

## Generating Students' Information Seeking Questions in the Scholar Lab: What Benefits Can We Expect From Inquiry Teaching Approaches?

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**The article starts with the next page.**

# Generating Students' Information Seeking Questions in the Scholar Lab: What Benefits Can We Expect From Inquiry Teaching Approaches?

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Physics teachers use experimental devices to show students how scientific concepts, principles, and laws are applied to understand the real world. This paper studies question generation of secondary and under-graduate university students when they are confronted with experimental devices in different but usual teaching situations: reading about devices while studying still images or diagrams, watching an experimental demonstration, and handling the devices in the laboratory. The influence of the prior scientific knowledge on the questions asked is also analysed. Inquiry learning environments, involving lab projects, seemed to stimulate more inferences addressed to causality when students tried to build mental models, whereas reading about devices with the help of still images stimulate more descriptive inferences and inhibited predictive ones.

*Keywords:* basic physics, problem solving, experimental devices, question generation

## INTRODUCTION

Teachers agree about the importance of experimental work in science education because it gives opportunities to develop some important competences in their students. First, practical work facilitates modelling reality with science (Truyol and Gangoso,

2012). Second, experimental situations in the Laboratory can be used to place the students' work close to the scientists' work (Chinn and Malhotra, 2002). Third, experimental work enables the developing of procedural competences such as using measuring techniques, controlling variables and relating numerical computing to real world. For their educational benefits, experimental activities in science education are a permanent focus of interest in many countries (see, for instance, Allen (2012) a special issue of the Eurasia Journal of Mathematics, Science & Technology Education devoted to practical work).

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### **State of the literature**

- Most of the literature emphasizes the gap between theoretical knowledge and practice in teaching. Gaining expertise in teaching narrows this gap.
- One instructional design theory that can be applied to provide increased development for preservice teachers is expertise-based training (XBT).
- XBT is based on the idea that theories and findings of expert research can be used to create instructional strategies to enhance advanced learners' expertise. Technology can benefit the presentation of these new methods.

### **Contribution of this paper to the literature**

- This study is an example of how to use technology to present experts' methods and strategies related to teaching in a real classroom.
- The current literature presents a consensus about decreased self-efficacy beliefs during classroom teaching. This study provides a method to bring real classroom experiences to teacher education courses.
- The literature reviewed on expertise in teaching and its effects on preservice teachers' self-efficacy beliefs was mostly theoretical articles. However, this study presents actual evidence of the effects of expertise in teaching on preservice teachers' self-efficacy beliefs.

Experimental devices are used in science education in different ways (Trumper, 2003; Holstein and Lunetta, 2004; Barolli, Luburú and Guridi, 2010 and references there in). This diversity is due, among other factors, to the varied conceptions that teachers have about what 'science' and 'science learning' are (Lederman, 1999). In fact, students faced experimental devices in science education, but not always in lab situations. Experimental devices appear in textbooks and are used in lecture demonstrations too. There are at least three basic different teaching situations involving experimental devices: a) Reading about the operation of experimental devices in a textbook, usually with the help of still images or diagrams; b) Watching the devices operation in a lecture demonstration or in a specialized movie; c) Handling the devices in a lab project. Reading about experimental devices or watching the devices operation in lecture demonstration are very frequent in science teaching but in these two ways students are not really engaged in experimental work. Both practices are typical in the 'reception learning paradigm' (Novak, 1979). Experimental projects, in which students are free to manipulate the devices, have been used in other teaching conceptions, as the 'learning by discovery'

approaches or, recently, 'inquiry teaching and learning' (Anderson, 2002).

Inquiry learning has been defined as the educational process in which students being engaged in conceptual understanding, ask questions and construct solutions (Gunstone and Mitchell, 1998). According to Schraw, Crippen, and Hartley (2006), inquiry teaching promotes self-regulation because students have to activate "cognitive and metacognitive strategies to monitor their understanding (...) such as predict-observe-explain (Windschitl, 2002) or question-asking (Chin and Brown, 2002)" in investigation activities (p. 118).

In this vein, the present paper focuses on question-asking when students face experimental devices in inquiry environments. We would like to obtain support for inquiry teaching involving practical work, not only from epistemic but also from psychological grounds. Comprehension monitoring has been associated to academic success (Wang, Haertel, and Walberg, 1993) and deep comprehension (Chin and Osborne, 2008), and question generation has been defined as a monitoring mechanism. Therefore, developing students' question asking in science education is essential to them to achieve deep understanding.

The aim of this paper is to obtain evidence about the type of questions generated when students are confronted with experimental devices handling them in the lab, as typical in inquiry teaching environments. We will use a cognitive approach to compare the above teaching situation to other usual teaching situations such as reading about experimental devices with the help of still images, and visualizing the devices operation in lecture demonstrations.

### **Students' questions in science education**

Scientific research begins with "a good question." In fact, teachers agree on the educational potential of students' questions (Chin and Osborne, 2008). Accordingly, students' questions in science education have been analysed from several perspectives -didactic, epistemic, cognitive, procedural, etc. They have been classified using different criteria (Scardamalia and Bereiter, 1992; Watts, Gould, and Alsop, 1997; Anderson and Krathwohl, 2001; Chin and Chia, 2004), their quality has been studied (Graesser and Person, 1994) or they have been associated to comprehension, (Chin and Brown, 2002; Harper, Etkina and Lin, 2003). Other studies, apart from the ones in science education, have shown an improvement in comprehension and memory when students were instructed in question asking (Craig, Gholson, Ventura, Graesser, & the Tutoring Research Group, 2000; Rosenshine, Meister, & Chapman, 1996).

