Experimentation of Java Software of Geometrical Optics JSGO during the geometrical construction of the virtual image

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ABSTRACT

This work aims to study the impact of using Java Software of Geometrical Optics JSGO on the geometrical construction success of the virtual image among the pupils in the first year of Baccalaureate, option: Experimental Sciences ES.

To examine this impact, we realized an experiment towards the end of the school year 2012/2013 among a group of learner consisting of 41 pupils. These pupils took a pretest using the traditional method, followed by a formation on how to use JSGO and finally they set for a posttest using the mentioned software.

The analysis of the results of our study "evolution of the nature of geometrical constructions produced" confirms that using JSGO does not induce, in any case, the pupils to make an error in the construction of the virtual image.

By analyzing the results concerning "pupils' conceptual difficulties" we have scored the presence of the conceptual difficulty associated with an incorrect status that about 32 % of learners attribute to the construction ray extension. The use of JSGO provides a useful tool to overcome this conceptual difficulty. This analysis also indicates that, despite the interactive character of JSGO, about 12 % of pupils still face the conceptual difficulty related to the correspondence image object (punctual and global) and also to the conceptual difficulty related to the minimum number of rays departing from the same point of the luminous object.

Finally, the study of "pupils' perceptions about using JSGO" showed that the participants are very satisfied with using this computer wizard.

Indexing terms/Keywords

Java Software of Geometrical Optics JSGO, virtual image, pretest, posttest, geometrical optics.

Academic Discipline and Sub-Disciplines

Education, Computer Technology and Didactic of Physical Sciences

SUBJECT CLASSIFICATION

Innovation in education

INTRODUCTION AND PROBLEM

For two decades, the modern methods based on the computer technology have developed in various fields. Thus, in the field of geometrical optics, many researchers have developed computer tools (platform, software, tutorial, simulation, etc.) that allow to the user to take advantage (courses, exercises, simulations, filmed manipulations, etc.). The use of these tools has generated numerous investigations interested in studying the impact produced by the use of these technologies on the students' learning.

(Benjelloun, Alami and Rebmann, 2003) analyzed the integration of a Java Software of Geometrical Optics JSGO in the situations of solving a problem among thirty - one students in the second year of university, option: Sciences of Physical Matter (SPM). Their results showed that, despite the high interactivity of JSGO with the optical components, the learners provided a false geometrical construction.

Bayrak (2008) investigated the effectiveness of the teaching assisted by computer in relation to the traditional teaching. The experimental group consisted of biology students who received a teaching of geometrical optics by using the simulation, whereas the control group consisted of chemistry students who received the same teaching by the traditional method. The results showed that the control group was less successful than the experimental group.

Bryan and Slough (2009) have studied the students' prediction about the images formation by using lenses, especially when the parts of the lens are covered. This study was conducted by examining the influences of four simulations which were designed differently. Their results revealed that the origin of construction rays affects the students' predictions, while the different numbers of construction rays have a little influence on their predictions.

The use of computer technology in teaching is increasingly solicited in the multimedia classrooms and in the laboratories. Therefore, several works have been carried out in the geometrical optics using computer tools to examine their influence on students' learning.

In the first instance, many researchers have shown that the integration of computer technology in the geometrical optics teaching has a positive influence on the acquisition of certain concepts.

Buty (2003) studied the incorporation of a materialized model into a teaching sequence of geometrical optics and the assumptions on which this incorporation is based. He showed that using this materialized model facilitates the physical sense construction and the modeling processes between, the world of models and theories and the world of events and objects.

(Ahaji and al, 2008) analyzed the effect of integrating a simulation of geometrical optics on the pupils' learning in the first year of Baccalaureate, option: experimental sciences. The results showed that the integration of this simulation has a positive effect on the teaching process.

In a second instance, the results presented by other researchers showed that it is not easy to prove the benefits of the integrating of the software tools on students' teaching.

(Kulik and al, 1980) presented the results of the meta-analysis of 59 independent evaluations conducted by computer. The result showed that the computer-assisted teaching carries a small contribution to the effectiveness of the teaching in college and has a little influence on pupils' attitudes towards the subject that they study.

Clark (2011) examined the teaching of image formation using converging, diverging lenses and mirrors among the students. These students are from two sections of high school and they are enrolled in the same course with the same professor. The first section carried out an activity of image formation using paper, pencil and ruler, while the other section did an activity of image formation through a computer simulation. The results showed that there was a significant advantage in the performance of the students who worked with, paper, pencil and ruler and that the computer-based teaching strategy may not always be the most beneficial for learning.

(Eylon, Ronen and Ganiel, 1996) have explored the use of the simulation to improve the teaching of geometrical optics in high school. Their comparative study showed that the only use of simulation has a limited influence on the learners' conceptual change. A major obstacle resides in the fact that "the student considers systematically the relation between the formation of images and its observation". In addition, this research showed the role of three factors in the students' conceptual change: computer tool, the task targeting the conceptual difficulty, and the reformulation of ideas.

