SUPPORTING INFORMATION

Introduction to light properties and basic principles of spectroscopy at high school level: a pilot study

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SUPPORTING INFORMATION

Observation and reflection forms

In the following we are reported an example of 'OBSERVATION FORM' and 'REFLECTION FORM? For one of the activities on the particle nature of light, which was the first step of the didactic pathway presented in the paper.

S1. Example of OBSERVATION FORM for the 'reflection and refraction of light':
Observation form for the phenomenon of light reflection and refraction (in Italian):

1st Part. Observe the phenomenon.
During this laboratorial activity, you will do several experiments by using a green laser. Observe carefully what your teacher is showing and fill the form (you can also copy the questions on your notebook and answer there.

Experiment	**Make a draw of what you have observed**	**Describe what you have observed**	**Have you ever observed similar phenomena before? Where?**
1. Laser light and mirrors			
2. Laser light and a liquid			
3. Laser light inside a liquid			
4. Laser light and a quarz prism			

S2. Example of REFLECTION FORM for the 'reflection and refraction of light':

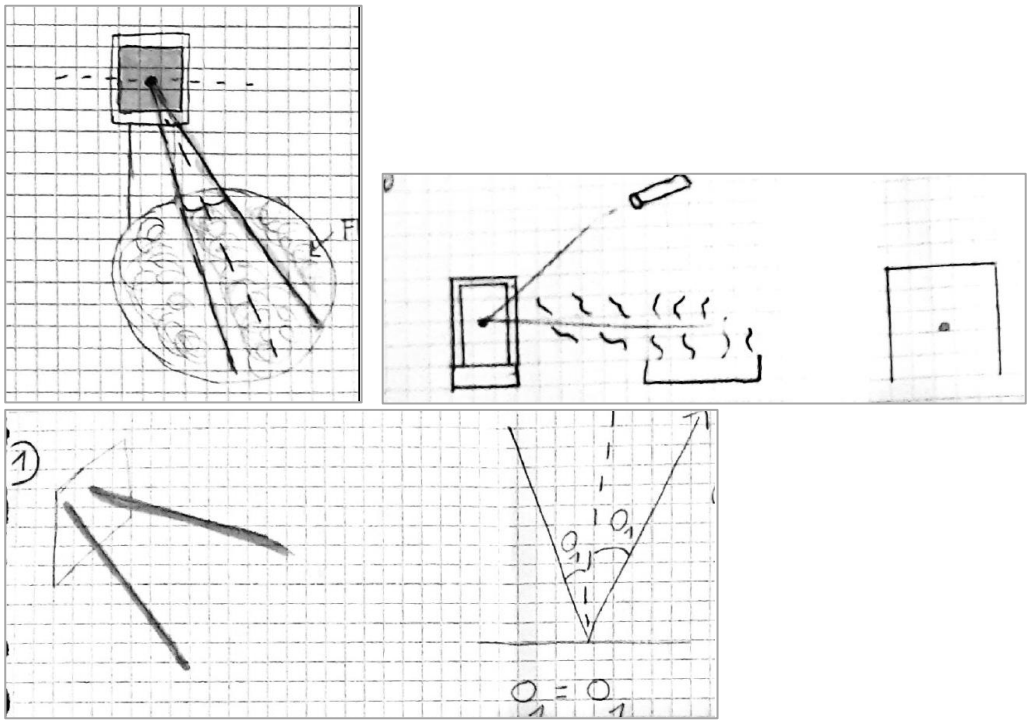
2nd Part. Reflect on the phenomena of light.
Answer to the questions:

1. What happens when the laser light turns on? How does the laser beam propagate?
……
2. Why the laser beam changes direction when it goes through a mirror? What is this phenomenon 'name'?
……..
3. Why we need vapor (or smoke) to see the laser pathway?
……
4. When a laser beam pass from one material to another it changes direction? In which point this phenomenon happen? What is the reason of this change in direction? What is this phenomenon name?
……..
5. What happen when you observe the laser beam passing from a water layer to an alcohol layer? What did you observe inside the two liquids? How do you explain this phenomenon?
……..
6. After these experiences, how do you explain the nature of light?
……

S3. Example of students' drawing concerning the phenomena of 'reflection and refraction of light':

