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Evaluation of the Effectiveness of a Method of Active Learning Based on Reigeluth and Stein's Elaboration Theory*

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Several studies have shown that methods of active learning are more effective for learning the concepts of physics than traditional methods. We propose an active learning method based on the Elaboration Theory of Instruction applied to topics of Geometrical Optics. The proposal was tested on a sample of 202 students distributed in eight natural groups, corresponding to classes of pre-engineer year secondary education ("2nd Year of Bachillerato" in Spain). Four of these groups followed the proposed Elaboration Theory-based instruction sequence, and the other four followed the control sequence of instruction corresponding to their teacher's traditional methods. Pre- and post-tests were applied designed to detect preconceptions in Geometrical Optics. Their results confirmed that, at least in teaching material of Geometrical Optics, sequencing the content and activities according to the prescriptions of Elaboration Theory improves the quality of the students' learning relative to traditional methods because, amongst other capacities, it is able to correct their preconceptions on the subject.

Keywords: research in physics; teaching methods; active learning; geometrical optics

1. INTRODUCTION

IN RECENT YEARS, engineer educators have begun to look more closely at what their students understand about science concepts. Student patterns of response to questions about natural phenomena often are in conflict with those accepted by the scientist community. The term 'misconception' will be used to refer to an incorrect pattern of response on the part of students. This pattern could be part of a coherent naive theory of some natural phenomenon or a more fragmented and primitive response produced on the spot as a result of the questions posed [1–3].

Numerous studies have shown active-learning methods to be effective in enhancing student learning of science concepts. These methods aim at promoting substantially greater engagement of students during in-class activities than occurs, for instance, in a traditional technology lecture [4–6].

Many of the implicit theories that often interfere with the teaching and learning process are to a great extent generated by an instructional sequence that fails to include a sufficient number of activities involving observation and analysis of the natural phenomena being taught.

We here present a proposal of active-learning or, following Hake [7], 'interactive engagement' (IE) methods based on Reigeluth and Stein's Elaboration Theory of Instruction [8] applied to topics related to Geometrical Optics located in the syllabus of pre-engineer secondary education. The basis of the Elaboration Theory is principally to establish how to organize, sequence and present the teaching of certain content pertaining to some macrolevel. As in the Theory of Meaningful Learning [9,10], we begin with analysis of the content of the different branches of the subject, with their most significant core concepts and their internal organization, i.e. what has been called the subject's logical structure. But unlike Meaningful Learning Theory, Reigeluth and Stein propose a spiral form of sequence beginning with a first simplest lesson, the 'epitome', and then progress in levels of increasing elaboration and complexity. Nevertheless, notwithstanding its undeniable theoretical strengths and recognized relevance as part of the constructivist approach to teaching [11], there have been very few studies of its actual effectiveness in different areas of learning.

Given our previous satisfactory results [12–14] and the scarcity of practical applications to engineer teaching of this powerful and solidly founded technology of instruction, we decided to make an in-depth study of a specific application of Elaboration Theory . We would thereby also be contributing to the endowment of teachers in the subject with an effective method for sequencing their instruction of the content.

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One aim was to answer a question that is very important for engineer teachers: can the classroom use of IE methods based on Elaboration Theory correct the misconceptions that the students may have, and thus increase the effectiveness of their learning beyond what is attained with the generally relatively unsystematic and not very reflective traditional methods?

The method we used was a quantitative study of pre- and post-test results, with the two tests (Appendix) being designed to detect preconceptions in geometrical optics. The participants were 202 students in the final year of secondary education, orientated to engineer higher education and the materials that were developed for the study now form the 'Geometrical Optics Teaching Unit' [15].

2. ELABORATION THEORY

We shall here just summarize the principles that Elaboration Theory is based on [8, 12–14], since an in-depth treatment is not the primary goal of the present article, and would necessarily be long and somewhat tedious.

Elaboration Theory is a technique for preparing an educational macrosequence structured cyclically as 'zooming in' from a wide overall perspective to ever greater detail. The zoom lens analogy of the technique of elaboration is probably one of Reigeluth's most interesting contributions to the Psychology of Instruction. For Reigeluth, the descent involved in the detailed elaboration of the general content must be alternated with frequent ascents. The result is a kind of spiral cyclic process, resembling the operation of the mechanism of a camera's zoom lens, combining various learning processes and strategies: subordinate, superordinate, coordinate and experiential.

In these processes, we have four teaching instruments that facilitate the sequencing and learning of the content: epitomes, levels of elaboration, learning prerequisites and support strategies.

A teaching and learning sequence begins with the epitome. This is a first panoramic view of the most general content that will later be dealt with in detail. In the photographic analogy, this is like using the wide-angle lens. The epitome presents a synthesis of the most general ideas in the context of some specific application, so that the overall relationships are given priority over particular content.

The epitome has to be structured around some organizing content which for Reigeluth may be a concept, a principle, or a procedure. The teacher must choose what to take as this backbone on which to build the learning process. The rest of the content will be linked in as support structures.