Finally, and related to the aim of this paper, questions about experimental devices have been also investigated. Students instructed in inquiry situations

learn to ask more and better quality questions than other students in different teaching situations do (Hartford and Good, 1982; Cuccio-Schirripa and Steiner, 2000). Graesser and Olde (2003) investigated the role of previous knowledge on question generation. Participants with different levels of expertise were faced with a broken device and they had to ask questions in order to repair it. The authors found that participants having higher expertise and knowledge about the device operation asked a higher amount of quality questions, i.e., those useful to repair the broken device.

In a previous study, Sanjosé, Torres and Soto (2012) analysed how different formats in the presentation of information on physical devices affected question generation in Secondary students. They consider reading about experimental devices (without any images or diagrams), visualizing the devices in a DVD, and also handling the devices in the lab. The reading condition generated more descriptive questions than the other conditions, the visualizing condition stimulated more predictive questions and the handling condition stimulated more explanation questions. The origin of the observed differences between the visualizing and the handling conditions, was not clearly stated, although the authors elaborated a non-contrasted conjecture to explain them.

The present study aims to replicate some findings of Sanjosé, Torres and Soto's (2012) study, but introduces some interesting innovations: 1) the consideration of still images together with texts, which is a usual learning situation in science classrooms; 2) the contribution of the still/dynamic images factor, together with the visualization/handling factor; 3) the contrast of the hypothesis about the reason why the differences between the visualizing and the handling conditions could appear; 4) the consideration of university students in the sample -having higher specific knowledge than secondary students-, to obtain new evidence about the contribution of science knowledge to question asking in science education; 5) the improvement of certain methodological aspects in order to diminish the error variance. From points (1), (2) and (4) we will obtain new specific data about question generation and self-regulated learning in lab situations. As point (3) concerns, we aimed to shed light on the reasons of the non-explained results obtained in Sanjosé and colleagues' work. Finally, point (5) involves some procedural details improving the *ceteris paribus* requirements with respect to that mentioned previous study.

### A cognitive approach to question generation

We will focus on a particular type of questions, the 'information seeking questions', (ISQs), i.e. questions aimed at obtaining additional information on content. They are very important in academic contexts. These

questions are considered to be 'prototypical,' 'genuine,' or 'sincere' by many researchers (Van der Meij, 1994; Flammer, 1981).

Even though students' questions have received attention by the researchers, less work have been devoted to propose cognitive mechanisms for question generation (Ram, 1991; Flammer, opus cit).

Recently, Otero proposed the 'Obstacle-Goal' model (2009) which postulates that ISQs are generated by subjects as a consequence of subjects' attempts to skip comprehension obstacles found in the way to their goal: to build an specific mental representation about the content. Thus, different questions are generated from different types of comprehension obstacles. This model is rooted in Nelson and Narens' (1990; Otero and Campanario, 1990) two-phase model of self-regulation processing, and also in Kintsch's cognitive theory for comprehension (Kintsch, 1998; Kintsch and Greeno, 1985) further developed for science comprehension (Greeno, 1989; Truyol, Sanjosé and Gangoso, 2012). According to this model, 'comprehension obstacles' refer to the impossibility of building the mental representation the subject needs to understand new information. Making inferences to elaborate the information and/or to link it with previous knowledge have been suggested to be the most important cognitive activity for science comprehension (Graesser and Zwaan, 1995). Thus, most of the comprehension obstacles in science understanding should come from intended but failed inferences. If students had the opportunity to ask questions, most ISQs would be associated with failed inferences in the process of building the attempted mental representation (Otero and Graesser, 2001). In science comprehension, these mental representations should be the Situation Model, the Scientific (or Abstract) Model (Greeno, op.cit).

Trabasso and Magliano (1996) studied inference generation in the process of conscious understanding of narrative texts, and identified three broad categories of inferences: associative, explanatory and predictive. 'Associations' provide information about features, properties, relations and descriptive detail of the entities (actors, objects, actions and events). 'Explanations' provide reasons about why something occurs. Lastly, 'Predictions' are forward-oriented and include consequences of actions or events, and they anticipate occurrences. Student questions should be associated to these inferences when they failed.

The Obstacle-Goal model assumes that the typology of inferences intended in science understanding tasks will be the same proposed by Trabasso and Magliano (op.cit). According to this assumption, a typology for students' information seeking questions is proposed:

- 1) *Association questions, Q1, aimed at knowing objects and events better (originated by non-achieved associative inferences), formed as "What..., How..., When...?"*

For instance, “What is the shape of a double cone?”, “How big is the bottle used in the Cartesian diver?”

- 2) Justification questions, Q2, aimed at justifying why objects and events ‘are the way they are’ (originated by non-achieved explanatory inferences), frequently formed as “Why..., Why not..., How is it that...?” For instance, “How is it possible that the double cone rolls the slope up?”; “Why does the Cartesian diver come up to the surface?”
- 3) Prediction questions, Q3, aimed at anticipating future happenings or events that could take place if the conditions were different to the ones explained in the information provided, formulated as “What would happen if..., What is going to happen...?” For instance, “What would happen if we used oil instead of water (in the Cartesian diver)?”; “What would happen if we increased the ‘V-shape’ angle of the guides?”

These three types of questions are also related to three main scientific competences: describing reality in scientific terms (modelling), explaining why objects and events are as they are using scientific laws and principles (establishing causal antecedents), and predicting events using hypothetic-deductive reasoning (predicting causal consequents). This typology has proven to be sufficient to account for the questions asked by students aimed to understand experimental devices (Torres, Duque, Ishiwa, Sánchez, Solaz-Portolés and Sanjosé, 2012). The Obstacle-Goal model has received empirical support in recent experiments, (Ishiwa, Sanjosé and Otero, 2012), hence we will adopt the above cognitive perspective for question generation.

### Hypotheses

As we said before, we aimed to obtain empirical evidence of the advantages of using experimental devices in lab situations. We compared an inquiry learning perspective, to other two very frequent learning situations involving experimental devices: using videos to show how experimental devices operate –students can visualize the operation of the devices in real time without the possibility of handling them, as in lecture demonstrations- and reading about devices with the help of still images in a textbook. We will refer to these three situations as the “LAB”, the “DVD” and the “Text-plus-Still-images” conditions.

