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2015 J. Phys.: Conf. Ser. 605 012041

(http://iopscience.iop.org/1742-6596/605/1/012041)

Journal of Physics: Conference Series **605** (2015) 012041 doi:10.1088/1742-6596/605/1/012041

Explore the concept of "light" and its interaction with matter: an inquiry-based science education project in primary school

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Abstract. The exploration process leading to the understanding of physical phenomena, such as light and its interaction with matter, raises great interest and curiosity in children. However, in most primary schools, children rarely have the opportunity to conduct science activities in which they can engage in an enquiry process even if by the action of the teacher. In this context, we have organised several in-service teacher training courses and carried out several pedagogic interventions in Portuguese primary schools, with the aim of promoting inquiry-based science education. This article describes one of those projects, developed with a class of the third grade, which explored the curricular topic "Light Experiments". Various activities were planned and implemented, during a total of ten hours spread over five lessons. The specific objectives of this paper are: to illustrate and analyse the teaching and learning process promoted in the classroom during the exploration of one of these lessons, and to assess children's learning three weeks after the lessons. The results suggest that children made significant learning which persisted. We conclude discussing some processes that stimulated children' learning, including the importance of teacher questioning in scaffolding children's learning and some didactic implications for teacher training.

1. Introduction

Very early on, children manifest a natural curiosity and interest in knowing and making sense of the world that surrounds them. The science teaching should take advantage and enhance these natural qualities of children, as they constitute the necessary support for active and meaningful learning in the classroom [1, 2, 3]. The goal is to "educate" the children's natural curiosity in order to develop more systematic, deeper and autonomous thinking patterns [4]; stimulate them to pose questions and look for possible answers for what they do and see; enable them to devise ways to test their ideas and thought strategies; to share and discuss their own theories and explanations with others [5, 2]. Unfortunately, the traditional science teaching works in a way that generally discourages the natural process of inquiry. Therefore, the inquiry activities are a privileged path to convert classrooms into places of leisure, satisfaction and personal fulfilment, as they allow the creation of a learning environment where children learn and do things they really enjoy [3, 6].

Inquiry-based teaching has been suggested by the science curriculum guidelines of many countries and recommended by several international reports and studies [7, 8, 9]. For example, the US *National Science Education Standards* were developed by the *National Research Council* to "promote a scientifically literate citizens". These Standards frequently encourage the use of inquiry in science classrooms, defining it as "... a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyse and interpret data; proposing answers, explanations and predictions; and communicating the results" [7, p. 23]. Inquiry can also be defined as the "intentional process of diagnosing problems, critiquing experiments and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers and forming coherent arguments" [10, p. 518].

The *National Research Council* [7] identifies five essential features for classroom inquiry: a) learners are engaged by scientifically oriented questions; b) learners give priority to evidence; c) learners formulate explanations from evidence, d) learners evaluate their explanations in light of alternative explanations; and e) learners communicate and justify their explanations. These features may vary in the amount of detailed guidance provided by the teachers. Thus, there may be different inquiry approaches, depending on the degree to which teachers structure what students do. These approaches are sometimes referred to as "guided" versus "open" inquiry. Guided inquiry teaching can be more focused on the development of particular science concepts. Open inquiry, on the other hand, will afford the best opportunities for cognitive development and scientific reasoning.

In science education, inquiry teaching reflects the concerns of Dewey, who, as early as the beginning of last century, considered that there was too much emphasis on facts and not enough emphasis on science in the development of thought and attitude of the mind. For Dewey, the student should be actively involved in the learning process and the teacher should take on a role of facilitator and guide. According to Drayton and Falk [11, p. 25], "The inquiry-based approach to science education [...] introduces students to science contents, including the process of investigation, in a context of reasoning, which gives science its dynamic nature and provides the logical framework that enables the understanding of scientific innovation and the evaluation of scientific claims. Inquiry is not process versus content; it is rather a way of learning content". Inquiry teaching is an approach that enables the learning of concepts and the development of process skills [2]. Thus, the alleged opposition between content and science process skills is a false dichotomy, as: "science process skills, on the one hand, and knowledge and comprehension, on the other, intensify each other in an interdependency that generates higher levels of process skills and higher levels of knowledge and comprehension" [3, pp. 58-59].