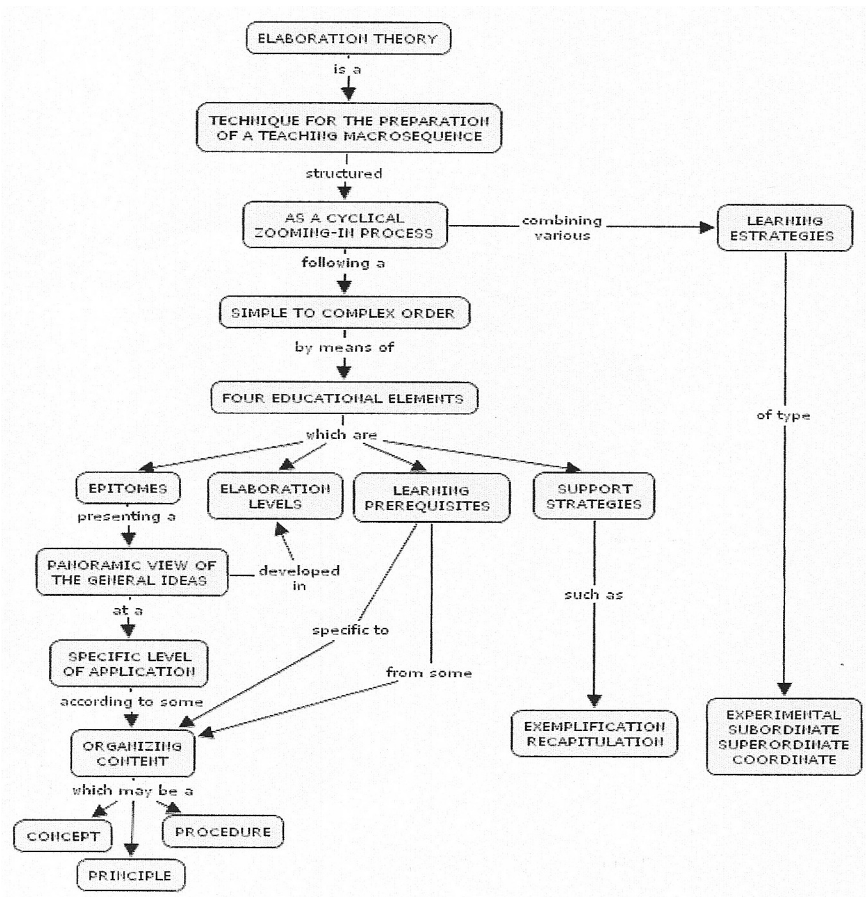

Fig. 1. Concept map of the logical structure of Elaboration Theory.

The general ideas presented in the epitome will be taken up again and enlarged upon each time we go into more depth in the content of the different levels of elaboration.

Reigeluth stresses the importance of the learning prerequisites. The teacher has to activate the students' prior knowledge and the strategies they need to be able to assimilate the fundamental elements of the content. These critical components are specific to the type of organizing content chosen, and will be the referents in planning the prerequisites for each step in the learning process.

As support strategies to construct these levels of elaboration, as well as the general audiovisual and technological resources, the teacher will use exemplification and recapitulation which also facilitate the continual cyclic process of transforming general concepts into more specific elements.

Figure 1 is a concept map showing the logical structure of the Elaboration Theory of Instruction [12].

2.1 Adapting the elaboration theory of instruction to engineer teaching

Reigeluth considers three types of organizing content, and indeed, together with the zooming-in analogy, this is another of the interesting contributions of Elaboration Theory to the Psychology of Instruction. We believe, however, that in the case of engineer teaching it is necessary to take the phenomenon into account [12], firstly as new learning content, and secondly as the only organizing content which can structure the learning sequence so that the other content (concepts, principles and procedures) are linked in as support elements. There is a threefold justification for this modification:

(1) Epistemologically: the connection with the processes of construction of scientific knowledge. The construction of scientific theories is founded on the observation of reality, specifically on the variety of natural phenomena.
(2) Psychologically: the connection with the student's need to obtain causal explanations.
(3) Pedagogically: constructing the teaching process around phenomena as the structural backbone favours the use of various experiential and discovery strategies of learning

3. STUDY DESIGN

We used a quasi-experimental multigroup design with pre- and post-tests and a control group.

Our principal hypothesis was that we achieve meaningful learning with the Elaboration Theory orientated preparation of teaching-learning sequences, since one of its capacities is to correct student preconceptions about the subject, which in our opinion means an improvement in the quality of learning.

The sample size was 202 subjects, divided into eight natural groups corresponding to 2nd Year of Bachillerato classes in six schools of the province of Badajoz. Four of the groups, 1–4, were assigned to the experimental condition (Elaboration Theory-based instruction sequence) and the other four, 5–8, to the control condition (the teacher's traditional instruction sequence). The groups consisted of between 15 and 39 students (Table 1).

Table 1. Distribution of students who participated in the study

Group	Type	Number of students
1	experimental	17
2	experimental	39
3	experimental	35
4	experimental	18
5	control	15
6	control	23
7	control	32
8	control	23

The independent variable was taken to be the method used to sequence the content in the Optics teaching unit. This had two values:

(1) Method based on the prescriptions derived from the Elaboration Theory of Instruction;
(2) Habitual method.