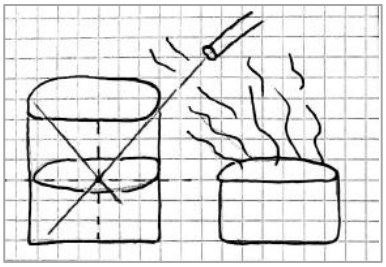
Example of draws and schemes done during the 'observation steps':

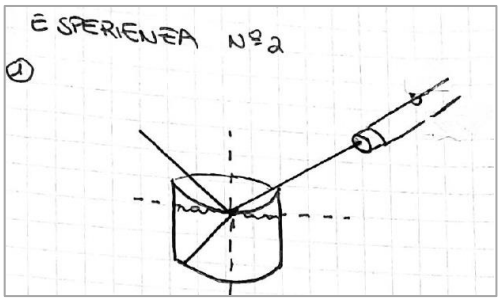
1. Laser light and mirrors

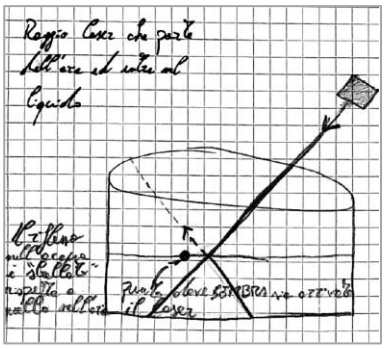


Comments of the teachers: in all drawings, students represent the laser beam as straight lines (about 85%). Only few students are able to correctly draw the incident and reflection angles (about 20%).

2. Laser light and a liquid

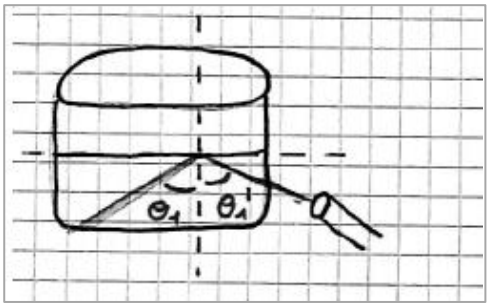


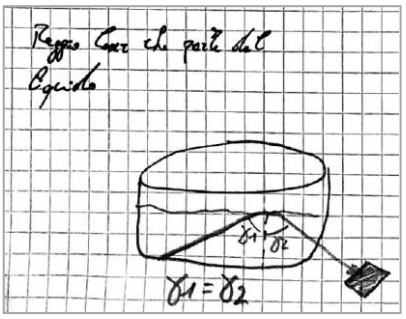


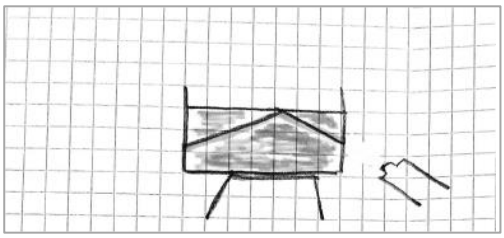


Comments by the teachers: most of the students draw the reflected beam by the water surface (about 90%). About 20% of students draw the refracted beam inside water correctly. Few students do not draw any beam inside the liquid (15%).

3. Laser light inside a liquid







Comments of the teachers: all students draw correctly the phenomenon of internal reflection (more then 95%). Some of them specify the angles of reflection (about 20%).

S4. Example of students' answers concerning the phenomena of 'reflection and refraction of light':

Selection of answers to the questions of the 'reflection' step:

Answers to question 1:

A. When the laser is turn on, we see it on the mirror.
B. We don't see the laser beam, we only see a spot on the mirror.
C. We can see the laser only if there is smoke or vapor.
D. When there is smoke we see a green line

Answers to question 2:

A. The laser change direction when it goes through the mirror
B. The laser beam goes toward the mirror and then it come back.

Answers to question 3:

A. The vapor is needed to see the laser beam.

Comments by the teachers: almost no students are able to give an explanation why we need vapor or smoke to see the beam path (less than 10%).

Answers to question 4:

A. The laser beam reflect on the surface of water.
B. I see that the laser beam enters into the liquid.
C. The laser beam in part goes inside the liquid and in part reflect on the opposite side.
D. The laser beam is split in two ones: one goes inside the liquid and the other goes in the opposite direction.

Comments by the teachers: similarly to the 'observation step', students do not describe the refraction phenomenon and the change in direction of the beam when a different material is encountered (less than 10%). This is much clearer to students only after watching the video about refraction and internal reflection (see ref. 34 and 35).

