* criticisable as regards a proper understanding of light and vision were indeed misunderstood by many students, and that this risk was underestimated by the trainee teachers consulted (Colin et al., 2002). One of these images is reproduced in Figure 2.

In terms of the grid proposed to analyse reading difficulties (Pinto et al., 2000), the image is too “selective”; that is, nothing is wrong, but too few elements are represented to ensure a proper understanding of the message (see also Galili & Hazan, 2000, p. 60). Although less of a caricature, the commonly-used diagram (Figure 1) can be qualified as overly selective too, because it does not depict the isotropic propagation of light, nor the fact that a part of the light continues on its rectilinear path around the lens. The role of the lens, recalled earlier, is not illustrated.

The idea of proposing another diagram at the very beginning of a course on optics seems appropriate, therefore, if we intend to teach students what a lens does to light and to help them not to reason in terms of a “travelling image” or one of its variants. This is not a new idea. Soon after the paper by Goldberg and Mc Dermott (1987) was published, Beaty (1987) blamed misleading textbook diagrams as being likely to “infect” students with mistaken ideas; but he did not propose any particular measures. Galili and Hazan (2000) recommended representing the entire flux falling on a convex lens to facilitate the understanding of what happens if half of the

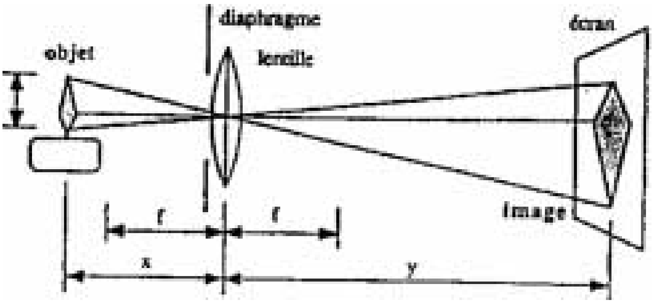


Figure 2. A problematic image used to show the reading difficulties of students and the relative lack of awareness of trainees on this point ("diaphragme", mask; "écran", screen; "lentille", lens; "objet", object)

lens is masked (see also Guesne, 1981), but they did not suggest representing the unaffected light passing by the lens. Kaminski (1991, p. 95) suggested using a diagram like that in Figure 3 with reference to viewing an object point (Viennot, 2003a, chapter 1), but to the authors' knowledge the possible impact of such a "detail" has not yet been formally evaluated.

Given the goal of making students understand what a lens does to light when an image is formed, and on the basis of Kaminski's suggestion, the following characteristics are retained here as relevant *a priori*:

- some deviated rays or beams are represented, whereas there are no construction rays; and
- the isotropic and rectilinear propagation of light is represented as unaffected around the lens.

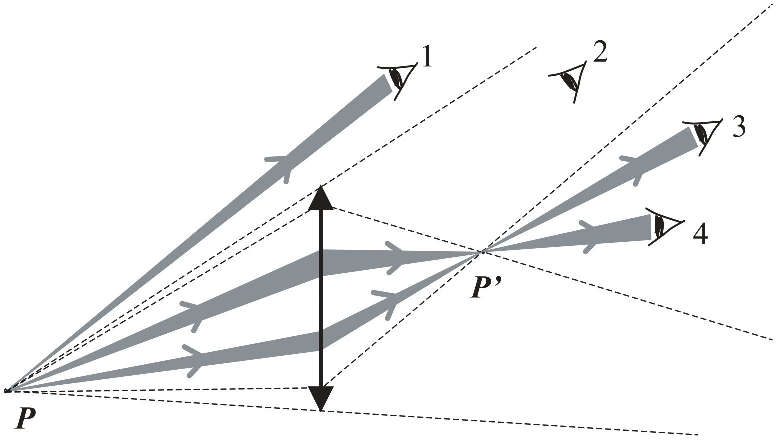


Figure 3. A diagram to represent how we can see an image formed by a convex lens (Kaminski, 1991, 1993; Kaminski & Mistrioti, 2000; Viennot, 2003a)

The first of these points is the basis of optical imagery in the Keplerian sense (i.e., in the Gauss approximation). Knowing what a lens does to a few rays (at least two) enables us to predict what it does to any other ray emitted by the same point source and reaching this lens. No single ray is more fundamentally constitutive of the image than any other; a set of rays plays the role of a "sample" (Fawaz & Viennot, 1986) or of "representative" rays that allow us to determine the path of the other rays.