The dependent variable, 'misconceptions', was defined from the need to correct the students' erroneous implicit theories about the phenomena of Geometrical Optics.

Appendix gives the two objective specific tests (a pre-test and a post-test) that were designed for use with all the groups to evaluate the dependent variable. Both tests consist of 10 items with 4 possible answers.

Misconceptions brought out by these tests were:

- Identifying light with its sources or with its effects [16]. (Item 1)
- Previous ideas on the mechanism of vision [16]. (Item 2)
- Relating the size of shadows with the brightness of the light source [17]. (Item 3)
- On the propagation of the light: the light from a source propagates in preferential directions [18]. (Item 4)
- Considering that light itself is visible [19]. (Item 5)
- Preconception on the position of the image formed in a plane mirror [20]. (Item 6)
- Considering that a magnifying glass increases the intensity (amount) of light [16]. (Item 7)
- Considering the existence of an image in the absence of lenses [21]. (Item 8)
- Difficulty in knowing where the real image is located (is it the light or the image that is propagated?) [22]. (Items 9 and 10)

The pre-test and post-test were different, although they were prepared together and are equivalent, in order to avoid the possible 'learning effect' between the pre-test and the post-test. Each teacher first gave his or her students the pre-test, and the results were the reference with which to grade each student [23].

In the instruction, the teacher followed the orientations based on Elaboration Theory with the experimental groups, and the traditional method with the control groups. Instruction lasted approximately five weeks in both cases. The post-test evaluation was done one month after the students of all the groups (experimental and control) had taken an official examination on the subject.

4. FORMAT OF FULLY INTERACTIVE CLASS FOLLOWING THE ELABORATION THEORY

Given the purpose of the educational principles governing the preparation of a teaching unit based on the Elaboration Theory, we distinguish three types of activity.

The first step is to design activities (for example, the pre-test used in the present study) to detect the implicit theories that our students may have about the natural phenomena that are going to be dealt with. These activities are therefore targeted at the student's cognitive context.

The starting point is to try to get our students to describe explicitly the alternative theories they have about the natural phenomena, and to confront the conceptual conflict that arises with the official theories. We think that starting out with the students' implicit theories is, as well as cognitively necessary, one of the options that is most motivating for them. The commitment that everybody has to individual operational schemes of knowledge quickly leads them into a shared experience in the class that they find suggestive and appealing. It brings into play the affective domain—a fundamental element of our pedagogical approach—in connection with the content being dealt with. We like to paraphrase Aristotle by saying that 'a man will learn nothing except on the basis of what he already knows' [24].

Activities for the epitome are above all targeted at the experiential by organizing and strengthening students' initial experience (which will later be enlarged on throughout the teaching unit). But they also affect the cognitive context, because they provide us with a good opportunity to explore students' previous instructional ideas (not the same as the misconceptions mentioned above).

The aim in the epitome is to introduce students to the topic, giving them a general overview which is at the same time based on concrete examples that are close to them. The epitome also provides another chance to continue insisting on the theories dealt with before.

It is advisable to let students participate freely, without correcting any scientific mistakes that they might make. The idea is to get them to give general descriptions based directly on their perception of the phenomena, to get them involved in the experience, and to really enjoy taking part. Experimenting with new ideas should provide sensations that the student picks up at an affective level. Although the teacher needs to channel the discussion and obtain a minimally coherent synthesis, he or she must not give in to the temptation to provide explanations for the observed facts beyond conjecture on the fundamental causal fact.

On finalizing the development of the epitome (and also after finishing the presentation of the content), we ask the students to make a concept map in which they specify graphically their knowledge of the phenomena that have been dealt with and the relationships between them. This activity seems to us to be very important since, as Novak and Gowin [25] point out, the act of making concept maps is a creative activity in which the student must make an effort to clarify meanings by identifying important concepts, relationships and structures within a specific domain of knowledge. The creation of knowledge requires a high level of meaningful learning, and is facilitated for students when they construct such maps of the concepts involved in a discipline [26]. Indeed, the important thing is the process of creation of the map rather than the end result, since the reproduction of a concept map reveals the processes through which meaningful learning is occurring [27].

Activities targeted at developing the content serve to complement and fill out the initially proposed experiments. The student is exposed to a process of reflection on those experiments, and to an application (action) as a result of the desirable cognitive and affective commitment which he or she must make.

By way of examples, we shall present activity No. 4 corresponding to the epitome, and activity No. 5 corresponding to the content. The other activities corresponding to the development of the epitome form part of the geometrical optics teaching unit [15].

Example activity: No. 4. Epitome (refraction and formation of images by plane interfaces). Material: a container of water, a pencil and a marble. Students will examine the empty container, especially observing its depth. The teacher next pours some water into the container and puts the pencil, at a slight inclination, partially into the water (Fig. 2).

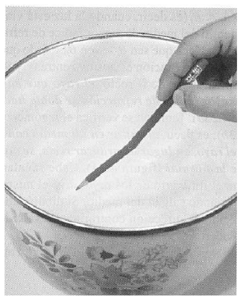

Fig. 2. Pencil partially in water.