An inquiry-based learning environment promotes opportunities for children "to learn science, to learn how to do science and to learn about science" [7, p. xv]. Inquiry-based science education in the early years of schooling is vital to help the children: understand the world around them; learn to obtain and organise information; develop ways to discover; test ideas and use evidence; and develop positive attitudes towards science [2, 12]. On the other hand, it can also help children develop very different thinking skills early on [13], e.g., scientific thought, critical thinking, autonomous problem solving, communication and metacognitive skills, which are likely to be transferred and applied to other contexts and learning situations [14, 15]. Inquiry-based science education not only contributes to a better understanding of scientific concepts and skills but, because science inquiry in the classroom is carried out in a social context, it also contributes to the children's social and intellectual development [14]. Research shows that, when involved in inquiry activities, children are more actively engaged in their learning; they use and develop skills from other curricular areas, including language and mathematics [14, 15, 16] and they develop a positive attitude towards science [2]. In addition, inquiry helps children to create "habits of mind" [14], which are transferred to other experiences and learning contexts. This science teaching practice has proven effective in increasing the students' interest and achievement levels at both primary and secondary levels [17], while, at the same time, stimulating the teachers' motivation [18].

However, in the majority of European countries, the reality of classrooms is that these approaches to science teaching and learning are still only implemented by relatively few primary school teachers [19, 20]. Several causes have been identified, including the realisation that teachers have insufficient scientific knowledge on the contents they need to approach with the students and limited conceptions on inquiry-based science education and its pedagogical approach in the classroom [2, 21, 22].

In Portugal, the situation is no different. Although the science curriculum of primary education suggests a teaching practice in which students should be "active observers, with the ability to discover, investigate, experiment and learn" [23, p. 102], such a teaching practice is still only occasional, with only a residual expression in the teachers' pedagogical practices [3].

In this context, we have been promoting many teachers training courses and developing small pedagogical intervention projects at some primary school classes, with the aim of promoting an inquiry-based science teaching practice. This article describes one of these projects, centred in an approach to the curricular topic "Light Experiments". For that purpose, several lessons were planned and implemented in the classroom. Thus, the specific objectives of this paper are: a) to describe and analyse the teaching and learning process promoted in the classroom during the exploration of one of these lessons, and b) to assess the learning acquired by the children.

2. Methodology

The pedagogical intervention project adopted an action research methodology and was carried out with a class of the 3rd year in a Portuguese primary school, situated in the suburbs of the city of Braga. The class was composed by 16 students, 10 boys and 6 girls, aged between 7 and 8 years. For two months, 5 lessons were taught on the curricular topic "Light Experiments", amounting to a total of 10 hours of intervention in the classroom, as presented in the following table:

Table 1. Lessons subject and duration.

Lesson subject	Duration
1. What is light? Why can't we see objects in the dark?	2 hours
2. How does light travel?	2 hours
3. Which materials let light travel through them?	2 hours
4. Reflection of light.	2 hours
5. Refraction of light.	2 hours
Total	10 hours

For each topic addressed, a teaching and learning plan was prepared, containing the following elements: i) learning goals; ii) materials needed for the groups to implement the planned activities; iii) guidelines for the teaching and learning process, and iv) an individual record sheet for each student. Each lesson, which corresponds to one action research cycle, begins with a teaching and learning plan, which is implemented flexibly, according to the teaching and learning processes generated and promoted in the class reality. The lessons were taught by the first author of this paper, who, in collaboration with the class teacher, played the role of both researcher and teacher.

The data generated in this intervention were collected using two complementary methods: the field notes made by the researcher and the audio recordings of the lessons. This raw data were subsequently compiled in the form of detailed narratives including the most relevant events that took place in the classroom – the class diaries. These constituted the principal method of recording data and, simultaneously, a strategy for reflection and for the modelling of the teaching and learning process [24, 25]. With the purpose of assessing the learnings achieved by the children, was built and applied a survey with true or false items, three weeks after the pedagogical intervention.

3. Results

The following presents the analysis of the class diary concerning "reflection of light" and the results of the applied questionnaire that intended to assess students learning, after three weeks of the pedagogical intervention in sciences.