Answer to question 5:

A. The laser beam is reflected by the surface of separation between the liquids.
B. We can see that the light does not go out of the liquid and it comes back.
C. The laser ray describes a V inside the liquid.
D. The laser beam bounces and comes back.

Answer to question 6:

A. Light is like a marble
B. Laser beam behaves as a line or segment
C. Light moves straight.

Comments by the teachers:
Most of the students say that they never note these properties of light (reflection and refraction) even though in several cases they are able to make analogies between the experiments performed in class and similar phenomena observed at home or in other contexts (80%).

The analysis of students' feedback (i.e. the analysis of the observation and reflection forms) contributed to the evaluation together with additional tests and quiz performed during the experimentation (not reported here).

The home-made spectroscope: materials, evaluation schemes:

Here we report part of the materials used for another step of the didactic pathway: the construction of a home-made spectroscope. This laboratorial activities was performed by all students who participated to the three experimentations and the material used for the evaluation was the same for high school and undergraduate students.

S5: Instruction given to the students to build the home-made spectroscope.

Part A.

After the lesson about the history of spectroscopy, let's build your own home-made spectroscope.
You can take inspiration from one of the following video, where different strategies are used to build an home-made spectroscope:

- https://www.youtube.com/watch?v=fl42pnUbCCA
- https://www.youtube.com/watch?v=SI6D6QwQUO0
- https://www.youtube.com/watch?v=ZJcl392f8ew

To build your home-made spectroscope, you can use a piece of a DVD or CD (several ones are in class). This is the most important part of the instrument, since it is the diffraction grating.
You can use a paper box, or a recycled food box, or a shoes box. Other materials that you may need are: cutter, papers, black Scotch tape, small plastic pieces.
After building your home-made spectroscope, fill the following form:

Describe the materials and the procedure used to build your home-made spectroscope	**Insert here some photos of your spectroscope**

Part B.

Observe several light sources and fill the form:

Describe the light source	Put here one or two photos made by using your smartphone	Comment the features of the photos (shape, colors, positions of color bands, …)

S6. Evaluation scheme for the activity of the home-made spectroscope

Aspect to be evaluated	Score (very good) Point: 4	Score (ggod) Point: 3	Score (sufficient) Point: 2	Score (not sufficient) Point: 1
EVALUATION OF PART A				
1) Description of the home-made spectroscope	Description is precise; all materials are described; details	Description is almost complete; Few aspects of the procedure or	Description is quite good, but some important aspects of the procedure,	Description is poor. Many aspects are missing, there are

	of the procedure are clearly described.	materials are missing	scheme of the spectroscope, materials are missing	some conceptual errors.
2) Evaluation of the drawing	The scheme is clear. All relevant parts are well represented.	The scheme is quite clear, but some parts are not represented very well.	Some parts are missing but the overall scheme of the spectrometer is acceptable	Scheme is not done, several parts are missing, it is not clear how the spectrometer was done.
3) Quality of the home-made spectroscope	The spectroscope is well done, all elements are present and it is working fine	The spectroscope is done correctly, but some parts are not fixed well or they are not in the exact position.	The spectroscope works, but there are some external lights entering due to not perfect building. Some elements are not fixed and the instrument is quite imprecise.	The spectroscope is not built well. There are some missing parts or some big errors.
EVALUATION OF PART B				
4)Number of light sources analysed and originality of the choice	Students analyzed more than 5 light sources. Some of them are original.	4 to 5 light sources have been analyzed and they are chosen accurately.	2 or 3 light sources were analyzed, not particularly original.	Only one light source was analyzed.
5) Quality of the images	Photos have high quality, the coloured spectra are clear and centered.	Photos quality is quite good, some parts of the image is not clear	Quality of photos is not good, some parts of the spectra are not visible and are not clear.	Photos are not clear at all or they are missing
6) Analysis of written comments on the coloured spectra	Comments are correct from the scientific point of view. Comments are complete and clear.	Comments are correct from the scientific point of view, but some explanation are missing or the description is not complete and clear.	Comments are correct but several aspects are missing. The description does not contain conceptual error but it is poor and language is not precise.	Comments are not correct, language is poor, and it is not scientifically accurate. Several important comments are missing.