Students are asked to indicate what they have observed, responding to the following questions:

- How do you see the pencil now?
- What is happening? (*Fundamental causal fact*)
- What makes the pencil looks bent? (*Positing a relationship*)

Next we put a marble into the container and ask the students to indicate what details they have observed. In particular:

- What depth is the marble seen at?
- What is happening? (*Fundamental causal fact*)
- If the depth (position of the marble) of the container is known, can the distance at which the marble is seen be predicted? What does it depend on? (*Positing a relationship*).

In both sections, the students can be asked:

- If the direction of the incident ray on the surface of the water is known, can the direction of the refracted ray be predicted? What does it depend on? (*Positing a relationship*).
- If the plane containing the ray of light reaching the surface of the water is known, can the plane containing the refracted ray be predicted? What does it depend on? (*Positing a relationship*).

Example activity: No. 5. Reflection of light by plane surfaces. Material: a light source, a sheet of paper, a grating diaphragm, a Hartl disc (a graduated circle of paper) and a mirror. The diaphragm is placed between the light source and the mirror. A straight line is drawn on the sheet of paper and the mirror is placed perpendicular to it. The 0°-180° line of the Hartl disc is made to coincide with this line, and the light source is pointed towards the mirror (Fig. 3) (a) so that the light beam strikes the mirror perpendicularly; (b) repeating the setup but for different directions (30°, 45°, 60°) of the incident ray.

Next, the teacher folds the sheet of paper in half, opens it up again, places the mirror on one of the halves, and orientates the other half in different positions so that the two halves form angles of 90°, 60°, 45°, . . . , and 0°. Open questions:

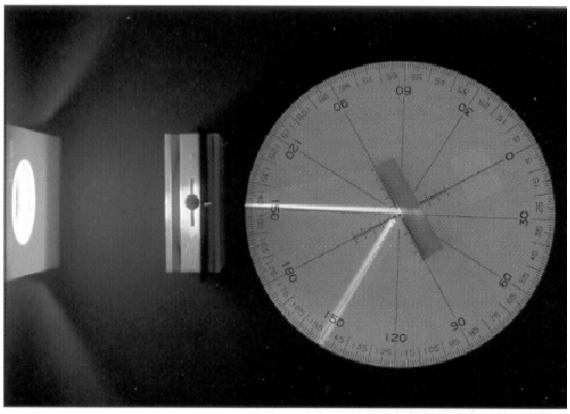

Fig. 3. Reflection of light in a mirror.

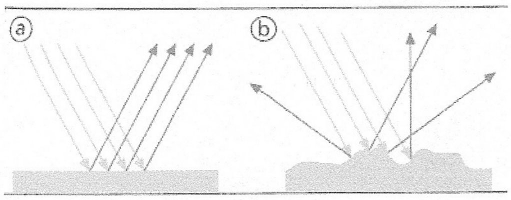

Fig. 4. Specular (a) and diffuse (b) reflection.

- What can you say about the incident and reflected angles with respect to each other in each case?
- In which plane are the incident and the reflected rays? What can you say about this plane with respect to the mirror?

The students are asked to:

- Draw a ray diagram of what they observed.
- Collaborating in groups of two or three, suggest the laws that govern this phenomenon.

The teacher makes a synthesis of the responses, then uses a ray diagram to enunciate the two laws of reflection:

(1) The incident ray, the normal and the reflected ray are in the same plane.
(2) The angle of incidence and the angle of reflection are equal.

The teacher will next indicate that the reflection we have just observed is called specular reflection, but that we must also consider diffuse reflection (scattering) which is the most common (Fig. 4). He or she will explain the differences between them, stressing that the laws of reflection are satisfied in both cases.

On the basis of the diffuse reflection or scattering of light, we can discuss with the students how we see objects that are not in themselves luminous. Open question—how do we see objects that are not luminous?

The teacher makes a synthesis of the students' answers, and then gives the final explanation.

5. ANALYSIS OF THE RESULTS

A multigroup one-way analysis of variance (ANOVA) [28, 29] was used to determine whether there were significant differences between the groups of students (both pre-test and post-test). Basically this technique consists of comparing the differences in the scores of the individuals of each group (intragroup variability) with the differences in the scores of the different groups (intergroup variability). If there is no statistically significant difference between the two, we then assume that the intergroup differences are also due to chance. If, however, the intergroup variability is significantly greater than the intragroup variability, we can take this as not due to chance but to the independent variable causing there to exist differences between groups [30]. The comparison is carried out by means of the F distribution [31] as follows.