3.1. Content analysis of the class diary

Students are arranged in small collaborative groups. The lesson begins with the following questions:

Journal of Physics: Conference Series **605** (2015) 012041 doi:10.1088/1742-6596/605/1/012041

- What happens when the light of a flashlight hits a mirror? And a cardstock?

Each group has on their table a mirror and a cardstock target, propped up with plasticine.

  - *The groups make predictions.*
    - In relation to the mirror, the prevailing prediction is that the light will be reflected: "the light hits the mirror and comes back" (Bruna); "it hits it and comes back" (Luís); "it reflects back" (Simão). Others make predictions using the knowledge acquired in previous classes: "the mirror is opaque and the light comes back" (Diogo); "opaque materials reflect light" (Lara).
    - In relation to the cardstock, predictions are divergent. Some argue that it does not reflect the light: "On the cardstock, it does not come back" (Eva); "the light will stay there" (Guilherme); "it hits and stays on the cardstock" (Gonçalo); while others maintain that the cardstock also reflects the light: "If the cardstock is opaque, the light also has to come back" (Joel).
- What must we do in order to see what will happen?
  - *The students suggest ways to test their predictions. Excerpt from the class diary:*

  [The majority of the students simply suggest "try it". However, some suggest a way to test their predictions: "We can point the flashlight at it and see if the light comes back. First, we point it at the mirror and if the light appears here on the table, it means it comes back" (Leonardo)].
  - *They test the predictions and make observations.*

  Each group of students is given a flashlight. The flashlight is covered with opaque paper, which has a slit in the middle. The students focus the light that passes through the slit onto the mirror and then onto the cardstock. Their observations are consistent with the idea that light "comes straight back" when pointed at the mirror; but in relation to the cardstock, they have doubts.
- What are the differences between what is happening with the mirror and with the cardstock?
  - *They reflect on their observations. Excerpt from the class diary:*

  [There is an apparently unanimous idea that both materials reflect light, but in a different way. "It is different. With the mirror, we see a clear line of light on the table, but with the cardstock, that doesn't happen" (Joel); "with the mirror, the light comes straight back and, with the cardstock, it comes back only a little bit" (Daniela); "the light hits the mirror and then comes straight back to the same place, in a straight line. With the cardstock, it does not seem to be hitting only this place (the table)" (Diogo), "With the mirror, the light comes straight back, you can see it here on the table" (Ângelo); "it goes straight, we learned this in the last lesson. Then it also comes back in a straight line" (Bárbara)].
- Will you be able to receive the light reflected from the mirror on a cardstock target?
  - *They test their ideas and communicate observations.*

  On their tables, groups assemble a device similar to that depicted on Figure 2, in order to make the cardstock target receive the light reflected from the mirror.

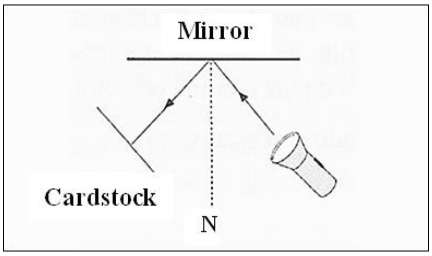



Figure 1. The students testing their ideas in groups.

After the test, the following comments were made: "the mirror has to be in front of the cardstock and the flashlight has to be in front of the mirror" (Francisca); "We pointed the flashlight at the mirror and the light reflected onto the cardstock" (Eva); "the cardstock has to be in front of the mirror, because the mirror reflects back" (Simão).

- Will you be able to receive, on a second cardstock, the light reflected by the mirror?
    - *They infer that the cardstock does not reflect light like a mirror. Excerpt from the class diary:*

[After several attempts, the groups are unanimous in stating that they are not able to receive the light reflected by the mirror on a second cardstock: "It does not work, but with another mirror it would. There would have to be two mirrors" (Eva). "Why do you think it is not possible?" – I ask. "Because the cardstock does not reflect" (Eva); "First, the light hits the mirror and reflects onto the cardstock but, afterwards, the light does not reflect from one cardstock to the other" (Daniela). "The mirror only reflects onto one cardstock and the cardstock is not the same as the mirror" (Leonardo). At this time, I explained that, because the cardstock is not smooth like the mirror, it reflects light in all directions. Therefore, we are not able to make the light appear on the other cardstock – diffuse reflection – whereas the mirror reflects light in a well-defined direction – specular reflection].