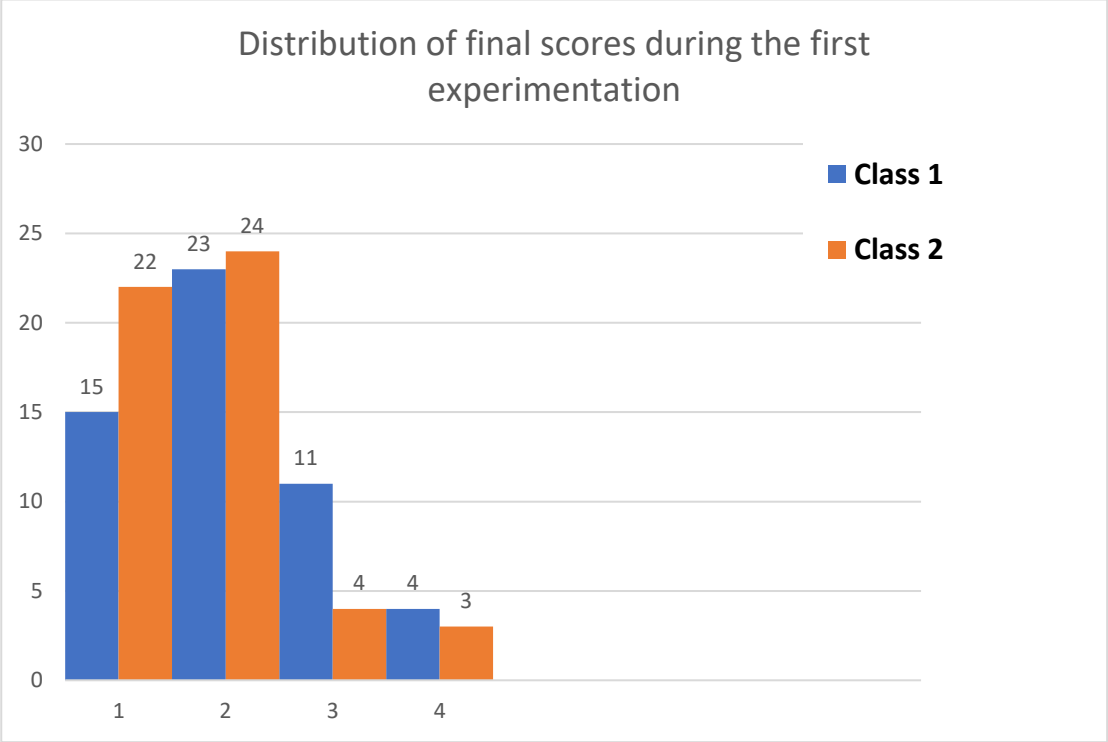
Final notes:

The maximum score of the first part of the evaluation is 12, and the maximum score of the second part of the evaluation is 12. In total, the following scheme for the final vote (from 3 to 10) is:

Score between 3 and 5 : final vote of 3;
Score between 6 and 8 : final vote of 4;
Score between 9 and 11 : final vote of 5;
Score between 12 and 14 : final vote of 6;
Score between 15 and 17 : final vote of 7;
Score between 18 and 20 : final vote of 8;