The possible advantages of the LAB condition, respect to the other two considered learning situations, can be originated by two main factors:

I) The static/dynamic nature of the observed images. In classroom demonstrations or in handling work in the lab, the operation of devices can be observed as a time-dependent event, whereas in textbooks the operation has to be imagined from text content and still images. The integration of textual information and images or graphics can improve comprehension (Schnotz, 2005). In addition, the visualization of an event developed in

time, can reduce the cognitive load with regard to the situation in which the process is re-constructed from mind, according to the Cognitive Load Theory, (Chandler and Sweller, 1991). In the last case, cognitive resources have to be dedicated to the de-codification of the text and/or to construct mental models to represent the temporal development of the event not directly perceived by senses. Höffler and Leutner (2007) found an instructional advantage for animations on still images with a moderate effect size, but the effect size became large when the animations were realistic. In a recent research on biology education, dynamic images (video) helped students to identify animal species in the reality (aquarium) better than book-based teaching (Pfeiffer, Scheiter, Kühl, and Gemballa, 2011).

According to the previous findings, our first hypothesis is:

**H1:** Students in the text-plus-still images condition (TSI onwards) will formulate a greater proportion of descriptive questions (Q1 onwards) and, therefore, less proportion of predictive questions, (Q2 and Q3 onwards) than the students in the conditions of dynamic images (DVD and LAB).

In the TSI condition, we expect students will find some obstacles to know the devices components and the devices operation along time. Thus, students will generate “What, When, How, Where” questions. However, when students can visualize a real device operation (in DVD or in LAB conditions), we expect this type of obstacles will almost disappear and the cognitive resources will be used to establish causal relationships.

In previous experiments on question generation from the reading of expository texts, many descriptive and causal questions but very few predictive questions were obtained (Costa, Caldeira, Gallástegui and Otero, 2000; Millis and Graesser, 1994; Graesser and Bertus, 1998). However, it has been found that students do generate predictive questions when they can watch videos about experimental devices (Sanjosé, Torres and Soto, 2012). As causal questions concerns, we expect that a significant proportion of questions might be of this type (Q2) in whatever condition. This is because causality is the most important relationship among ideas in comprehension (Millis and Graesser, 1994, Singer and Gagnon, 1999; Wiley and Myers, 2003).

II) The possibility of handling the devices. The possibility of interacting with real devices manipulating them in the LAB condition opens the way to the activation of sensory-motor resources in the brain, which could affect reasoning (Barsalou, 2008, Zwaan, 2004). Moreover, the possibility of free manipulation could alter the proportions of causal and predictive questions on the devices. When a student tries to understand the causal operation of the devices, he/she can elaborate a conjecture about the causal role of a

certain factor, thus formulating a “What would happen if this factor was altered?”-question (Q3). In the handling condition, instead of formulating this Q3 question, the subject has the possibility of modifying the factor and seeing what happens. This possibility does not exist in the only-watching, DVD condition. When a student cannot understand what has happened as consequence of some change carried out in the device, then a different and specific causal question will appear, Q2. That is, the possibility of handling the devices can eliminate some Q3, predictive questions, but, on the other hand, it opens the way for new Q2 questions.

Our second hypothesis is:

**H2:** Students in the handling (LAB) condition will produce a higher proportion of explanation “Why did this happen?”-type questions (Q2), but a lower proportion of Prediction “What would happen if?”-type questions (Q3) than students in the Visualization-without-handling (DVD) condition. These LAB/DVD differences in the proportions of Q2 and Q3 will be due to the extra-amount of questions formulated after, and as consequence of, the handling of the devices in the LAB condition.

III) Finally, previous knowledge in science should be associated with the mental representation students try to elaborate about the devices operation. We expect that the higher the level of previous knowledge, the more frequent the use of scientific concepts, theories, and principles to model the devices operation. Therefore, in any of the considered learning situations, the obstacles detected on the way to comprehension could also depend on previous knowledge, and that could influence the way questions are formulated (Miyake and Norman, 1979).

Our third hypothesis is:

**H3:** No matter the experimental condition, high knowledge students will include in their questions a greater amount of scientific terms than low knowledge students will.

## METHOD

### Participants

Ninety-one Secondary students and ninety University male and female students from a large city, participated in this study. The secondary school students belonged to 10<sup>th</sup> grade groups in a public school of high academic level. All of them were taking Physics. The university students were in the second year of a grade in Physics in a public university and were taking Mechanics (a part of Physics, which is very relevant for the comprehension of the devices). We expected the academic level to be associated with the prior specific science knowledge.

**Table 1.** Distribution of the participants according to the experimental conditions and academic levels

	Second.10 <sup>th</sup>	Univ.	Totals
TSI	25	26	51
DVD	30	31	61
LAB	36	33	69
Totals	91	90	181

Table 1 shows the distribution of the participants according to the factors considered.

The Secondary participants belonged to three intact and equivalent groups, so each group was randomly assigned to one of the three experimental conditions. University students belonged to two groups. They were assigned at random to one of the three experimental conditions in each group.

### Materials

Dillon (1990) proved that perplexity brings about the generation of questions in students. Thus, we used two experimental devices operating in an amazing, unexpected way (Torres et al. 2012). These devices are:

- 1) *A Double Cone, which rolls downward on a slope formed by two straight guides, but able to roll towards the upper part of the ramp when the two guides are in a “V-shape” with the vertex in the lower part of the slope.*
- 2) *The Cartesian Diver, which sinks to the bottom when the water bottle in which it floats is squeezed, but returns to the surface when the squeezing releases.*

They both are well-known experimental devices (Websites, 2012) whose physical explanation can be found in Appendix 1.

The devices were manufactured under the specifications of the researchers and their good operation was tested repeatedly to avoid any risk in their manipulation.