As for the second characteristic, it may seem quite irrelevant. We will see that this may not be the case. Indeed, representing the flux of unaffected light passing around the lens is a way of stressing that the flux of light that hits the lens is only a part of a larger flux, and, in brief, that *even* an entire lens does not mean an entire flux. This simple detail could be conducive to a proper understanding of what happens if only a part of the lens is used.

In what follows, such a diagram will be termed "basic", as a reminder that it is considered here as a useful foundation for the proper understanding of optical imagery. At the other end of a continuum of possible versions, a diagram will be termed "classic" if it provides construction rays only (no beams, no ordinary rays) and if the light passing around the lens is not shown.

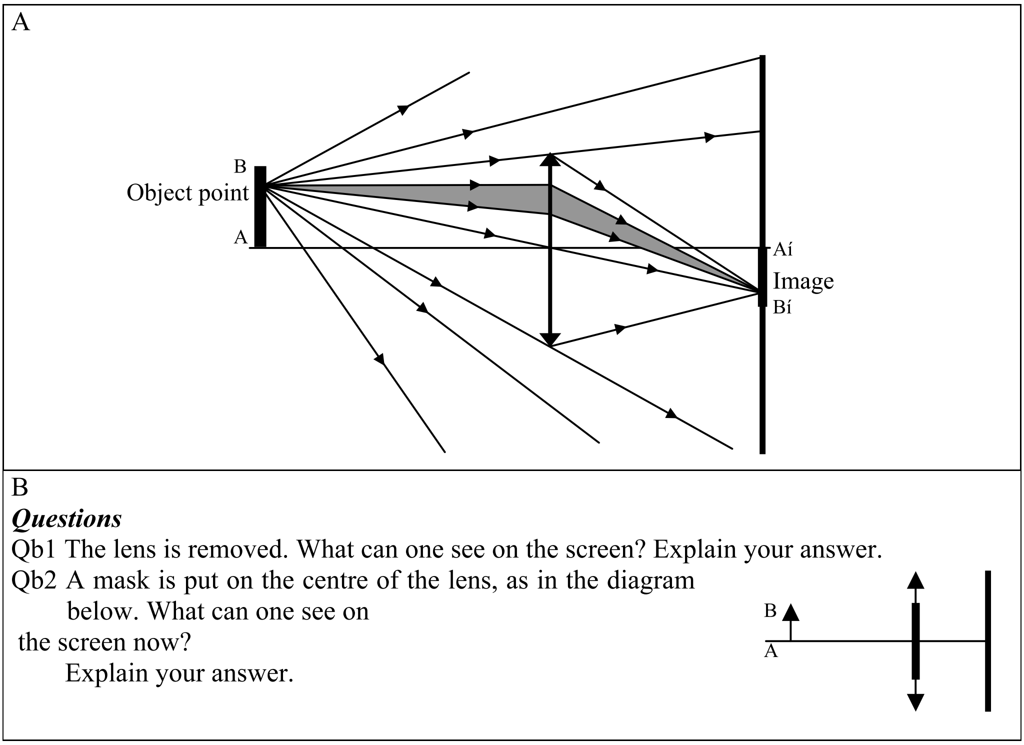
In this investigation, we sought to determine whether the single fact of providing students with a "basic" diagram instead of a "classical" one could help them give fewer answers of the common types recalled above.

Method and Experimental Results

First Indications, with Degree Students

A preliminary investigation was conducted with a small group of 12 degree students who were presented with the diagram shown in Figure 4A. They had been taught optics in the previous years in an uncontrolled—probably very classical—manner, and they were consulted without being given any new information on this topic. The questions were as follows: What will you see on the screen if the lens is removed? If half of the lens is masked? Each time the students were asked to explain their answers. It was most surprising to observe that only 1 out of 12 answers could be interpreted in terms of a "travelling image". Moreover, once the forms had been collected, one of the students spontaneously said "What was really new and decisive for me was the set of undeviated rays represented around the lens".

Although an effect of that kind had been expected, it proved surprisingly noticeable. However, the sample was very small. We therefore decided to conduct a more extended and systematical investigation with another sample, to compare the answers given when this type of question is accompanied by a basic diagram (Qb: the index "b" means "basic") with those given when the introductory diagram is of a classical type (Qc; see also Figure 1). The first question was the same as the first question in the previous investigation (Qb1, Qc1) and the second question (Qb2, Qc2) was also similar to that used previously, except that it was the centre of the lens that was masked (Figure 4B). The samples were from three different academic levels (Table 1): trainee teachers who already have their



Questions

Qb1 The lens is removed. What can one see on the screen? Explain your answer.