The intergroup and the intragroup variability are defined respectively as the intergroup mean square difference ($MS_{\text{intergroup}}$) and the intragroup mean square difference ($MS_{\text{intragroup}}$):

$$MS_{\text{intergroup}} = \frac{SS_{\text{intergroup}}}{k-1} = \frac{\sum_{i=1}^{k} (\bar{X}_i - \bar{X}_t)^2 n}{k-1} \quad (1)$$

$$MS_{\text{intragroup}} = \frac{SS_{\text{intragroup}}}{N-k} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n} (\bar{X}_{ij} - \bar{X}_i)^2}{N-k} \quad (2)$$

where N is the total number of subjects, n the number of subjects in each group, k the number of groups, $\bar{X}_t$ the mean score of all the subjects, $\bar{X}_i$ the mean score of group i, and there are $N-1$ total degrees-of-freedom (dof), $k-1$ intergroup dof, and $N-k$ intragroup dof. The F-test is now applied to determine whether the value of the intergroup mean square difference is significantly greater than the intragroup value:

$$F_{\text{calc}} = \frac{MS_{\text{intergroup}}}{MS_{\text{intragroup}}} \quad (3)$$

The value of F_{calc} is compared with the critical value F_{tab} in the Fisher-Snedecor tables of the distribution [32] to establish the opportune conclusion: if $F_{calc} > F_{tab}$ then one can state that there are indeed significant differences between the groups.

5.1 Pre-test results

To check that possible differences in ability and prior knowledge of the students in the different groups would not negate the effectiveness of the method, a pre-test ANOVA was performed to check for intergroup differences in starting level. For a significance level of a = 0.05 and the value of the degrees of freedom, the critical value F_{tab} (a,dof_1,dof_2) = F_{tab} was found in the Fisher-Snedecor tables. The results (Table 2) clearly showed that there were no significant differences between the eight groups ($F_{calc} < F_{tab} = 2.01$).

In sum, the analysis of variance of the pre-test results showed that in general the eight groups were homogeneous, which was to be expected given the universality of implicit theories.

5.2 Post-test results

The analysis of variance of the post-test results (Table 3) showed that there were now significant differences between the eight groups ($F_{cal} > F_{tab}$).

A second ANOVA was performed to check for differences between the experimental (Groups 1–4) and the control (Groups 5–8) instructional methods.This ANOVA (Table 4) confirmed the significance of the differences between the mean scores of both groups.

Table 2. Pre-test results of the ANOVA for the variable 'implicit theories'

	Sum of squares	dof	Mean square	F_{calc}	F_{tab}
Inter-group	31.811	7	4.544	1.549	2.01
Intra-group	569.025	194	2.933		
Total	600.837	201			

Table 3. Post-test results of the ANOVA for the variable 'implicit theories'

	Sum of squares	dof	Mean square	F_{calc}	F_{tab}
Inter-group	112.657	7	16.094	6.019	2.01
Intra-group	510.720	191	2.674		
Total	623.377	198			

Table 4. Post-test results of the ANOVA for the variable 'implicit theories' of the experimental (1–4) and control (5–8) groups

	Sum of squares	dof	Mean square	F_{calc}	F_{tab}
Inter-group	77.340	1	77.340	27.903	3.84
Intra-group	546.037	197	2.772		
Total	623.377	198			

These results seem to indicate that the difference is due to the independent variable [30]. In our case, this is fundamentally an effect of the teaching methods used.

To complement the foregoing studies, for each of the eight groups, we analysed the means obtained for each group and the differences in pre-test and post-test means as a measure of the 'amount of learning' that the group had made. From these values, we calculated the average normalized gain (G)[4] for a group as the ratio between the actual average gain (amount of learning (D)) and the maximum possible average gain,

$$G = \frac{D}{10 - M_i} \quad (4)$$

where M_i are the initial (pre) group averages. Table 5 presents the results.

We observe from the table that all four experimental groups had both higher post-test mean scores and greater increases in these scores than the control groups. The latter was even the case for Groups 3 and 4 which began with two of the three highest pre-test mean scores.

There stand out the major increases in the means of Groups 1 and 2, which started out with the lowest means of the eight groups. They even surpassed the post-test mean of all the control groups which started out with a higher pre-test mean.

The case of Group 6 merits a comment apart. This was the only group which had a lower post-

Table 5. Values of the means, differences between the means of the pre-test and post-test results (D) and the average normalized gain (G)

Group	Pre-test mean	Post-test mean	D	G	Condition
1	4.4118	6.4375	2.0254	0.36	**experimental**
2	4.5128	6.5676	2.0548	0.37	**experimental**
3	4.9143	5.5429	0.6286	0.12	**experimental**
4	5.9444	6.7647	0.8203	0.20	**experimental**
5	4.7333	4.9333	0.2	0.04	control
6	5.0870	4.5714	–0.5156	–0.10	control
7	4.8750	5.3437	0.4687	0.09	control
8	4.8564	5.0526	0.4004	0.08	control

test than pre-test mean score (the only negative value of the difference in Table 5). Although this result seems in principle illogical in that the students answered the test following instruction in the topic more poorly than the initial test, we think that it is due to the appearance of what is known as 'cognitive conflict'. At the time of doing the post-test, there co-exist in the students' minds the scientific theories that the teacher has attempted to explain and their own preconceptions about the natural phenomena they had been studying. This gives rise to a transitory situation of 'feeling lost' until the scientific theory is eventually 'comprehended' and 'displaces' the preconceptions. It seems evident that in this case no meaningful learning has been achieved.

6. CONCLUSIONS

The results confirm our principal hypothesis and show with considerable clarity that, in teaching the content of Optics, sequencing the content and activities according to the prescriptions of Reigeluth and Stein's Elaboration Theory is more effective than traditional methods which are generally less reflexive and systematic.