Two short texts were prepared with the description and operation of each device. These same texts were used in all of the three experimental conditions. Each text was composed of three parts: a) the activation of a well-known explanatory schema (i.e. when a round object is abandoned on an inclined plane, it rolls the slope down); b) the presentation of an event hoped for according to this explanatory schema (a cylinder rolling the slope down); c) the introduction of a ‘discrepant event’ with this explanatory schema (the double cone seems to roll the slope upwards).

For the visualization without handling (DVD) condition, two image files were elaborated by filming the operation of the real devices. The experimental set-ups were carried out in the school lab and we proceeded to the filming of their operation afterwards. The filming

was carried out by an audio-visual technician with professional equipment. Various shots were taken from different perspectives to facilitate the visualization of the operation of the devices. The filming of each device lasted between 4 min 30 sec, and 5 min 00 sec.

For the TSI condition, we proceeded in the following way: from each video recording, 3 specific still shots were selected, one for each of the parts of the text, to which labels, arrows, etc. were added, as it is typical in schematic images in textbooks. These modified still shots were the ones used in the TSI condition. In such a way, we tried to make some variables constant (i.e. realism of the images).

Appendix II shows one of the texts with one still image used in the TSI condition.

### Variables

The independent variables were the experimental condition (TSI/ DVD/ LAB) and the academic level (10<sup>th</sup> grade / university). The questions of each type, Q1, Q2, Q3; and the total amount of questions formulated by each student, Q<sub>tot</sub>, were accounted for.

The causal questions generated after, and as consequence of the handling of the devices in LAB condition, Q<sub>2aftermanip</sub>, were accounted for separately. We simply paid attention to that questions referring to actions or observed results not present in the initial setting and operation of the devices. These specific questions, Q<sub>2aftermanip</sub>, should not be generated in the DVD condition. Finally, the amount of questions whose formulation included at least one scientific term, Q<sub>sci</sub>, was also considered.

The dependent variables were the proportions of each type of question with regard to the total amount of questions: PropQ1 = Q1/ Q<sub>tot</sub>; PropQ2= Q2/ Q<sub>tot</sub>; PropQ3= Q3/ Q<sub>tot</sub>. Differences in the proportions of each type of question can be associated with different types of mental representations students try to construct, and with the obstacles found by them. For instance, a greater proportion of Q2 questions would indicate a greater concern for saving causal comprehension obstacles, or for justifying “Why are things the way they are?” A greater proportion of questions with scientific terms, PropQ<sub>sci</sub>, could indicate greater efforts of modelling reality with science by the students.

### Procedure

An ethical protocol was respected in the entire process. Professors, parents, and students were informed weeks before the experiment was conducted, to assure consented and willing participation. The

researchers committed themselves to respect the confidentiality of the data at every moment.

To preserve the validity of the study, it was proper to assure (to the degree possible), that the students would formulate the questions that they really needed in order to understand the devices, and not ‘all of the questions that came to mind’. Thus, we use the particular procedure by Torres and colleagues (2012). In the instructions, two experimental sessions were announced. In the first session, students should have comprehended the operation of the devices, and in the second session, they would do a comprehension test, which would be the source of the experimental data. In the first session, students could formulate all of the questions they needed to comprehend the devices, (and to hand them in). The researcher would respond to each student’s questions before the second session, so that performance in the comprehension test would improve. In this way, the focus of attention drifts away from the questions themselves to the comprehension of experimental devices. After the taking of data in the first session, the students were informed that the second session would not be necessary and the researchers answered the students’ questions in front of the group-class.

In the TSI condition, the session took place in a classroom and was carried out for groups of participants together. One of the researchers delivered the instructions to students and read them aloud. When doubts were clarified, the first text with still images was handed out. The order of the texts was counterbalanced. After the text with the still images, a blank sheet of paper was included to write the questions down. Upon finalizing the questions on the first text, the question sheets were collected and the second text with still images was handed out. Time was limited to 15 min for each device.

In the DVD condition, the session took place in a computer lab in which each participant was assigned a personal computer. The instructions were handed out, read aloud, and explained to the students in this condition, in identical fashion as what was carried out in the TSI condition. Then, the text of the first device (without the still images) was handed out, with the blank sheet of paper for students’ questions. On each computer, the two files with the video-recordings of the operation of each device, were previously installed. Each student could see the filming and read the text at his/her own pace. After collecting the questions of the first device, the second text was handed out and the second filming was seen under an identical procedure. Researchers controlled that each student should only see the corresponding device in each moment. The order of each device was also counterbalanced. The time was also limited to 15 min per device.

**Table 2.** Mean values (and standard deviations) for each type of question in the experimental conditions and academic levels. Both devices have been considered together.

	Qtot	PropQ1	PropQ2	PropQ3	PropQsci
Secondary 10 <sup>th</sup> gr. (totals)	11.4 (3.6)	.16 (.16)	.56 (.20)	.27 (.19)	.25 (.18)
Still images (TSI)	9.4 (2.6)	.23 (.23)	.64 (.23)	.13 (.12)	.25 (.19)
Dynamic images	12.2 (3.6)	.14 (.11)	.53 (.19)	.33 (.19)	.25 (.18)
DVD	11.3 (4.0)	.11 (.12)	.47 (.18)	.42 (.17)	.18 (.14)
LAB	13.0 (3.1)	.16 (.10)	.58 (.19)	.26 (.17)	.31 (.19)
University (totals)	11.4 (3.3)	.17 (.14)	.56 (.21)	.28 (.21)	.42 (.22)
Still images (TSI)	11.5 (2.8)	.19 (.19)	.67 (.16)	.14 (.10)	.34 (.19)
Dynamic images	11.3 (3.5)	.16 (.12)	.52 (.21)	.32 (.22)	.45 (.23)
DVD	11.7 (3.7)	.15 (.12)	.44 (.19)	.41 (.20)	.29 (.14)
LAB	11.0 (3.3)	.17 (.12)	.58 (.21)	.25 (.20)	.61 (.19)
Both levels (totals)	11.4 (3.4)	.17 (.16)	.56 (.21)	.27 (.20)	.34 (.22)
Still images (TSI)	10.5 (2.9)	.21 (.21)	.65 (.19)	.13 (.11)	.29 (.19)
Dynamic images	11.8 (3.6)	.13 (.12)	.52 (.20)	.33 (.20)	.35 (.23)
DVD	11.5 (3.8)	.16 (.11)	.46 (.19)	.42 (.19)	.24 (.15)
LAB	12.0 (3.3)	.17 (.15)	.58 (.19)	.25 (.18)	.45 (.24)