Qb2 A mask is put on the centre of the lens, as in the diagram below. What can one see on the screen now? Explain your answer.

Figure 4. (A) A "basic" diagram used to introduce the questions shown in (B), Qb1, Qb2; the second question is accompanied by a complementary drawing

degree in physics, degree students, and students in the final year of secondary school (Grade 12).

The Investigation Conducted with Trainee Physics Teachers and with Degree Students

First, a group of 60 trainee physics teachers in their first teaching year—at secondary-school level—was presented with the two versions of the questionnaire just described. They had their degree in physics and had not been taught more advanced topics in geometrical optics since then. In order to be accepted in this training year (in a French institute, "Institut Universitaire de Formation des Maîtres"), they had

Table 1. The different samples consulted

Population	*N*
Trainee physics teachers	60
Degree students	20
Students in Grade 12	45

been selected on the basis of their general knowledge of physics. The training course was intended to help them reflect on their teaching practice, and the topic of optics had not yet been broached. Each side of the room was given one version, this random partition resulting in two *a priori* equivalent subgroups; one (b, $N = 29$) had the "basic" version (Qb1, Qb2), and the other (subgroup c, $N = 31$) had the "classic" version (Qc1, Qc2). In fact, two different groups of trainees were concerned; the same procedure was used each time, and the answers were regrouped in two subgroups. The results are presented in Tables 2–4.

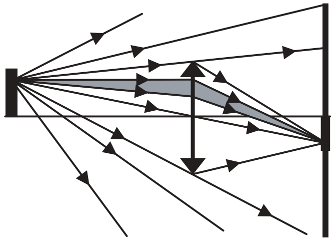
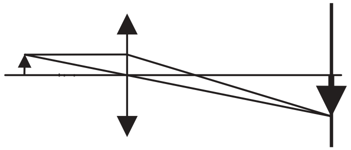
In the case of the removed lens (Q1), some answers were vague—"an image", "a spot", a "halo", sometimes "blurred", "indistinct". Other answers to Q1 included some more specific elements, such as "a large spot, low luminosity". It is often quite difficult to decide the extent to which a given student has understood what is happening in the proposed situations. Some correct drawings were found in the two subgroups, including one with the answer "nothing"—which, although not very academic, can be considered as attesting to a good comprehension of the phenomenon, yet might be ambiguous on its own. Elsewhere, "a diffuse image" (Qb1) could suggest a misunderstanding, if not the "travelling image" syndrome. But, in one of the answers, this prediction is accompanied with a correct drawing and the *caveat* that students may wrongly predict that "an image will be seen on the screen".

By contrast, some answers are unambiguously correct, as when, for example, the screen is said to be "uniformly illuminated", or "white". There are also some clear "travelling image" type of answers, or others that mention a variant, with an enlarged object or shadow. Thus, considering the cases of answers that were very clearly correct (Table 2; 14/29 (b) vs 3/31 (c)) and answers that were no less clearly of a "travelling image" type or a variant (3/29 (b) and 9/31 (c)), it seems at first sight that these answers were indeed influenced by the diagram provided. When the "intermediate" answers (i.e., ambiguous answers with at least one unambiguous element suggesting a proper understanding) are regrouped with the correct ones in a first category (21/29 (b) and 8/31 (c)), and when the very ambiguous answers are regrouped with the "travelling image" type in a second category (8/29 (b) and 23/31 (c)), a χ^2 test for these two enlarged categories indicates a very significant difference ($\chi^2 = 13.04$; $p = .01$; no theoretical frequency lower than 10).

It is also worth noting that, for Q1, two arguments appeared with varying degrees of frequency in the two subgroups, notwithstanding the answer provided (Table 3): "The rays are not deviated" or "propagate in straight lines" are two comments provided in the classical version of the questionnaire (vs. 0 in the basic version), whereas statements such as "they are no longer concentrated", "they do not converge any more", "they spread out in space", or "the lens does not play its role any more" are provided by 13 students in the basic version as opposed to only four in the classic one. These two types of comments are both correct, but the second may have been prompted by a more *global* view of what happens to the rays, and therefore by a better understanding of the lens as an imager.