In a second work, (Benjelloun, Alami and Rebmann, 2004) evaluated, among students from the second year of university, the contribution of the use of Java Software of Geometrical Optics JSGO to overcome some conceptual difficulties in geometrical optics using a converging lens. These conceptual difficulties are related to the tracing of construction rays and its extensions when an optical component is moved; and they are also related to the physical sense attributed by the student to the formed optical image. These authors showed a "reverse evolution from correct answers with a correct justification using, paper and pencil to correct answers without justification by using JSGO".

Zacharia (2005) studied the impact of interactive simulations on the explanations' quality of the teachers of sciences. The simulations have targeted the thermal, mechanical and optical phenomena. Data were collected through semi-structured interviews and were analyzed using a content analysis approach. The results showed that to have a positive impact on the explanations quality of science teachers, it is very important to combine the use of simulation with the "to predict- to observe- to explain" model.

While researches have confirmed that the use of computers' technology is beneficial to teaching geometrical optics, others have shown that it is not easy to prove the positive influence of using such tool. From this point of view, we targeted through this work, an objective that lies in the study of the influence of using the computer tool named "Java Software of Geometrical Optics (JSGO)" on the nature of the geometrical construction of the virtual image produced. And, in the case where this usage appears favorable, we will study the conceptual difficulty (difficulties) to which the integration of JSGO is useful.

Research questions

The questions which our research is interested in are:

Does using JSGO represent a useful tool for the geometrical construction of the virtual image? What is (are) the conceptual difficulty (difficulties) for which the use of JSGO is helpful? Can the use of JSGO induce the learners to make an error in the geometrical construction? What is the influence of using JSGO on the execution time-management?

RESEARCH FRAMEWORK

1. Description of tests and learners' corpus

During this research we developed within the framework of Gauss conditions a pretest and a posttest concerning the geometrical construction of the virtual image. Each of them consists of two sub-tests: A first variant sub-test and a second variant sub-test as described below:

The first variant sub-tests: 1-1; 2-1 (Appendix 1) are simple and classical exercises of the construction of the virtual image we can find in the school textbooks.

The second variant sub-tests: 1-2; 2-2 (Appendix 1) are classical exercises of the geometrical construction of the virtual image which we have modified to render them less stereotyped and less unusual than the exercises studied often in the classroom.

The tests are similar in content but they differ in the schemas. The sub-tests: 1-1 and 1-2 are respectively equivalent to the sub-tests: 2-1 and 2-2. This equivalence has been proven by calculating the difficulty index of each sub-test among an external corpus of learners who worked with the traditional method.

The participants are from the first year of baccalaureate, between 16 and 18 years old, option: Experimental Sciences ES. These participants have already received a classical teaching of the geometrical construction of a virtual image.

2. Description of Java Software of Geometrical Optics JSGO

Java Software of Geometrical Optics that we denote by JSGO is a wizard that enables to realize interactive schemas and measurements of angles and distances. It is an essential component of the open access online university (Rebmann, 2000). The window of JSGO (Figure 1) is constituted of a left part called "the store" that contains all the elements available, and of a right part reserved to the geometrical construction. To work with JSGO, the mouse is the only element that the user manipulates.
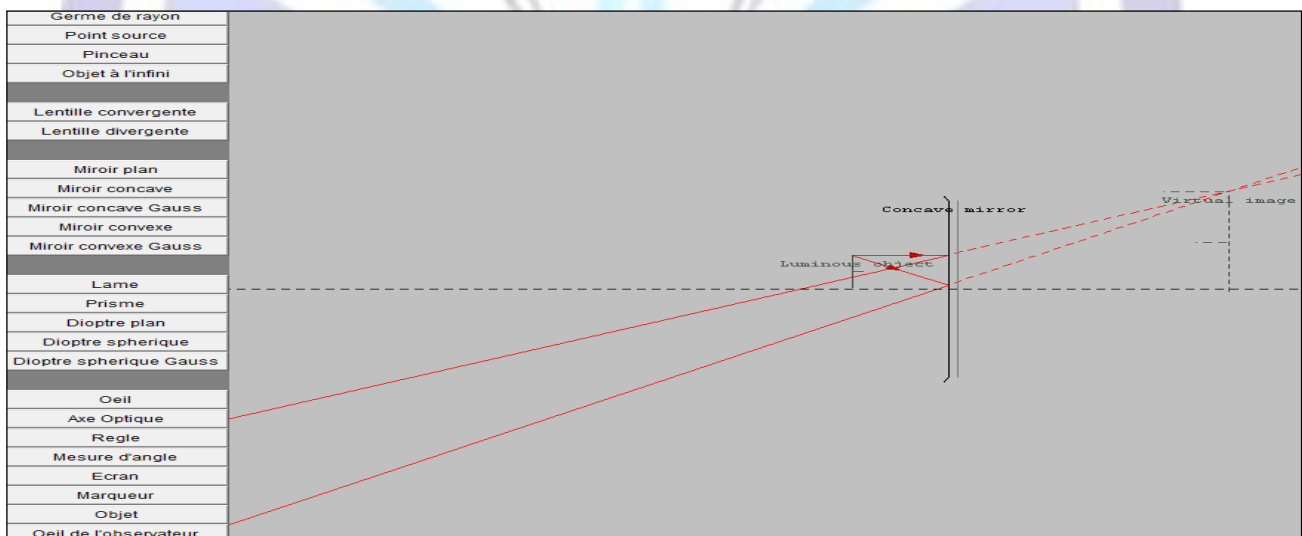