In the handling condition, LAB, the participants were taken to the lab one by one, since data collection was individual. Before proceeding, they were given and read aloud the instruction sheet. After solving the participant's doubts, the first text and the blank sheet were handed to him/her so that he/she could write his/her questions down. Afterwards, the student was placed in front of the first device and one of the researchers operated the device a couple of times. While making the device work, the researcher orally narrated the same information written on the corresponding text. Afterwards, the researcher invited the student to handle the artefact by himself/herself and to write his/her questions on a blank sheet. Complete freedom was given to the student for 15 minutes. After time was up, the sheet with the questions was taken up and everything proceeded in the same fashion with the second device. The order of presentation of the devices was balanced.

The questions formulated in writing by the students were classified according to the assumed taxonomy (Q1, Q2, Q3). To guarantee the validity of the procedure, a subset of 33% of the questions was classified by two of the researchers independently, and the inter-coder agreement was calculated computing the Cohen's Kappa. A value of 0.72 was obtained and hence the agreement was not considered good enough. After a discussion and clarification session, another subset of 33% of the total amount of questions was considered and the same procedure was followed. This second time, the Kappa value reached 0.83 so we went ahead,

reclassified the initial sub-group and classified the remaining 33% of questions asked. No more inter-coder disagreements were found.

## RESULTS AND DISCUSSION

A total amount of 2064 questions, aimed at obtaining information on the devices, were collected. This corresponds to a general average of more than 11 questions per subject, that is, more than 5.5 questions per subject and per device, which is a very high figure. Thus, the procedure stimulated students' information seeking questions.

The independent variables, i.e. the proportions over the total for each type of question and the total amount of formulated questions (Qtot), were also distributed according to a normal curve (K-S:  $p > .05$ ).

Table 2 shows the averages (and standard deviations) obtained in the two devices, for the proportions of each type of question in each experimental condition and educational level.

Table 3 shows the most frequent students' questions and the most frequent scientific terms mentioned. Other important, but not mentioned scientific concepts are also listed in Table 3.

In order to contrast H1, we compared the still images condition (TSI) with the dynamic images conditions (DVD + LAB). The independent-groups t-test was used. When the homoscedasticity condition was not fulfilled, according to the Levene's test, the degrees of freedom were corrected.

**Table 3.** The most frequent students' questions and the most frequent scientific concepts mentioned. Other important but not mentioned scientific concepts are also listed.

Questions	Type
<b>Questions which do not include physics terms</b>	
-What are the dimensions of the double cone?	Q1
-Is there a bubble of air inside the cap?	Q1
-Why does the double cone go up?	Q2
-Why does the diver sink and then rise?	Q2
-What would happen if instead of a double cone, it were another figure?	Q3
-What would happen if we removed the bottle top?	Q3
-What would happen if the bottle were completely filled with water?	Q3
<b>Questions which include physics term or parameters</b>	
-What is the range of opening angles of the guides so that the cone goes up?	Q1
-What is the pressure inside the Cartesian diver?	Q1
-What forces act on the double cone?	Q1
-Is the opening angle of the guides related to the incline angle of these same guides?	Q2
-Does the speed with which the diver submerges depend on the strength we exert?	Q2
-Is the air pressure on the inside of the pen cap what makes it submerge?	Q2
-Would it go up at the same speed if the angle between the guides were greater?	Q3
-What would happen if the density of the water were different?	Q3
<b>Most common physics concepts in students' questions:</b>	
Diver: Weight, Force, Pressure, Density, Speed	
Acrobat: Weight, Friction, Opening Angle, Incline Angle, Speed	
<b>Important physics concepts which were not mentioned:</b>	
Diver: Boyle and Mariotte's law (Pressure and Volume relationship in gases); Pascal's Principle; Newton's 2 <sup>nd</sup> Law	
Double-cone: Net Force; Normal Force; Rigid body; Torque.	

**Table 4.** Statistical data for the analyses carried out to contrast the three hypotheses formulated. 't' stands for the independent groups Student's t-test; 'F' is the Snedecor's test in ANOVAs, 'p' is the significance, and 'η<sup>2</sup>' measures the effect size.

		PropQ1	PropQ2	PropQ3
<b>H1</b>	Still vs Dynamic	t(62.5)=2.055	t(179)= 3.994	t(157.2)= -8.219
	Images	p= .044; η <sup>2</sup> = .04 t(128)= -1.658	p< .001; η <sup>2</sup> = .08 t(128)= -3.822	p< .001; η <sup>2</sup> = .19 t(128)= 4.974
<b>H2</b>	DVD vs LAB	p= .10	p< .001; η <sup>2</sup> = .10	p< .001; η <sup>2</sup> = .16
<b>PropQsci</b>				
<b>H3</b>	Level: 10 <sup>th</sup> gr/Univ.		F(1,175)= 38.620; p< .001; η <sup>2</sup> = .18	
	Condition: TSI/DVD/LAB		F(2,175)= 28.350; p< .001; η <sup>2</sup> = .25	
	Interaction Level X Condition		F(2,175)= 6.667; p= .002; η <sup>2</sup> = .07	

In order to contrast hypothesis H2 about the specific effects from handling -apart from the ones coming from watching real images-, the DVD and LAB conditions were compared to each other and the independent-groups t-test was also used.