In the case of a mask placed on the centre of a lens (Q2), the answers were less ambiguous. Answers such as "same image", or "A′B′" were given sometimes with an

Table 2. Answers of trainee teachers and degree students to the "basic" and "classic" versions of Q1

Q1 ***Exclusive categories ↓***	**With basic diagram** Qb1			**With classic diagram** Qc1		
						
	Trainees	**Degree**	**Together**	**Trainees**	**Degree**	**Together**
	N=29	N=10	**N=39**	N=31	N=10	**N=41**
"Correct"						
White + *correct drawing**, Screen uniformly illuminated, Uniform spot	14	6	**20**	3	2	**5**
"Intermediate"						
Ambiguous with at least one unambiguous comment or drawing suggesting a proper understanding: large spot, low luminosity, "nothing", light diffused in all directions, diffuse image (+)** *correct drawing**	7	1	**8**	5	2	**7**
"Very ambiguous"						
Image, halo, a luminous spot (+) blurred or indistinct *without any other indication of understanding*	5	0	**5**	14	0	**14**
"Travelling image or variants"						
*Object directly projected on the screen, erect (+)** larger (+) shadow large and blurred, A′B′=AB (+) erect*	3	3	**6**	9	6	**15**

Notes: *Rectilinear lines diverging from a point source and reaching the screen, covering its surface. **(+), in some cases.

Table 3. Occurrence of two particular types of comments by trainee teachers and degree students for Q1

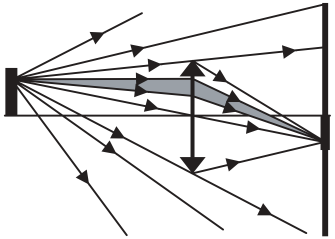
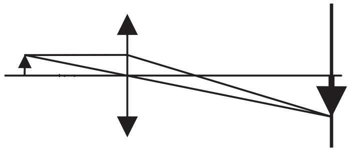
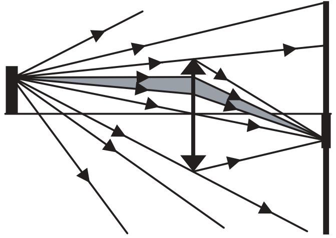
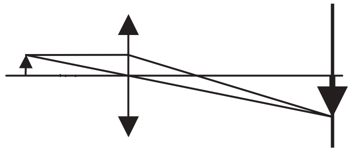
Q1 ***Non exclusive comments* ↓**	**With basic diagram Qb1** 			**With classic diagram** Q**c1** 		
	Trainees	**Degree**	**Together**	**Trainees**	**Together**	**Degree**
	N=29	N=10	**N=39**	N=31	N=10	**N=41**
The rays are no longer deviated *or* Light propagates in straight lines *(whatever the rest of the answer)*	0	2	**2**	2	1	**3**
The rays are no longer concentrated, *or* they spread out in space *or* the lens does not play its role any more *(whatever the rest of the answer)*	13	4	**17**	4	1	**5**

Table 4. Comments of trainee teachers and degree students in response to the “basic” and “classic” versions of question Q2

Q2 ***Exclusive categories*** ↓	**With basic diagram** Qb2 			**With classic diagram** Qc2 		
	Trainees	**Degree**	**Together**	**Trainees**	**Degree**	**Together**
	N=29	N=10	**N=39**	N=31	N=10	**N=41**
The same thing or A′B′(+) less distinct (+)* Gauss approx, (+) Less luminous	26	8	**34**	17	2	**19**
A black spot at the centre of the screen *or* of the image, image of the mask, black spot (+) halo	3	2	**5**	14	8	**22**

Note: *(+), In some cases.

additional comment concerning the lower luminosity or a concern—relating to Gauss conditions—about the sharpness of the image. These responses were regrouped as "correct" although they were not always complete. Various words such as a "black spot", a "halo", an "image of the mask" were considered as linked to a travelling image syndrome. The two subgroups respectively gave 26/29(b) vs 17/31(c) "correct" answers, mentioning a lower luminosity or the Gauss approximation, whereas the typical error, "a black hole (will be seen) in the image", was given by only 3/29 trainees in the subgroup with a basic diagram as opposed to 14/31 in subgroup c.