The importance of observation and experiment, both for the development of Applied Sciences and for the comprehensive elaboration of causal explanations during the learning process, makes Reigeluth and Stein's theory a highly useful point from which to begin if the specific modifications that we have proposed are taken into account: to consider phenomena first as new learning content, and second as the organizing backbone of the learning sequence on to which the other content (concepts, principles and procedures) can be hooked as support.

Another important conclusion concerns the weight of the principal independent variable (the method of sequencing the content and the activities) in the variations observed between the pre-test and post-test results. At the beginning of the study, we expected positive results for both groups. But we were unsure of being able to even minimally isolate the effect of the methodological orientations used from other variables inherent in prior communicative teaching methods, with slightly better results in the experimental groups than in the control and teaching skills of each teacher. The results not only showed a significant improvement due to the methodological approach in the experimental groups over the control groups, but also that a post-test ANOVA comparing the four experimental groups did not find that any differences due to the specific interaction between each group and each teacher were really significant [33].

Apart from experimental problems, the external validity of a study that in no way was going to be purely of a 'laboratory' type seems beyond all doubt. For us at the end of the study, the solidest (even if not the most objective) proof of the potential of this method lay in the enthusiasm of the participating teachers with the experimental groups as they observed the changes in their students under completely natural conditions, both of teaching and of evaluating the learning in the classroom.

Finally, we would emphasize that, while the learning gains may seem low compared with other studies of the same type, those studies used tests specifically designed to assess students' understanding in different disciplines. In the present case, we evaluated learning gains in correcting preconceptions which we believe is the starting point for meaningful learning.

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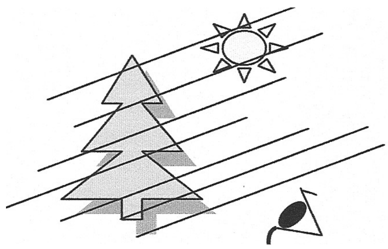
APPENDIX

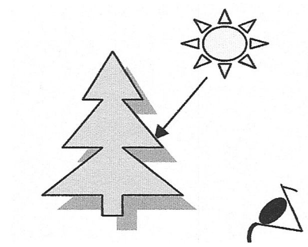
1. Test of implicit theories (pre-test)

1. In a room, there is a lit lamp, a mirror, a table and several chairs. Where is there light?
   (a) The light is in the lamp.
   (b) In the lamp and the mirror.
   (c) In all the objects: the walls, the mirror, the table, the chairs.
   (d) In all the room.

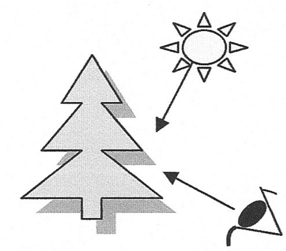
2. Which of the following diagrams do you believe best explains why we see the tree?



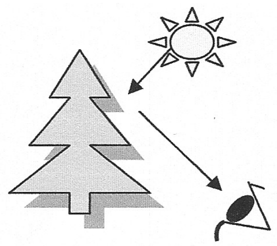
(a) The sunlight fills the space.



(b) The tree is lit by the sun.



(c) Vision goes from the eye to the tree which is lit by the sun.



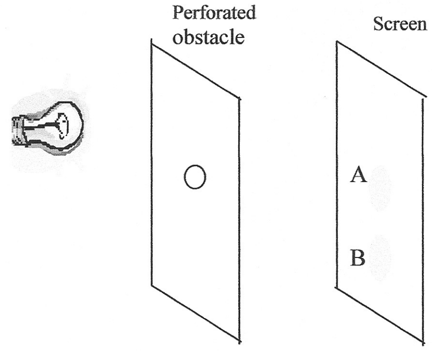
(d) The sunlight is reflected by the tree and reaches our eyes.

3. What is the shadow of an object illuminated by a dim light bulb like with respect to the shadow of the same object illuminated by a bright light bulb?

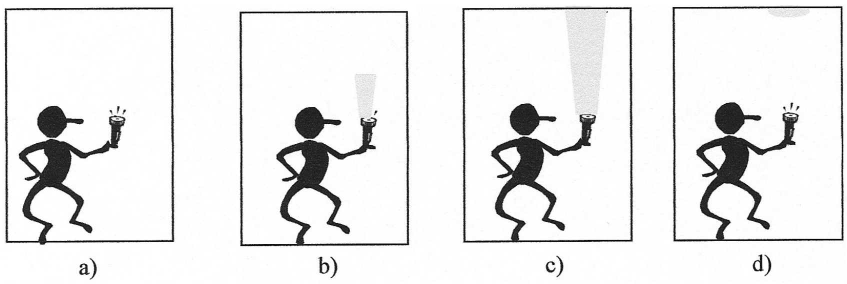
   (a) Bigger.
   (b) Smaller.
   (c) The same size.
   (d) I do not know.

4. The following figure shows a light bulb, an obstacle with a hole in it and a screen. Does light reach the screen?

   (a) No.
   (b) Yes, it will be illuminated in zone A.
   (c) Yes, it will be illuminated in zone B.
   (d) Yes, it will be illuminated in zones A and B.