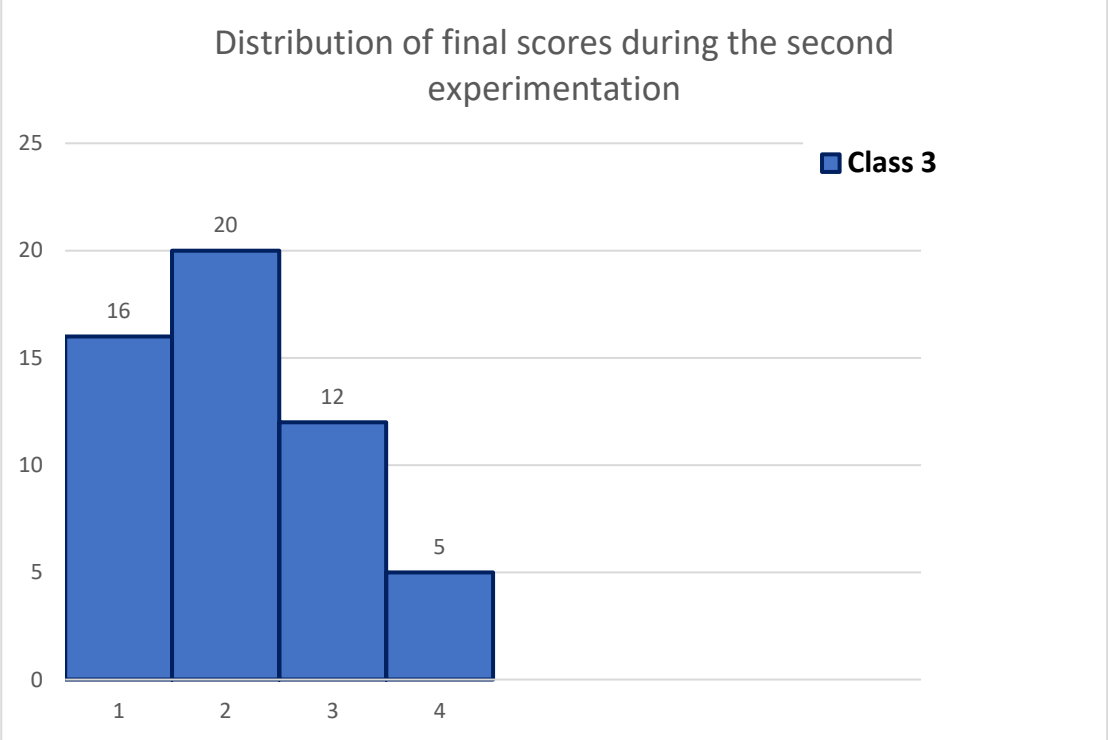
Score between 21 and 23: final vote of 9; Score of 24: final vote of 10;

S7. Plot showing the distribution of final scores obtained during the first experimentation

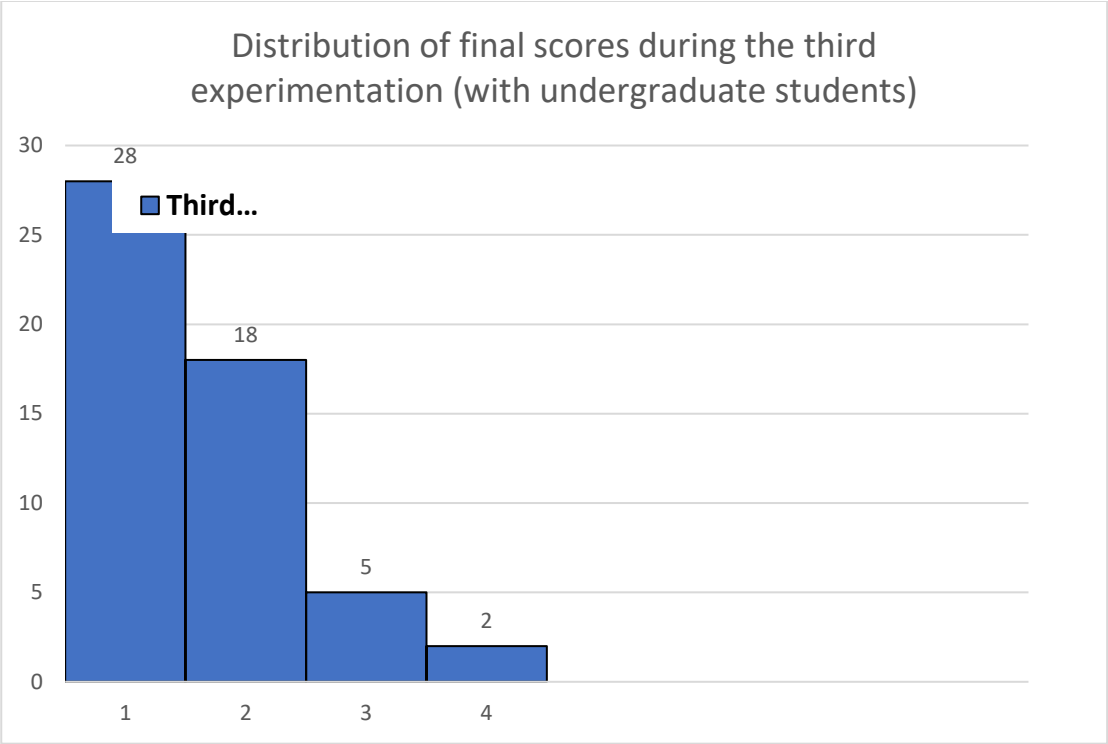


#note that none of the students got score 3 and score 4 (not sufficient).