To complement the preliminary observation, a questionnaire identical to that distributed to the trainee teachers was given to a group of degree students ($N = 20$), using the same procedure. These students had been taught geometrical imaging before. The results were analysed in the same way as the preceding ones, and are presented in Tables 2–4. As their main characteristics appear very similar, they have been regrouped with those of the preceding sample and the total for each category also appears in the same tables. For the purposes of our final discussion, the corresponding sample can be described as comprising students in at least the third year at university, who had been taught optics previously—and classically—in the course of their studies at university. It cannot be ruled out that the trainee teachers would be able to solve *more complex* problems than the degree students in this domain, but they were previously presented, in the course of their studies, with the *same kind* of problems (i.e., calculating the positions and sizes of images with lenses or mirrors, using construction rays). With the respondents thus regrouped, two statistical tests, for Q1 (with two enlarged categories, as stated earlier) and Q2, respectively, indicate very significant differences (respectively $\chi^2 = 14.4$, $p = .01$; and $\chi^2 = 17.59$, $p = .001$; no theoretical frequency lower than 10).

Moreover, two facts are worth noting. First, inappropriate wording is sometimes observed in association with an—apparently—good comprehension of the phenomenon. In one case, for instance, it is said (Qc2) that what will be seen with a masked lens is "object AB, less luminous than without the mask". Such an answer uses an inappropriate designation of image A′B′, but the rest is clearly correct. Secondly, a trainee or a degree student may well make a comment suggesting holistic transport in Qb—"object directly projected on the screen, larger …, erect"—and be quite explicit and correct in his/her comment in Qb2: "image of AB because there are light rays coming from AB that pass above and below the mask". Similarly, several trainees who responded in Qc2 in a manner clearly recalling the "travelling image" were much less explicitly wrong in Qb1.

To sum up, although it was often difficult to determine, in a clear-cut manner, whether a given person had or had not misunderstood the proposed phenomena, these results are compatible with the hypothesis that the basic diagram encourages a proper understanding of the imaging role of the lens. In some respects the results are rather convincing: there was an abundance of elaborate or explicit responses in Q1 and explicitly correct answers in Q2 with the basic diagram, and comments suggesting a "travelling image" in both of the questions with the classical one. It is also observed that the words used to designate what is seen on the screen may vary—"image", "spot",

Table 5. Answers of students in Grade 12 to the "basic" and "classical" versions of question Q1 (same categories as in Table 2)

Q1 ***Exclusive categories*** ↓	**With "basic" diagram Qb1** **Students in grade 12** N=23	**With "classic" diagram Qc1** **Students in grade 12** N=22
"Correct"	**7**	**3**
"Intermediate"	**2**	**6**
"Very ambiguous"	**5**	**2**
"Travelling image or variants"	**9**	**11**

or even "object" or "object-image"—so that an inappropriate term may well accompany an unambiguously correct comment or drawing. Therefore, in this attempt to evaluate the impact of a critical detail of teaching practice—in this case, a diagram—an analysis based merely on the keywords "image", "object", and so on, would be more misleading than ever. Some trainees or degree students, indeed, might have attained an intermediary comprehension, although a proper mastery of the vocabulary had not yet been reached, nor a total consistency applied across the situations. These persons may, however, have gained something from the critical detail under scrutiny. In such a case, the desired effect may remain partly undetectable until some additional event triggers a complete understanding and an acceptation of the taught content.

The results obtained at a lower academic level will shed some light on this question.

Investigation with a Group of Students in Grade 12

An investigation similar to that just described was conducted among students in Grade 12 ($N = 45$). These students had been taught optics previously. Two

Table 6. Occurrence of two particular types of students' comments in Q1

Q1 ***Non exclusive comments*** ↓	**With "basic" diagram Qb1** **Students in grade 12** N=23	**With "classic" diagram Qc1** **Students in grade 12** N=22
The rays are no longer deviated *or* Light propagates in straight lines *(whatever the rest of the answer)*	**5**	**12**
The rays are no longer concentrated, *or* they spread out in space *or* the lens does not play its role any more *(irrespective of the rest of the answer)*	**12**	**5**

Table 7. Answers of students in Grade 12 to the "basic" and "classical" versions of question Q2

Q2 ***Exclusive categories*** ↓	**With "basic" diagram Qb2** **Students in grade 12** N=23	**With "classic" diagram Qc2** **Students in grade 12** N=22
The same thing *or* A′B′ (+) less sharp (+) Gauss approx, (+) less luminous	**0**	**5**
A black spot at the centre of the screen *or* of the image, image of the mask, black spot (+) halo	**23**	**17**

subgroups were given two different versions of Q1 and Q2; the one starting with a basic diagram drawn for a point source and the other with a classic diagram (as in Figure 1). As in the preceding investigation, the second diagram, explaining the situation in Q2 (see Figure 4), was the same in both versions. The results are presented in Tables 5–7.