Finally, in order to contrast H3, a 3X2 ANOVA was carried out, taking the experimental condition (TSI/ DVD/ LAB) and the Educational Level (10th grade / university) as the two factors.

Table 4 shows the main data of the statistical analyses computed for the three hypotheses formulated.

As predicted in H1, the still images condition (TSI) generated a higher proportion of Association-type questions than the dynamic images conditions (DVD + LAB). Dunnet *post-hoc* analysis showed significant differences between the TSI and the DVD experimental conditions, but not between the TSI and the LAB conditions. The last result was due to the extra-amount of Association questions asking for particular values of the experimental setting parameters (for instance: "What is the maximum angle for the slope so that the double cone can roll up"?), generated in the LAB condition.

**Table 5.** Questions formulated after manipulation and proportion of Explanation and Prediction questions when these questions are subtracted or added to the quantities Q2 and Q3, respectively. The proportions in the DVD condition are the same as the ones in Table 2.

	Q2 <sub>aftermanip</sub>	Prop(Q2-Q2 <sub>aftermanip</sub> )	Prop(Q3+Q2 <sub>aftermanip</sub> )
LAB (both levels)	1.4 (1.5)	.46 (.18)	.37 (.19)
Secondary 10 <sup>th</sup> grade	1.8 (1.6)	.44 (.16)	.40 (.17)
University	0.9 (1.2)	.48 (.19)	.34 (.21)
DVD (both levels)	---	.45 (.19)	.41 (.19)
Secondary 10 <sup>th</sup> grade	---	.47 (.18)	.42 (.17)
University	---	.42 (.19)	.40 (.21)

As it can be seen in Table 4, there were significant differences between the LAB and the DVD conditions due to the possibility of the free handling of the devices, supporting H2. These differences only implied the proportions of Explanation and Prediction questions, but not the proportion of Association questions.

In order to complete the contrast of H2, we studied whether the observed DVD/ LAB differences in Q2 and in Q3 were due to the possibility of doing an immediate test for the student's conjectures in the LAB condition, but not in the DVD condition. Thus, the causal-type questions formulated after, and as consequence of manipulations, Q2<sub>aftermanip</sub>, were accounted apart from the rest of the Q2 questions in the LAB condition, and scored separately. Some examples of this kind of questions are: "Why cannot the double cone roll up now?" (asked after decreasing the the 'V-shape' angle of the guides); "Why can the ball roll the slope up?", (after using a ball instead of the double cone or the cylinder); "Why cannot the Cartesian diver float now?", (after putting the cap inside the bottle upside down, and observing the cap sinking); "Why do I need less pressure when there is more water in the bottle?", (after filling the bottle up with water, and squeezing the bottle to make the diver sink), etc.

Before handling originating a new Q2<sub>aftermanip</sub> question, the subject has to generate a "What would happen if?" question. For instance, before handling the Cartesian diver to take some water out of the bottle, then asking the question: "Why does the pressure exerted have to be greater when there is less volume of water in the bottle?", the student had to generate a silent question similar to: "What would happen if less water was inside the bottle?" Therefore, in the LAB condition each explicit Q2<sub>aftermanip</sub> question has associated a silent, implicit Q3 question.

Therefore, if we added Q2<sub>aftermanip</sub> to the amount of "What would happen if" questions, Q3, we would obtain a best estimation for the amount of the questions generated in the LAB condition, verbally explicit or not. This amount of Q3 questions have to be compared to the quantity of Q3 in the DVD condition.

As Q2<sub>aftermanip</sub> cannot be generated in the DVD condition, we can compute Q2 - Q2<sub>aftermanip</sub> in the LAB condition and compare this Explanation questions, generated apart from the handling) in both conditions (see Table 5). ANOVA showed that the previously found significant differences between the two conditions disappeared ( $F < 1$ ). Neither was the academic level significant ( $F < 1$ ), nor was interaction produced ( $F < 1$ ). The proportion of Q3+Q2<sub>aftermanip</sub> was also compared with the proportion of Q3 in the DVD condition by means of ANOVA. The significant differences between conditions showed in Table 4, also disappeared for these variables ( $F(1,126) = 1.588$ ;  $p = .210$ ). In addition, the Academic Level did not produce significant differences ( $F(1,126) = 1.228$ ;  $p = .270$ ) and there was no significant interaction between both factors ( $F < 1$ ).

Summing up, the observed LAB/DVD differences in the proportion of Explanation questions were caused by Q2<sub>aftermanip</sub>, and once removed, those differences disappeared. Similarly, when we accounted for the implicit, silent "What would happen if?" questions preceding each of the Q2<sub>aftermanip</sub> questions, the LAB/DVD differences in the proportion of Prediction questions also disappeared.

Finally, and concerning hypothesis H3 (see Table 5), the university students generated a higher proportion of questions including scientific terms, Qsci, than the secondary students, and the LAB condition generated a higher proportion of Qsci than the DVD and the TSI conditions (Dunnet:  $p < .001$  in both comparisons). The DVD and the TSI conditions were not significantly different generating this kind of questions (Scheffé:  $p = .27$ ). Moreover, there was a significant interaction effect because university students were particularly stimulated to ask scientific questions in the LAB condition. Specifically, in the LAB condition university students used more scientific laws to ask causal-type questions. Once they activated a scientific causal schema, they asked for particular values of some relevant parameters (or setting variables) so increasing the number of Association-type questions (for example: "What is the minimum pressure causing the 'Cartesian diver' to

sink?”). Anyway, only 25% of the questions asked by Secondary students, and 42% in the case of University students included scientific terms. These results show the difficulties students had using the abstract concepts of science to model reality, despite the fact they had studied advanced science courses.