Figure 1: Geometrical construction of the image of an object placed between the principal focal object and the principal optical center of a concave mirror.

Properties of JSGO

The installation of Java software is essential to JSGO function, and the power of this software resides in it high degree of interactivity with the "optical components" and in particular, the tracing of the construction ray and its extension. In fact the JSGO "traces" the construction ray extension in accordance with its virtual nature that makes it pass through the obstacles and remain indifferent to the change of the refraction index of the medium. It is sufficient that the user "click" on the part of construction ray to extend it.

However, although the JSGO is sufficiently complete and efficient in offering a wide variety of objects with the possibility of acting on their properties, it has some limitations such as: the disappearance of the construction ray extension tracing when moving objects, also, the letters in the schema have a confusing nature (JSGO "allocates" the letter F to the luminous object, while it is usually attributed to the principal focal object; and the principal focal object is just indicated on JSGO by a bold point) . In addition, there is no possibility to save the geometrical constructions produced. The only means of keeping track is to make a "screen capture".

RESEARCH METHODOLOGY

In answer to the research questions we have adopted a procedure based on:

- A comparative analysis of the number of successful geometrical construction produced by the pupils between pretest and posttest.
- An analysis of the pupils' conceptual difficulties encountered in the false constructions produced.

Unfolding of experiment

To examine the impact of using JSGO on the nature of the geometrical construction of the virtual image produced, we realized an experiment on a group consisting of 41 pupils towards the end of the school year 2012/2013.

These pupils took a pretest followed by a 55 minute formation on how to use JSGO and finally they set for a posttest using the mentioned software.

For the pretest pupils should construct the virtual image (s) using only the traditional tools: paper, pencil, ruler and protractor, while for the posttest participants are supposed using only JSGO for their construction.

Phase 1: Administration of pretest

The pretest carried out in this research reflects the reality of teaching in the classroom. The time given to participants for doing pretest is 20 minutes (10 minutes for each sub-test). Our decision to set a time limit is justified for two reasons: first, the time given to pupils seems to us adequate, because it is worth thrice the average of the time that the secondary teachers (who helped us to conduct the experiment) have set to resolve the pretest. Second, the responses' time limit allowed us to study the impact of using JSGO on the execution time-management.

Phase 2: Administration of posttest

After collecting the copies related to the pretest and before the JSGO experimentation through the posttest, pupils benefited from a formation of 50 minutes concerning the use of this tool. We have informed the participants that using JSGO does not permit to save the geometrical constructions produced, and that the only way to keep track is to make a "screen capture". We have showed them how to access the JSGO website; however we worked outside the context of online university, to avoid the risk of internet connection rupture.

The posttest has a different timing from the pretest. Indeed, for doing the posttest, the pupils have an additional time of 20 minutes than the time given for doing the pretest in order to reproduce the schema initially provided (on paper) on the JSGO screen. During this phase each pupil worked individually on a computer. Amongst the Guidelines that were given to participants in the two phases: after tracing the constructions rays and its extensions, they must place the virtual image formed in its position. Once the collection of "screen captures" was completed, we set up an evaluation grid to analyze the constructions produced.

ANALYSIS AND DISCUSSION OF RESULTS

1. Evolution of the nature of geometrical constructions produced

The results of geometrical construction produced by pupils are presented in table 1 below:

Table1:Pupils' evolution during the geometrical constructions			
Test	Pretest (paper pencil)		Posttest (using JSGO)	
Pupils	Sub-test 1-1	Sub-test 1-2	Sub-test 2-1	Sub-test 2-2
P_1	+	+	+	+
P_2	-	-	-	-
P_3	+	+	+	+