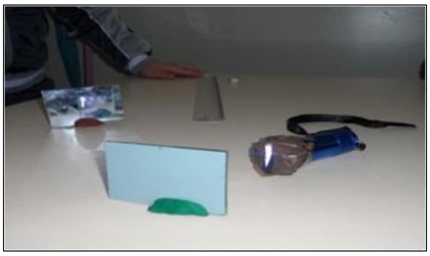
- Do you think we can reflect light from one mirror to another?
    - *They predict the path of the light between the two mirrors. Excerpt from the class diary:*

[The class is unanimous in answering "yes". A second mirror is distributed to the groups. When questioned, the students correctly predict the path of light between the two mirrors: "The light hits the mirror and then comes back, and we are going to put the mirror… here!" (Joel's group); "the light comes from the flashlight this way, hits this mirror (the first one) and then it goes onto this one (the second mirror)" (Daniela)].

- *They test their predictions and interpret the observations made. Excerpt from the class diary:*

["The light goes this way, this way and this way" – referring to the trajectory of the light between the two mirrors. "Then what figure does the light form?" – I ask. "It is like a reversed "V" (Diogo); "It always makes a "V" and the mirror is always at the tip of the "V". "If we put another mirror, we get another "V" (Simão)].

- *They record the light path on their individual record sheets.*



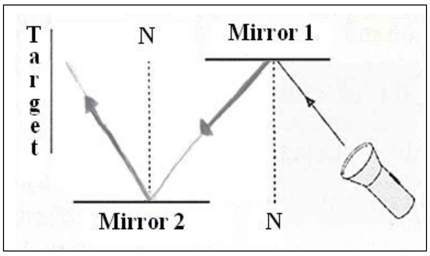


Figure 2. Example of a record made by the student.

- *They infer and communicate the path of light between the two mirrors. Excerpt from the class diary:*

["How did you draw the path of the light?" – I ask. "We drew it from the flashlight to mirror 1. And then from 1 to 2 and then onto the target" (Leonardo). "And how are the lines?" – I ask. "The lines are straight" (Bruna). "They are straight and make sort of a "V" (Ângelo). The majority of the students drew the light path correctly. The comments within the groups revealed a good understanding: "The light comes and goes like this, perpendicularly" (Joel); "it reflects from the mirror and makes a perpendicular line onto the other" (Lara); "the line that goes one way is similar to the one that comes back" (Bruna); "from one mirror, it reflects onto the other and then it goes from that one onto the cardstock" (Diogo)].

- *They identify regularities, recognising that light is reflected according to a certain rule.*

Through successive questioning, the children are stimulated to think about the rule that governs the reflection of light. From the drawings they made in their records, they infer that the dotted line drawn perpendicularly to the plane of the mirror, divides the angle formed by the incident and reflected rays into two equal angles. Excerpt from the class diary:

[“The light comes (reflected light) the same way as it goes (incident light)” (Ângelo). Some fail to understand Ângelo’s reasoning. Bruna clarifies her colleague’s idea: “when the light is hitting at an angle, it is reflected with the same angle”. “It's like an axis of symmetry, it is here, dotted on the diagram” – adds Eva. “The line on one side must be equal to the line on the other side, because they are symmetrical” (Daniela). “It is like there is always a symmetry in the middle of the two lines, the one that goes and the one that comes” (Lara). Joel, in conclusion, states: if the light goes in a diagonal, it also comes back in a diagonal, with the same angle. Their ideas are already quite mature and so I mention the fact that the angle formed between the symmetry axis (normal) and the incident ray is equal to the angle formed between the symmetry axis (normal) and the reflected ray].

- *The students build a periscope and make observations.*

Figure 3. Periscopes built by the students.

3.2. Assessment of the student’s learning

Three weeks after the pedagogical intervention, students answered individually to a questionnaire with true or false items. The following table shows the results obtained.

Table 2. Lessons subject and duration.