S8. Plot showing the distribution of final scores obtained during the second experimentation



S9. Plot showing the distribution of final scores obtained during the third experimentation



Example of final survey used to evaluate the level of interest and engagement of students

S10. Questions of the final survey provided to undergraduate students during the third experimentation

Question 1. *How do you think the historical part to introduce spectroscopy is useful to understand the basic principle of spectroscopy?*

- ○ Very much;
- ○ more yes, than no;
- ◉ So and so;
- ○ Not at all.

Question 2. *The activity about the building of the home-made spectroscope was:*

☐ useful to know the optical elements and how they work;

☐ useful to know the phenomenon of dispersion of light;
☐ not very useful because it is too simple;
☐ not very useful for the topic;

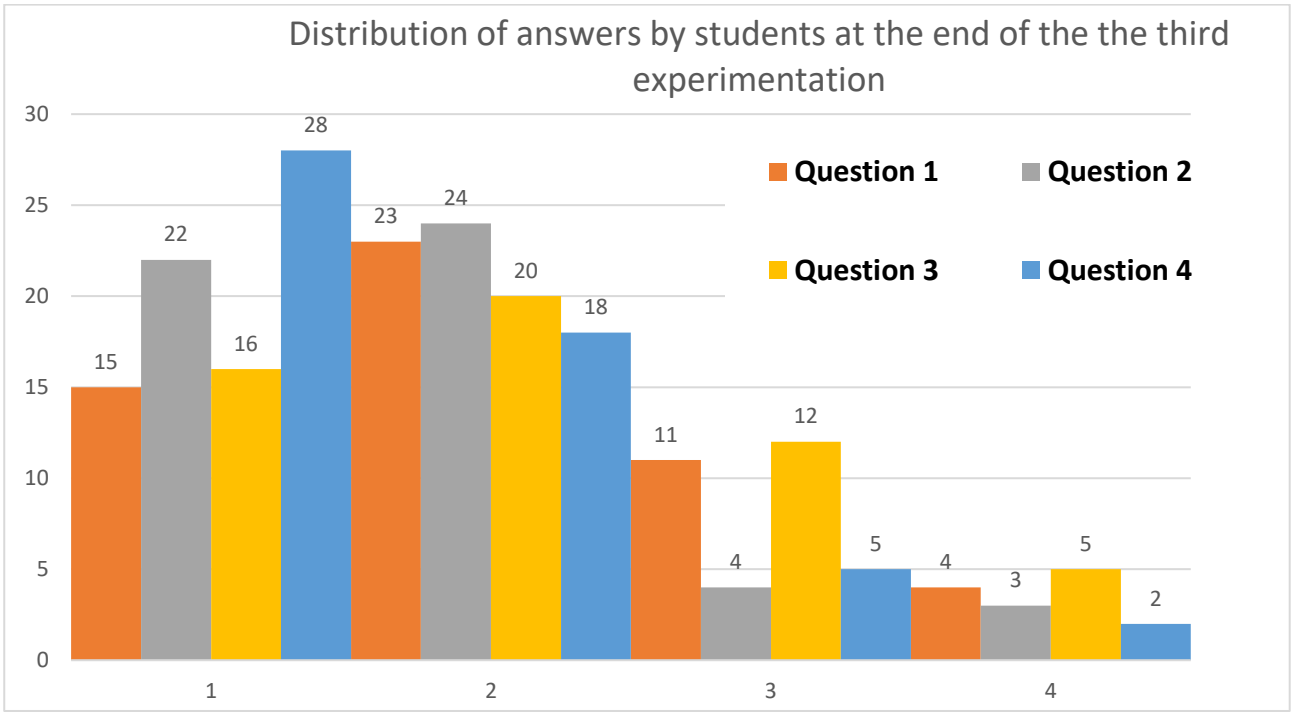
Question 3. *How important is the knowledge of the historical progress of instruments for a chemist, according to you?*

☐Very much;
☐More yes, than no;
☐So and so;
☐Not at all;

Question 4. *How did you like the laboratorial activities about the introduction of light phenomena?*

☐Very much;
☐More yes, than no;
☐So and so;
☐Not at all;

S11. Result of the final survey provided to undergraduate students during the third experimentation.



This plot shows that most of the students selected the first of second options for the four questions. The first and second options are positive, while the third and forth options are negative.