P4	-	-	-	-
P5	-	-	-	-
P6	+	+	+	+
P7	-	-	-	-
P8	+	-	+	+
P9	+	-	+	+
P10	-	-	-	-
P11	-	-	-	-
P12	+	+	+	+
P13	-	-	-	-
P14	+	-	+	+
P15	-	-	-	-
P16	+	+	+	+
P17	+	-	+	+
P18	-	-	-	-
P19	+	+	+	+
P20	+	-	+	+
P21	-	-	-	-
P22	+	+	+	+
P23	-	-	-	-
P24	+	-	+	+
P25	+	+	+	+
P26	-	-	-	-
P27	+	-	+	+
P28	-	-	-	-
P29	+	+	+	+
P30	+	+	+	+
P31	+	+	+	+
P32	+	+	+	+
P33	+	-	+	+
P34	+	+	+	+
P35	+	-	+	+
P36	+	+	+	+
P37	-	-	+	+
P38	+	+	+	+
P39	+	+	+	+
P40	-	-	+	+
P41	+	+	+	+
Averages	0,317	0,207	0,341	0,341
	The experimental averages associated with the pretest		**The experimental averages associated with the posttest**	

We assigned the value 0.5 to the success of a sub-test, by one pupil, and the value 0 in case of failure.

The calculation of the Relative Difference RD_1 representing the difference between the experimental average associated with the pretest 1-1 and that associated with the posttest 2-1, shows that this difference is worth 7,03 %.

$$\text{Indeed: } RD_1 = [(0,341-0,317)/0,317]*100 = 7,57 \%$$

Given the variability encountered among pupils in general, and given that the measurement of a parameter related to the human beings is appreciated to some tens percent, it seems that the value of 7,57 % indicates that there is a small difference between both experimental averages. This result confirms in another way that it is possible that there is an influence of using JSGO on the success of the geometrical construction of the virtual image associated to the posttest 2-1, but it is not significant.

The calculation of the Relative Difference RD_2 representing the difference between the experimental average associated with the pretest 1-2 and that related to the posttest 2-2 shows that this difference is worth 64,73 %.

$$\text{Indeed: } RD_2 = [(0,341-0,207)/0,207]*100 = 64,73 \%$$

This result illustrates the presence of a significant difference between both experimental averages. We can say that this result confirms in another way that using JSGO has a significant influence on the success of the geometrical construction related to the posttest 2-2.

Table 1 indicates that we have recorded no negative evolution during the passage from a sub-test of the pretest to an equivalent sub-test of the posttest. This enables us to say that using JSGO does not induce, in any case, the learners to make an error in the construction of the virtual image.

2. Impact of using JSGO on the nature of geometrical construction produced

To analyze the impact of using JSGO on the nature of geometrical construction produced, we have chosen to present the results in table 1 in the form of another table (table 2) below:

Table 2: Number of correct constructions, false constructions and copies without constructions of pupils according to the variant shown in the sub-test

The variant	Sub-tests	Nature of construction		
		C.C	F.C	C.W.C
First variant	Pretest 1-1	26	12	3
	Posttest 2-1	28	10	3
Second variant	Pretest 1-2	17	19	5
	Posttest 2-2	28	8	5

Codification of notations

C.C = Correct Construction. **F.C** = False Construction. **C.W.C** = Copy or "Screen capture" Without any Construction.

Discussion

The pupils responded respectively better to the posttests: 2-1 and 2-2 than to the pretests: 1-1 and 1-2. Indeed, pupils have respectively scored 28 correct constructions for the posttests: 2-1 and 2-2, against 26 and 17 correct constructions for the pretests: 1-1 and 1-2. Thereby we can conclude that the number of pupils who are able to produce correct constructions using JSGO is higher than the number of pupils who have produced correct constructions using the traditional method.

Pupils have answered much better for the pretest 1-1 than the pretest 1-2.This result shows that the presence of the opaque medium in the schema related to the pretest 1-2 rendered the construction of the virtual image more difficult than the geometrical construction related to the pretest 1-1.

Analysis of results using the Chi-square of Statistical Test

To get an idea on the effect of using JSGO on the success of doing sub-tests associated with the same variant, we studied this effect using the Chi square of Statistical Test: (Chi 2). The theoretical numbers calculated are greater than or equal to 5. The calculation of the Chi-square was carried out using the predefined functions of Excel statistical software of Microsoft Office.

Both hypotheses emitted to study the effect of using JSGO on the success of the first variant sub-tests 2-1

Null hypothesis (H_0): "The success, or not, of a first variant sub-test by the pupils" and "the pupils use JSGO, or not" are independent.

Alternative hypothesis (H_1): "The success, or not, of a first variant sub-test by the pupils" and "the pupils use JSGO, or not" are not independent.

Both hypotheses emitted to study the effect of using JSGO on the success of the second variant subtests 2-2

Null hypothesis (H'_0): "The success, or not, of a second variant sub-test by the pupils" and "the pupils use JSGO, or not" are independent.

Alternative hypothesis (H'_1): "The success, or not, of a second variant sub-test by the pupils" and "the pupils use JSGO, or not" are not independent.

The results of Chi-square Statistical Test are presented in table 3 below:

Table 3: The value of Chi-square, the interval of critical probability p and the accepted hypothesis, associated to the same variant sub-tests.