## CONCLUSIONS

There is a clear agreement that formulating hypotheses and knowing how to contrast them is essential for students' scientific education, because it is one of the ways in which scientific knowledge is constructed and validated (Gil, 1986). However, not every teaching situation allows students to develop this competence. Inquiry learning is one of these situations, which frequently use experimental devices to propose scholar research projects to students. In this study we have explored the contribution of two components present in the use of experimental devices in lab to promote causal and hypothetical-deductive reasoning: a) the possibility of visualizing the dynamics of the devices operating through time, and b) the possibility of handling the devices.

The results from the present study can be summarized as follows:

**1)** Compared to learning situations in which students read about experimental devices with the help of still images, the possibility of visualizing real devices (thus, dynamic images) stimulated in students significantly more “Why?” questions (medium effect size) and significantly more “What would happen if?” questions (large effect size). As expected according to Chandler and Sweller's work (1991), the condition with still images seemed to demand more cognitive resources than the conditions of dynamic images to represent the phenomena through time. The possibility of visualizing the temporal development of a phenomenon seemed to release the working memory from the effort of adequately representing the entities (objects and events), which allowed these cognitive resources to be dedicated to causal antecedents or consequents. As causal antecedents and causal consequents imply two or more entities -the ‘cause’ and the ‘consequent’-, knowing these entities seems to be a prerequisite for looking for their relationship. Therefore, subjects ask Association questions before asking Explanation of Prediction questions. If the representation of the entities is difficult, a working memory overload could inhibit asking for other, non-descriptive questions. In our study, compared to the possibility of visualizing real devices operating along time, the text-plus-still images condition promoted the elaboration of more descriptive inferences, and inhibited predictive inferences in the construction of students' mental representations.

**2)** Handling the devices helped students to advance through the ‘space of the problem’ (Newel and Simon, 1972) towards the goal (comprehending the device). This experimental situation allowed students to answer some hypothetical-deductive questions immediately, using a “handle-and-see-what-happens” strategy. After handling, and as consequence of it, new causal questions were generated which, in time, could open a way to new conjectures and ways of handling. These extra causal questions produced significant differences in the distribution of the questions between the handling condition and the only-watching condition (with medium and large effect sizes). The reason is that this kind of questions cannot be generated in the only-watching condition because students cannot check their conjectures but only ask hypothetical-deductive “What would happen if?” questions. Thus, if freedom of action is allowed to vary the set-up of the devices, the learning activities could simulate a scientific research project fostering more causal questioning, and deep comprehension of science phenomena. Our data have shown that inquiry learning in lab can generate more questions addressed to causality (to causal antecedents and consequents), which could gain specific importance as “research questions,” that is, questions that initiate learning processes in the science classroom.

**3)** High knowledge students attempted to modelling reality using science more than low knowledge students as expected (the observed effect size was large), but again more science knowledge was activated and used when students had the possibility of handling the devices. However, students used scientific knowledge in a poor way, usually alone in a sentence. They scarcely included full scientific ideas involving scientific modelling in their questions. For example, the crucial question, “What would be the relation between the three angles so that the centre of mass of the double cone went down while rolling up the slope?” was never asked, nor was the question, “What factor is creating the Archimedes buoyant force acting on the Cartesian diver?” Similar difficulties were found by Olsher and Dreyfus (1999) in junior high-school students, long time ago. Recently, Truyol and Gangoso (2012) obtained the same result in university physics students: it was hard for them to solve physics problems successfully, when the physics model was not explicit in the problem statement so solvers had to elaborate it. These findings and ours show that scientific modelling is hard to perform even for students in advanced science courses.

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APPENDIX I: Experimental devices used

THE CARTESIAN DIVER

In a flexible covered bottle, a volume of liquid is to be found in such a way that it does not totally fill it. In this liquid, the Cartesian diver is found, made in the following way: plasticine is placed on a pen cap as a counterweight and is fixed with wire to the cap. The diver is placed in such a way that it floats vertically, doing so carefully so that this way an air bubble is formed inside, between the upper part of the cap and the surface of the water.

The diver ascends or descends depending on the relation between its weight and the buoyant force. Upon squeezing the bottle by hand, the pressure inside is increased: in the liquid, which is diffused in its cavity due to the Pascal principle, and in the air. This makes the volume of the air bubble decrease inside the pen cap (the Boyle and Mariotte law:  $PV = nRT$ ; like  $T = cte$ , so  $PV = cte$ ; as,  $P_{2b} > P_{1b}$  so  $V_{2b} < V_{1b}$ ). Upon diminishing the interior volume of the diver, the buoyant force diminishes (it diminishes the volume of water displaced by the air bubble). If the increase in pressure inside the bottle is such that the buoyant force on the diver is less than its weight, the diver will sink. By releasing the bottle, the pressure inside decreases so increasing the volume of the air bubble inside the pen cap. Therefore the buoyant force increases making the diver rise again to the surface.

THE CLIMBING ACROBAT (the double cone)

This consists of a double cone and two straight circular-section guides, which constitute a ramp by which the double cone moves. The guides can vary the opening angle between them in such a way that they can be parallel or adopt a “V” form. When the guides are parallel, the double cone descends by the ramp, as expected. But if the guides form a “V” with the vertex below, the double cone rolls towards the high part of the ramp without help. When the guides are in a “V”, with the vertex in the low part of the ramp, the guides separate from one another to the degree that the cone goes up the ramp. This implies that the double cone “sinks” more and more between them. That is, to the degree that the double cone rolls up, on one hand, its CM gets higher due to the ramp, and on the other hand, it loses height by sinking between the two guides in the “V” form. If the second effect is greater than the first, the movement will be spontaneous, for the CM, globally, will descend to the degree that the apparatus rolls toward the high part of the ramp. That is, the double cone will move in such a way that its energy potential decreases. This is the condition which is fulfilled in the device. The condition can be expressed in geometric terms from the 3 angles implied: the angle of the ramp’s incline ( $\alpha$ ), half of the angle of the opening of the guides ( $\beta$ ), and half of the cone’s own angle ( $\gamma$ ).