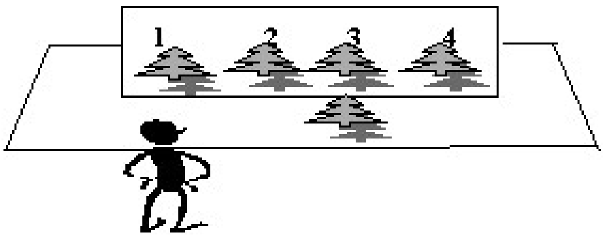


5. In a dark room which is perfectly clean, with no dust or smoke in the air, we turn on a torch aimed at the ceiling. Choose the drawing that represents what you would observe.



6. In the following figure, where does the observer locate the image of the tree in the mirror?

(a) Position 1, in front of the observer.
(b) Position 2, between the observer and the tree.
(c) Position 3, opposite the tree.
(d) Position 4, to the right of the tree.

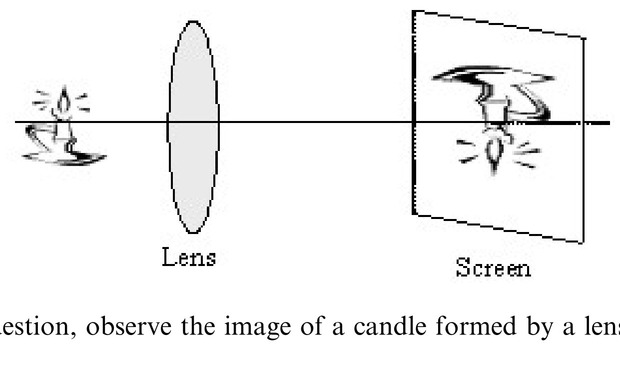


7. When the light from the sun goes through a magnifying glass it can burn a piece of paper. In this situation, which of the following cases is true?

(a) The amount of light that leaves the magnifying glass is greater than the amount reaching the magnifying glass.
(b) The amount of light that leaves the magnifying glass is less than the amount reaching the magnifying glass.
(c) The amount of light that leaves the magnifying glass is equal to the amount reaching the magnifying glass.
(d) The amount of light reaching the paper depends on how dark the paper is.

8. Observe the inverted image of the candle that the lens forms on the screen. When the lens is taken away:

(a) The image disappears.
(b) The image on the screen will still be seen, but the right way up.
(c) The image on the screen will still be seen, but smaller.
(d) The image on the screen will still be seen, but the right way up and the same size.

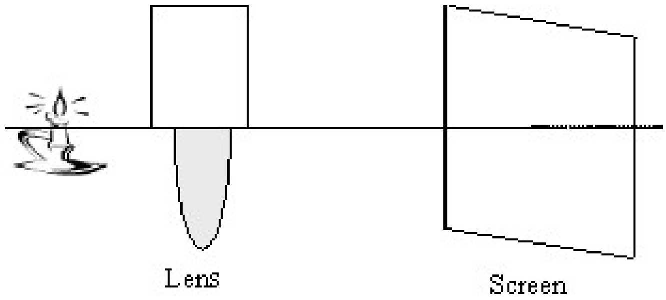


9. Like in the previous question, observe the image of a candle formed by a lens on the screen. When the screen is taken away:

(a) The image is not formed.
(b) The image is not seen, but it is formed.
(c) The image does not disappear but it is the right way up.
(d) The image does not disappear but it becomes smaller.

10. Still with the same figure, if half of the lens is covered up:

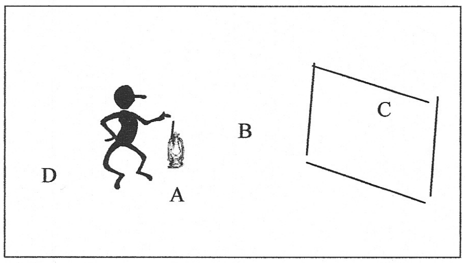
(a) Only the corresponding half of the image will be formed.
(b) The whole image will be formed.
(c) The image will not be formed.
(d) An image will be formed that is half the size of the previous one.



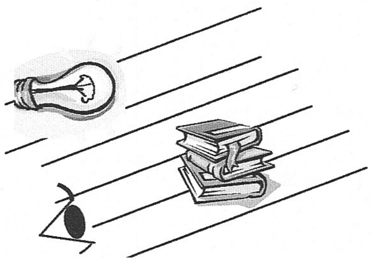
1. Test of implicit theories (post-test)
1. In a room that is initially in the dark we light a lamp that illuminates the wall. The situation is shown in the figure. Where is there light?

(a) There is light only in zone A.
(b) There is light only in zones A and C.
(c) There is light only in zones A, B, and C.
(d) There is light everywhere . . . A, B, C, and D.

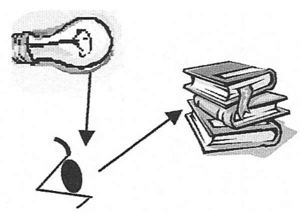
A is the lamp. B is the space between the lamp and the wall. C is the wall. D is the zone behind the lamp.