Variant	Chi-square value	Interval the critical probability: p	The accepted hypothesis
First variant	0,216	$0,05 < p$	H_0
Second variant	5,959	$p < 0,05$	H'_1

For the first variant sub-tests, where the critical probability is more than 5%, we cannot reject the null hypothesis (H_0) and we accept it. For the second variant subtests, where the critical probability is less than 5%, we can reject the null hypothesis (H'_0) and accept the hypothesis (H'_1). In other words, the results show no significant influence of using JSGO on the success of the first variant sub-test 2-1, although the use of this tool has a significant influence on the success of the second variant sub-test 2-2.

Indeed, the non significant influence on the first variant sub-tests can be justified by the fact that, the schemas of the sub-test 2-1 is "poor" in "optical components" (just a convergent lens). Therefore the power of JSGO which resides in its great interactivity with "optical components" becomes "low" and the construction of the virtual image using JSGO seems like a construction using traditional method.

The significant and positive impact of using JSGO on the success of the second variant sub-test 2-2 can be justified by the fact that the schema of the sub-test 2-2 is "rich" in "optical components". This takes advantage from the high interactivity of JSGO for the construction of the virtual image. The high interactivity of JSGO with the "optical components" associated with the schema of sub-test 2-2 facilitates the construction of the virtual image for pupils, while for the sub-test 1-2 pupils encounter some difficulty in the image construction using the traditional method.

3. Pupils' conceptual difficulties

We analyzed the geometrical constructions produced by classifying the false geometrical constructions according to the conceptual difficulties below:

CD. 1 = Conceptual difficulty related to the correspondence image object (punctual and global).

CD. 2 = Conceptual difficulty associated with the minimum number of rays departing from the same point of the luminous object.

CD. 3 = Conceptual difficulty related to the tracing of construction ray.

CD. 4 = Conceptual difficulty associated to the tracing of construction ray extension.

CD = Computer difficulty associated with using JSGO.

The results of the conceptual difficulties encountered by the pupils are presented in table 4 below:

Table 4: Number of conceptual difficulties experienced in the false constructions produced by the pupils.

Sub-test	Nature of conceptual difficulty				
	CD. 1	CD. 2	CD. 3	CD. 4	CD
Pretest 1-1	3	4	4	3	****
Pretest 1-2	4	6	4	12	****
Posttest 2-1	6	5	0	0	1
Posttest 2-2	5	4	0	0	1

Before we start our discussion, we note that some false constructions have more than one conceptual difficulty.

The pupils showed 12 difficulties associated with the tracing of construction ray extension in the pretest 1-2 (the number of the construction produced for this pretest is 38) against 0 difficulties in the post test 2-2. This result indicates that about 32 % of pupils come up against this conceptual difficulty in doing pre test 1-2.

In the false schemas corresponding to the pretest 1-2, 32 % of pupils consider that the opaque medium "prevents" the formation of the virtual image (Figure 10, Appendix 2). This allows us to say that 32 % of pupils consider that the opaque medium "blocks" the construction ray extension.

The positive effect of using JSGO is expected because this software "traces" in an "automatic way" the construction ray extension. So, we can say that using JSGO represents a very useful tool to surmount this conceptual difficulty. However, it is difficult to know if we have really obtained a conceptual change associated with the tracing of construction ray extension.

For both sub-tests of the post test, the analysis showed that using JSGO generates a little difficulty. Indeed, approximately 2 difficulties have been recorded in the "screen captures" corresponding to these false constructions. In fact, we noticed a "poor" reproduction of the schema on JSGO screen (The schema on "screen capture" does not reflect the schema corresponding to the sub-test submitted).

For all sub-tests the pupils produced about 5 difficulties associated with the minimum number of rays departing from the same point of the luminous object, while the number of the construction produced is about 37. This result illustrates that about 13 % of pupils encountered this conceptual difficulty. In the false geometrical constructions corresponding to this conceptual difficulty, we note that one construction ray departing from a point of the luminous object has been traced, or a lot of construction rays have been traced, but each one departs from a different point of the luminous object.

For all sub-tests, the number of the difficulties associated with the correspondence image object (punctual and global) proven in the false geometrical constructions produced by pupils is about 4 (about 11 % of pupils encountered this conceptual difficulty for each sub-test). This result reflects that despite the high interactive character of the JSGO, 11 % of pupils come up against this conceptual difficulty.

4. Pupils' perceptions about using JSGO

To analyze the pupils' perceptions we used a Likert scale of 4 levels ranging from "strongly disagree" to "strongly agree".

Level 1: "Strongly disagree" assigned to the weighted value 1

Level 2: "Disagree" assigned to the weighted value 2.

Level 3: "Agree" assigned to the weighted value 3.

Level 4: "Strongly agree" assigned to the weighted value 4.