Items	Correct answers (%)
1. We can only see an object if there is light.	15 (94%)
2. Our eyes are light sources.	16 (100%)
3. A window is a light source.	15 (94%)
4. All objects send to our eyes the light they receive.	9 (56%)
5. I can see a pencil because it emits its own light.	15 (94%)
6. In a completely dark room I could not see anything.	16 (100%)
7. The light propagates in all directions in "curves".	16 (100%)
8. Objects that let some light pass through are called translucent.	16 (100%)
9. All materials let light passes through.	16 (100%)
10. Shadows are formed when light falls on opaque materials.	11 (69%)
11. A mirror does not form shadows.	7 (44%)
12. Light is reflected when it strikes a mirror.	14 (88%)
13. The light reflected by a mirror spreads in all directions.	13 (81%)
14. Light curves when it travels from one transparent substance to another.	12 (74%)

These results suggest that the learning acquired by the students was meaningful because it is long-lasting, as opposed to memorized learning, which is soon forgotten [26].

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4. Final considerations

The analysis of the class diary shows that the children are capable of overcoming complex challenges of a cognitive nature when these are approached in a collaborative context, of stimulation and freedom to express their thoughts. Thus, they become active and reflective subjects in the learning process [27]. In the previously discussed learning case, students: a) begin by elaborating predictions about what happens when the light of a flashlight hits a mirror and a cardstock; b) suggest ways to test their predictions; c) in group, test the predictions and make observations; d) reflect on their observations and identify differences between light reflected from the mirror and from the cardstock - regular and diffuse reflection; e) predict the path of the light between two mirrors; f) test their predictions and interpret the observations made; g) record the light path on their individual record sheets; h) infer and communicate to the class the path of light between the two mirrors; i) identify regularities, recognising that light is reflected according to a certain rule - the law of reflection; j) transfer the knowledge developed and apply it in the construction of a periscope; l) with the periscope, observe outside of the classroom. All throughout this learning process, the meanings that students gradually construct are subject to collective discussion and reflection, in a context of social interaction [28], aiming at the construction of socially enriched meanings and shared by a growing number of students. In this way, the social interaction generated among the children and between them and the teacher, promotes higher levels of learning. This is consistent with Harlen, when he refers that "interactions among students and between students and teachers are needed for inquiry-based learning, with the teacher having a key role" [29, p. 2]. The teacher, through a process of questioning, stimulator of thought and action in the students [3], supports their individual and collective cognitive activity [30, 31]. Through this process of questioning, guided by the teacher, students are able to reach higher levels of comprehension and develop better reasoning skills, which they would not be able to achieve without support. All this, as supported by Sá [3] and Harlen [2, 29], entails great personal and intellectual involvement by the student and is closely dependent on an intervention intentionally guided by the teacher, which aims at promoting in students both the construction of meanings that are more consistent with reality and the development of scientific process skills. The intentionality with which the research/teacher conducts their educational action is in line with a reflective practice, in the way they regulate and provide feedback to the children's joint cognitive activity, through continuous questioning, which stimulates reflection and action.

The data contained in the class diaries takes on the nature of a sample of the learning acquired by the children and, therefore, does not allow drawing any inference on the individual level of learning achieved by each one. However, the results of the questionnaire administered 3 weeks after the lessons shows that most of the children in the class acquired a solid knowledge about light and its interaction with the materials. According to Coll and Martín [26], an evaluation that is based on the consideration of an instant situation is unreliable, as it does not take into account the dynamic nature or the temporal dimension of the meaning construction process. In this sense, the results obtained in the questionnaire also allow claiming that this learning was significant, as opposed to memorisation, which is quickly forgotten.

Lastly, we would like to point out that the initial and in-service training of primary school teachers should be able to endow them not only with scientific knowledge in elementary physics, but also with specific didactic knowledge on how to explore the different curricular topics with the children. The development of this knowledge should be based on the data and tools that emerge from research undertaken with children in the classroom context. Research in science education should offer fruitful elements to support the educative action of the teachers. In this sense, the analysis presented in this article, about the activity "Reflection of light" may constitute both a didactic resource for teacher training and an element of support for those teachers, so that, in similar contexts, they are able to promote the same teaching and learning process with their students.

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