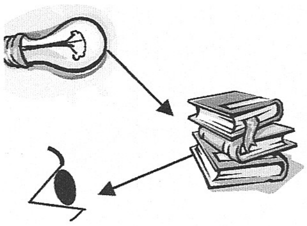
2. Which of the following diagrams do you believe best explains why we see the books?



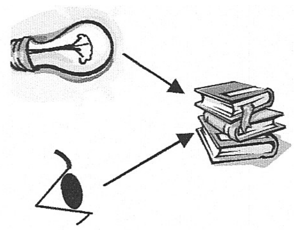
(a) The light of the bulb fills the space.



(b) The eye is lit by the bulb and the vision goes from the eye to the books.



(c) The light of the bulb is reflected by the books and reaches our eyes.



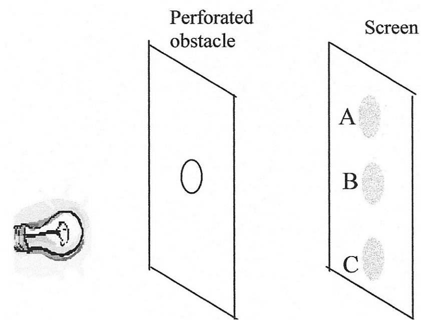
(d) Vision goes from the eye to the books which are lit by the bulb.

3. We have a light source and an opaque object that projects a shadow on a screen. What will the shadow of the illuminated object be like if we change the light source to one that is dimmer?

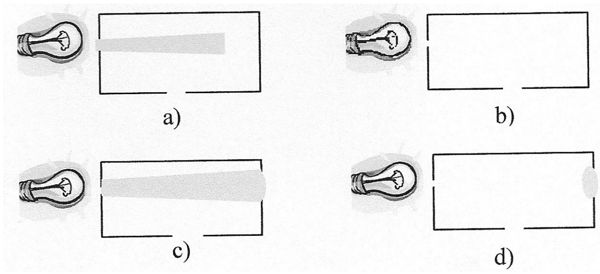
(a) The same size as before.
(b) Bigger than before.
(c) Smaller than before.
(d) I do not know.

4. The following figure shows a light bulb, an obstacle with a hole in it, and a screen. Which zone of the screen will be illuminated?

(a) Zone A.
(b) Zone A and zone B.
(c) Zone A, zone B, and zone C.
(d) The screen will not be illuminated.

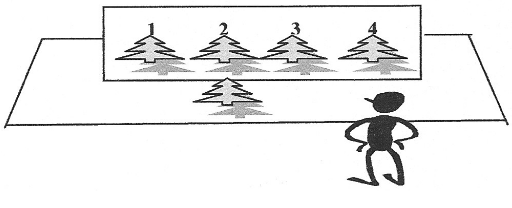


5. We have a perfectly closed box except for a small hole that allows the passage of a very narrow beam of light. If through a small window made in the lower part of the box we observe what happens inside, which of the following drawings represents what we see?



6. In the following figure, where does the observer locate the image of the tree in the mirror?

(a) Position 1, to the left of the tree.
(b) Position 2, opposite the tree.
(c) Position 3, between the observer and the tree.
(d) Position 4, opposite the observer.

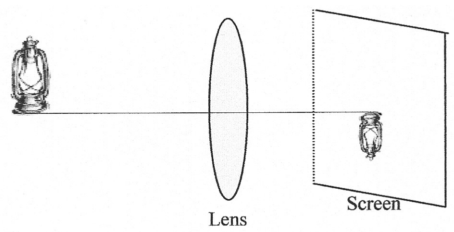


7. Light from the sun passing through a converging lens can burn a piece of paper. In this situation, which of the following cases is true?

(a) The amount of light that leaves the lens has heated up.
(b) The amount of light that leaves the lens is equal to the amount reaching the lens.
(c) The amount of light that leaves the lens is greater than the amount reaching the lens.
(d) The amount of light that leaves the lens is less than the amount reaching the lens.

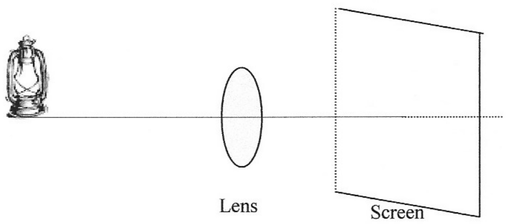
8. In the figure, there is a converging lens placed between the lamp and the screen so that an inverted image of the lamp is formed. If we take the lens away:

(a) The image formed will be the right way up.
(b) The image formed will be bigger and the right way up.
(c) The image formed will be the right way up and the same size.
(d) The image will not be formed.



9. In the previous figure, what will happen if we take the screen away?
(a) The image will not be seen, but it will be formed.
(b) The image will appear the right way up.
(c) The image will appear bigger.
(d) The image will not be formed.

10. Let us suppose that in the figure of Question 8 we change the lens for another of smaller size.
(a) The image will not be formed.
(b) A smaller image will be formed than in the previous case.
(c) Only half of the image will be formed.
(d) The same image will be formed.



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