The results of pupils' perceptions are presented in table 5 below:

Table 5: Grid of learner' perceptions concerning the use of JSGO

The proposed affirmation	Strongly disagree	Disagree	Agree	Strongly agree	The average ranking
The menu of JSGO is clear	0	2	4	35	3,80
	0%	5%	10%	85%	
The JSGO is well adapted to my needs	0	5	5	31	3,63
	0%	12%	12%	76%	
The use of JSGO is motivating as a traditional method of construction	2	4	4	31	3,56
	5%	10%	10%	75%	
The JSGO assisted me to construct the virtual image	2	5	6	28	3,46
	5%	12%	15%	68%	
I can manage my time using JSGO	4	4	8	25	3,31
	10%	10%	20%	60%	

Note: The number in each cell represents the number of pupils who have chosen a particular level for the proposed affirmation.

Generally, the grid of learners' perceptions indicates that the majority of pupils "strongly agree" with the proposed affirmations concerning the use of JSGO. Regarding the proposition "the use of JSGO assisted me to construct the virtual image" the average of 3,46 means that the result is found on the left of the level "strongly agree" and is nearer to the level "agree". This can be explained by the important interactivity offered by JSGO. Likewise, 85 % of participants chose the level "strongly agree" to the proposition "the menu of JSGO is clear". The average of 3,80 means that the result lies nearer to the level "strongly agree". For the proposition associated with the time management, 20 % of the learners are unable to manage their time using JSGO. However, the average of 3,31 indicates that the result of pupils' perceptions is found nearer to the level "agree". We can conclude that pupils are predominantly very satisfied with the proposition concerning the use of JSGO. The use of this software rendered the geometrical construction of the virtual image more motivating and attractive than a construction using a traditional method. This is proven by the average of 3,56 concerning the proposition "the use of JSGO is motivating as a traditional method of construction".

CONCLUSION

This work has enabled us to study the impact of using Java Software of Geometrical Optics JSGO on the success of the geometrical construction of the virtual image among the pupils in the first year of Baccalaureate Experimental Sciences ES

The analysis of the results of our study "evolution of constructions nature produced" showed that we did not record any negative evolution in the geometrical construction during the passage from a sub-test of the pretest, to an equivalent sub-test of the posttest. This result proves that using JSGO does not induce, in any case, the pupils to make an error in the construction of the virtual image.

By using the Chi-square of Statistical Test, we have scored that using JSGO has no significant influence on the success of the geometrical construction of the virtual image associated with the first variant sub-test. However, using this tool through the second variant sub-test leads to a number of correct constructions which is higher than that noticed when using traditional method. This expected result raised some questions about the importance of the introduction of adequate pedagogical scenarios that help get a good profit from this computer-assistant learning.

It is true that the technique of tracing of construction ray and it extension using JSGO can be performed in an algorithmic way, without necessarily mastering this technique by the pupil. In fact, it is not easy to know if the improvement of the results is really due to a better understanding of knowledge brought into play when solving the second variant sub-test. However, using JSGO permits to overcome this conceptual difficulty.

This analysis also indicates that, despite the interactive character of JSGO, about 12 % of pupils face the conceptual difficulty associated with the correspondence image object (punctual and global), and also the difficulty related to the minimum number of construction rays departing from the same point of the luminous object. This result joined that of (Benjelloun and al, 2003) concerning the production of false geometrical constructions by the students in the second years of university even using JSGO;

Finally, we note that our study of the pupils' perceptions about using JSGO showed that the participants are very satisfied regarding the use of this computer wizard.

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Appendix 1

Presentation of pretest

Sub-test 1-1

Enunciated: A luminous object of small dimensions in the form of the letter F is placed on the principal optical axis of a convergent lens (L), between the principal focal object and the principal optical center (Figure 2). Construct geometrically, the image F_1 of the luminous object F through the lens (L).
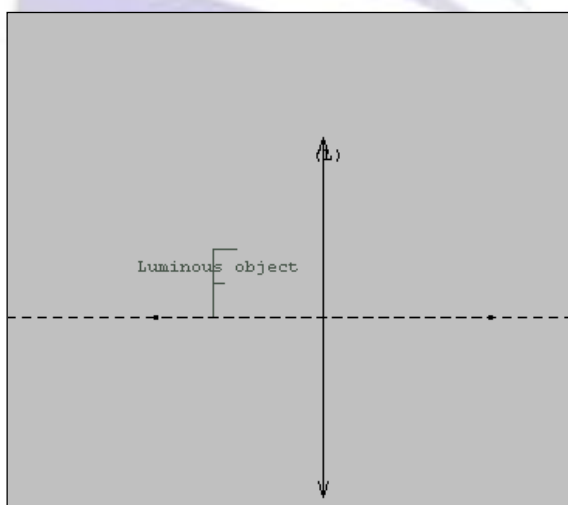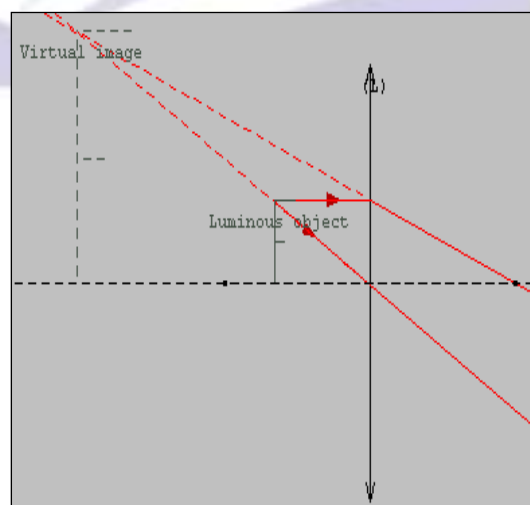