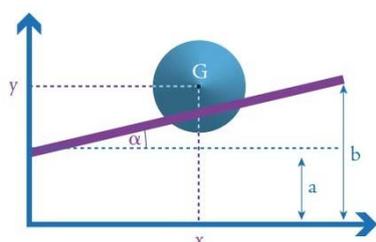


Figure 1A) Acrobat as seen from side

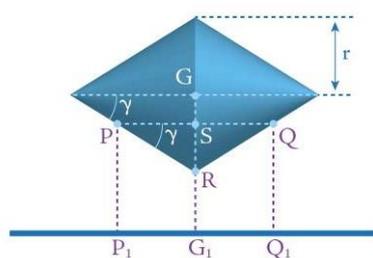


Figure 1B) Double cone as seen from front

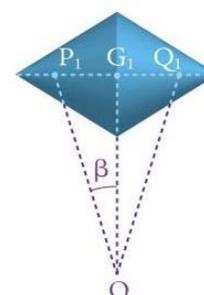


Figure 1C) Double cone as seen from bottom

(Source: Defying gravity: The uphill roller, J. Havil,

<http://plus.maths.org/content/os/issue40/features/uphill/index>, visited on 2/6/2012)

Situating the double cone in the lowest part of the ramp (on the vertex of the “V” formed by the two guides which constitute the ramp), to the degree that the double cone rolls toward the high part of the ramp, the height gained by the CM, and (Figure 1A), it is the subtraction between what ascends the ramp vertically,  $h$ , and what has sunken the double cone between the guides,  $a$ :  $y = h - SR$  (see Figure 1B). The horizontal and vertical run of the double cone is related to the angle of the ramp:  $\tan(\alpha) = h/x$  (Figure 1A); from which  $h = x \tan(\alpha)$ . For its part, due to the sinking of the double cone, the CM (in the geometric center of the figure) descends a height  $SR = PS \tan(\gamma)$ , being  $PS = PQ/2$  the distance of horizontal separation between the guides in the point in which the double cone is found supported (Figure 1B). But  $\tan(\beta) = P_1Q_1/2x = PQ/2x = PS/x$  (Figure 1C). Therefore,  $SR = x \tan(\beta) \tan(\gamma)$ .

Since  $h = y - SR$ , we have  $h = y - SR = x \tan(\alpha) - x \tan(\beta) \tan(\gamma) = x (\tan(\alpha) - \tan(\beta) \tan(\gamma))$ . So that there may be spontaneous movement,  $h < 0$ , that is,  $\tan(\alpha) < \tan(\beta) \tan(\gamma)$  should be demanded, which is the design condition of the device so that it may work in the desired way.

**APPENDIX II. One of the texts used in the experiment, and one of the still images with it.**

(The structural parts of the text have been added in parenthesis).

**The ‘Climbing Acrobat’**

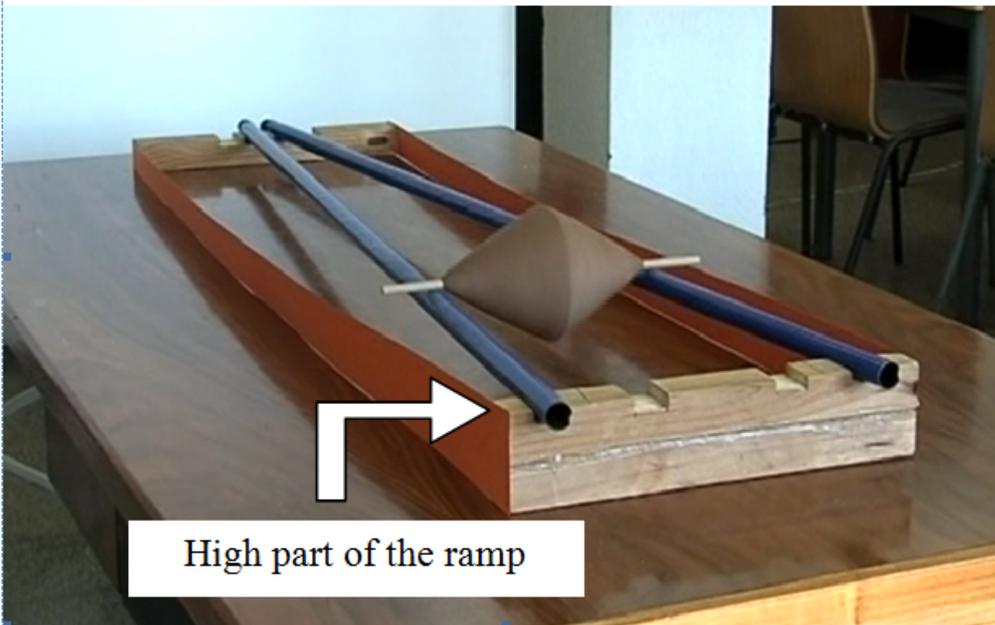
We know that a round object rolls downward on an inclined plane. It cannot move upwards unless it has a motor or something that pushes it. (*Activation of a pre-existent explicative scheme*)

The ‘climbing acrobat’ consists of a double cone -two cones united by their bases-, and an inclined plane formed by two upright bars which are used as guides. If the two bars which form the ramp parallel-wise are set in place, and then the double cone is situated on top of them, the object rolls towards the low part of the ramp, as is expected.

(*Presentation of an event expected according to the previously explicative scheme*)

However, when the two bars which form the ramp are placed in the “V” form with their vertex in the low part of the ramp, the double cone rolls and moves towards the high part of the ramp without help! (*Introduction of the ‘dissenting event’ to provoke perplexity*)

The acrobat rolls toward the high part of the slope formed by the guides in “V” form



**Figure 2.** One of the still images for the “climbing acrobat” text.