Again, a slight positive effect was observed—or rather, "suspected" (a χ^2 test would not be valid)—in favour of subgroup b: 7/23 (b) vs 3/22 (c) students gave a clearly correct answer, whereas 9/23 answers were clearly of the "travelling image" type in subgroup b as opposed to 11/22 in the other group. It was also in subgroup b that the role of the lens was most clearly mentioned: 13/23 students in this subgroup (as opposed to 7/22 in the other) gave comments such as "the rays are no longer concentrated, they spread out in space, lighting the screen", "the light rays are scattered", "the lens permits the rays emitted by the object to converge onto the screen", "if the lens is removed, the rays are no longer concentrated towards a point", "the lens does not play its role any longer", "the beams would spread on the whole screen; without the lens, the light rays would propagate in an anarchic way." By contrast, comments such as "the rays are no longer deviated" or "propagate in straight lines", with no additional argument, are mainly observed in subgroup c (12/23 vs 4/22).

Strikingly, however, the answers of the students in subgroup b to question Q2 are by no means better. In fact, all of the students in this subgroup answered in terms of a travelling image, whereas most of them (17/22) did so in the other subgroup. The main result in this sample is that, globally, the students experienced great difficulty with this content. However, the answers to Q1 collected in subgroup b show that some students (7/23), although ranked in categories referring to the travelling image syndrome after Q2, were in fact capable of applying completely correct reasoning to this situation.

A provisional conclusion might be the following. At this low level of competency, some students in the observed group were able to draw profitable conclusions from the basic diagram in order to solve Q1, but, concerning Q2, they were overcome by the complexity of the problem, and the basic diagram seems to have been of no help at all—apparently. This said, given the fact that the answers collected in Q1 are in some respects better in subgroup b, it is not evident that these students did not benefit *at all* from being given the basic diagram. All this, of course, has to be confirmed with larger samples, but we should keep in mind that what really matters, ultimately, are phenomena that can be observed by the teacher him/herself in his/her class. With a few hundred Grade 12 students, for example, we might observe a significant difference of results in favour of the basic diagram; but if an individual teacher cannot see any effect in his/her class, he/she might well remain sceptical about the usefulness of such a tool.

Final Remarks

The target of this investigation was to evaluate the impact of a diagram in terms of a better comprehension of optical imagery. The paradoxical situation here is that, most of the time, such a potentially critical detail of practice is not likely to produce the least effect, when applied in isolation. The perspective adopted here is that a real step toward the comprehension of a commonly misunderstood topic can be made only when several details of practice are in mutual resonance, within the framework of a definite rationale. This said, one may wish for more specific information on such and such a detail of teaching strategy, rather than content oneself with simply experimenting different sets of grouped didactic actions. Hence the present investigation.

This investigation has enabled us to observe a difference in the frequency of answers among students presented with apparently very similar questions. Here, the physical situations did not differ as regards irrelevant parameters. That kind of comparison, often referred to as "question-dependence", is commonplace in research on students' conceptions (Viennot, 1994). Here, the proposed situations were the same, and the comparison bore on a graphical document intended to facilitate the solution of the problem posed. The samples questioned were the two halves of a given group, and the experiment was conducted at three different academic levels: Grade 12, degree students, and trainee teachers.

What we present here are only preliminary conclusions, and further research is obviously needed. As regards students experiencing great difficulty with the concept domain under study, no effect, broadly speaking, was observed in terms of correct answers. Let us imagine a teacher at Grade 12 level, with no particular concern for research, going over the answers analysed here. One might safely predict that he/she would conclude that there is no point in providing students with the basic diagram. But at least a few signs cast doubt on such a totally negative conclusion. With the version involving the basic diagram, more comments show a proper understanding of the role of a lens, beyond the mere idea of "deviated rays". This better comprehension seems to have facilitated a correct answer for one of the questions but not for the other. It is tempting to think that, for the students consulted, the first question was more accessible to autonomous reasoning on the basis of the proposed "basic diagram", whereas in the second question the threshold was too high. But that argument, taken on its own, is somewhat inconclusive.