Figure 2: Schema of sub-test 1-1

Figure 3: correct construction of sub-test 1-1

Sub-test 1-2

Enunciated: Now, we place, an opaque medium tangent on the left side of the principal optical axis (Figure 4). Construct geometrically F_2 the image of the luminous object F through the system: {(L) + opaque medium}.
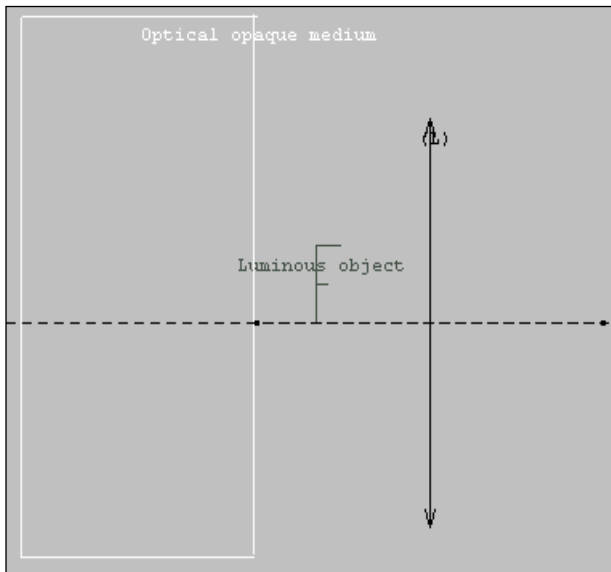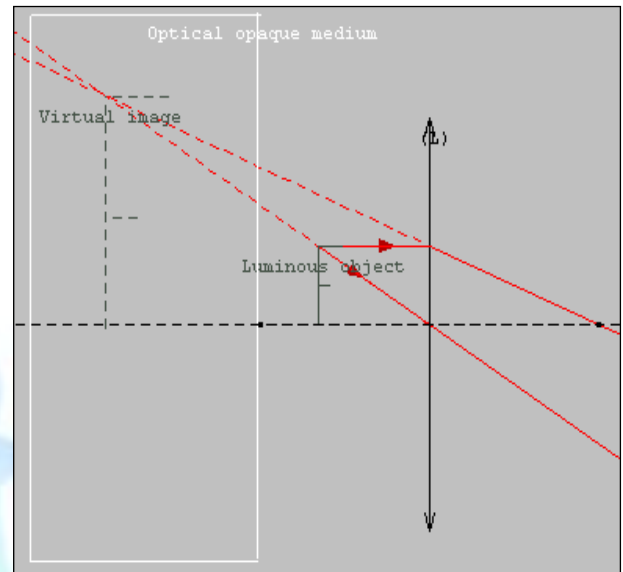

Figure 4: Schema of sub-test 1-2

Figure 5: correct construction of sub-test 1-2

Presentation of posttest

Sub-test 2-1

Enunciated: A luminous object of small dimensions in the form of the letter F, is placed vertically in vacuum (the index of refraction of vacuum is n=1) in front of a plane mirror (PM) (Figure 6). Construct, geometrically, the image F_3 of the luminous object F through the plane mirror (PM).
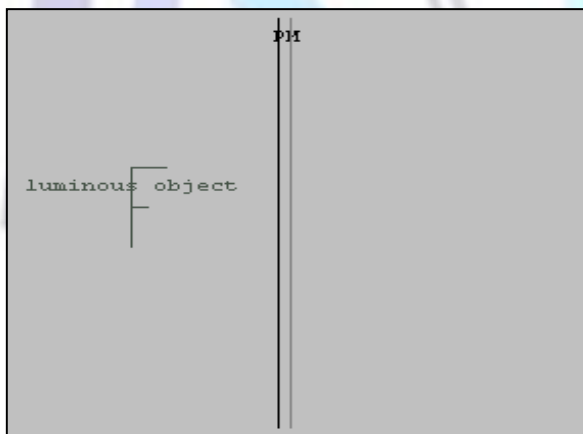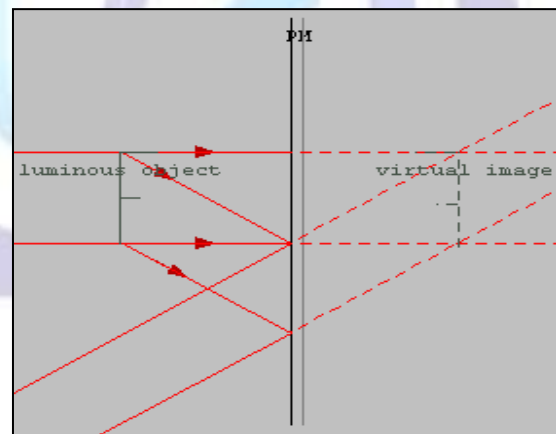