However, if we now consider learners at a higher academic level (i.e., the trainee physics teachers or degree students), it seems that relatively clear effects were observed in favour of the basic diagram, for both of the questions discussed. We can imagine that, given the higher level of these students, the “accessibility” of the questions was relatively greater, or else that the threshold for autonomous and successful reasoning appears lower.

If our analysis turns out to be compatible with further results, it will shed some light on, or confirm, previous intuitions (Viennot & Rainson, 1999) about evaluating research-based sequences and some ingredients that are thought to be “critical”. The role of an isolated detail may remain undetectable in the majority of cases; that is, concerning topics that are considered difficult and learners whose state of comprehension is quite distant from the conceptual target. In such cases, given that the effects of each detail are not simply additive, when a noticeable conceptual progress is observed, it can be ascribed to a kind of resonance between all the ingredients brought to bear by the experimenters. One might say that “a critical mass of critical details” is necessary (Viennot, 2003b). In order to observe the effects of an isolated element of a teaching strategy both directly and in a focused way, it is probably necessary to experiment it with students who are, so to speak, on the threshold of the understanding that is aimed at, as were the trainee teachers or the degree students consulted in this study. Broadly speaking, it is a matter of the relative “distance” of the question with respect to the level of the learners consulted.

Incidentally, we might return to some of our previous studies about students’ conceptions and ask ourselves whether each time a student says that an image will be seen on the screen in the absence of a lens, for instance, he/she is in the same hopeless state of incomprehension. Some aspects of the answers observed here suggest that this is not the case. The words “image”, “spot”, “object” (on the screen) do not convey a stable meaning in many students’ comments, but this does not mean that a partial understanding had not been reached. For instance, one student might say that the “image” was “indistinct”, and then provide a diagram showing the light emitted by a point source propagating isotropically towards the screen, with the warning that it would be wrong to say that an image would be seen on the screen. An intermediate state of understanding can thus be assumed, in order to interpret the various aspects of a given answer. The idea that a partial understanding may be hidden by non-academic wording is not new and has long been discussed, with reference to Davidson’s principle of charity (Lijnse, 1994), for instance. Here, the point is to discuss the possible links between such a state of affairs and the outcomes of a given didactic intervention.

When students are too far from the targeted level of understanding, as were the students in Grade 12 consulted here, an isolated detail of teaching strategy cannot produce a visible effect in terms of correct answers. This is not surprising, but it is interesting with respect to the question of evaluating critical details in isolation. Indeed, we cannot conclude that this detail—here, a diagram—has no effect at all. With this group, a positive effect was observed for one question but not for what might be considered a more complex one. The students may have derived some benefit from the basic diagram for one question, although that critical detail alone was insufficient to help the students concerned to solve the other, more destabilising, question. As far as the degree students and trainees are concerned, it might be said that they had arrived at a kind of metastable situation, one nearer a proper understanding, and hence the visibly positive effects of the supposedly favourable detail. Such a "metastable" situation could be seen as a useful circumstance in which to evaluate a given aspect of teaching practice, even if it is only a "detail". It would be useful, then, to look for such privileged situations in order to assess the value of various "supposedly critical" details.

This said, teaching does not just mean providing a final impulse, a kind of conceptual flick, with which to help students reach the required understanding; it often means helping them build up a comprehension that is rather far from their starting point. This brings us back to our initial statement. Even if a series of "small" aspects of practice are supposed to be—or, ideally, known to be—useful as didactic tools, they should be seen simply as elements to be inserted in a global, well-defined strategy, one that is in full coherence with a clear teaching goal and a no less definite rationale.

As suggested elsewhere (Chauvet, 2001; Colin, Hirn-Chaine, & Viennot, 2001; Rebmann & Chauvet, 2001; Viennot, Chauvet, Colin, & Rebmann, 2004), our challenge is a tough one, but it is of the highest importance: to contribute to teachers' reflections on these matters so that they may better harmonise global orientations and principles on the one hand, and particular "details" of teaching strategy on the other. When the critical importance of a particular aspect can be evidenced with trainee teachers themselves—"privileged detectors", as they turned out to be in this study—the ensuing discussion is likely to be especially fruitful.

Note

1. Science Teacher Training in an Information Society (STTIS) is a research project founded by the European Union, DG XII, within the framework of the TSER programme, No. SOE2-CT97 20 20, coordinated by R. Pinto, UAB, Barcelona (http://www.blues.uab.es/~idmc42).

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