Figure 6: schema of sub-test 2-1

Figure 7: correct construction of sub-test 2-1

Sub-test 2-2

Enunciated: Now, we place, a refracting medium (the refraction index of this medium is n = 1.5) tangent on the right side of plane mirror (PM) (Figure 8). Construct geometrically, the image F_4 of the luminous object F through the system: {(PM) + refracting medium}.
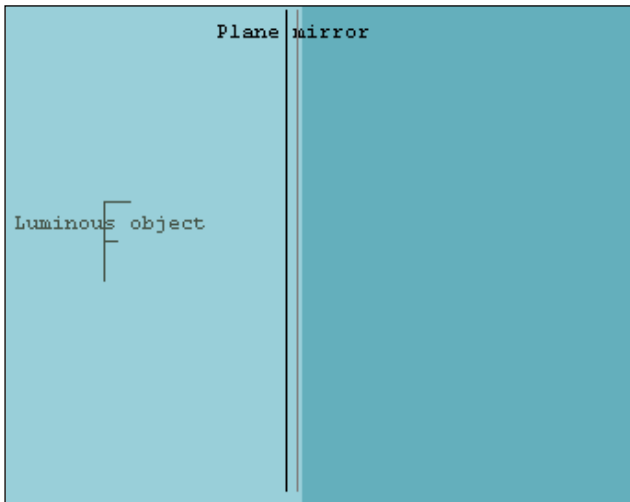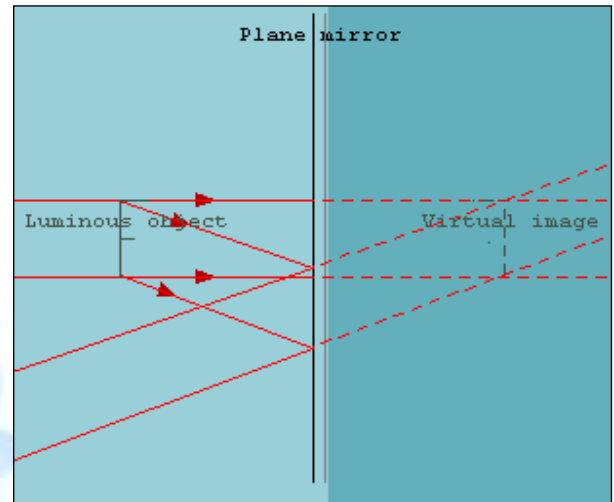

Figure 8: schema of sub-test 2-2

Figure 9: correct construction of sub-test 2-2

Appendix 2

False geometrical constructions associated with the pretest: 1-2
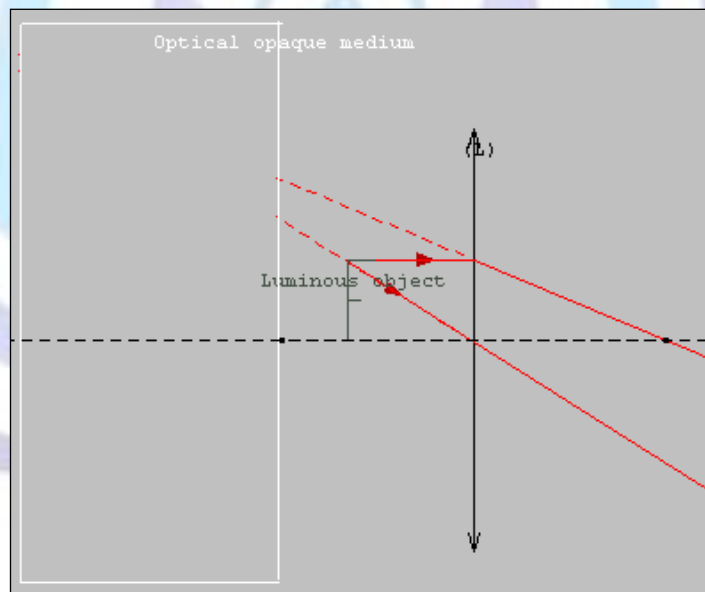

Figure 10: A false geometrical construction in which the construction rays extensions are "blocked" by the opaque medium.