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Video worked examples to support the development of elementary students' science process skills: A case study in an inquiry activity on electrical circuits

Solé-Llussà, A.^a, Aguilar, D.^{a*} and M. Ibáñez^b

^aDepartment of Specific Didactics, University of Lleida, Lleida, Spain; ^bDepartment of Environmental Sciences, University of Lleida, Lleida, Spain.

**Corresponding author:* David Aguilar Camaño.

Faculty of Education, Psychology and Social Work

University of Lleida, Spain.

Av. de l'Estudi General, 4. 25001, Lleida (Spain)

0034 973 706 510

daguilar@didesp.udl.cat

ORCID: 0000-0001-5940-3339

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Abstract:

Background: Scientific inquiry is a widely accepted methodology to promote science process skills. In inquiry activities, students develop their understanding by addressing questions, performing scientific research and interpreting results derived from their research. Developing these science skills to perform scientific inquiries is considered a learning objective in primary science education. Although this methodology yields good results, it can be too cognitively demanding for inexperienced students. Guides are therefore needed to support the development of novel inquirer activities.

Purpose: In the present work, a didactic strategy based on video worked examples is proposed for guiding the inquiry process in an elementary education classroom.

Sample: This study included 30 elementary school students in the fifth and sixth grade from one rural school in Catalonia (eastern Spain).

Design and method: The present work is a case study in which a quantitative method is applied to achieve the research objectives. Six open-ended questions were used to analyse the performance of the different science process skills.

Results: Results confirm that the strategy based on the use of video worked examples to support an inquiry activity provides students with a structure for the inquiry process, and in particular, improve their questioning, collection, processing and analysing skills. These data reinforce the idea that offering supports and instructions renders an opportunity to practise science process skills and improve the students' understanding and application of these abilities. Moreover, video worked examples supported transferring scientific skills to other scientific contexts.

Conclusions: The use of video worked examples as a didactic strategy has a positive impact on the students' inquiry behavior. This strategy promoted positive classroom dynamics reflected in improved students' autonomy, collaborative work and motivation when performing an inquiry activity.

Keywords: Electric circuits; elementary education; inquiry; process skills; video worked examples.

Introduction

Contemporary frameworks for science education highlight the fact that one of the main goals for students is to become scientifically literate citizens (Organization for Economic Cooperation and Development [OECD] 2016). Scientific literacy can be defined as the capacity to use scientific knowledge to identify questions, explain scientific phenomena and draw evidence-based conclusions to understand the natural world and the changes made to it through humans' activity (OECD 2016). This means that students need to understand scientific concepts to account for everyday natural phenomena as well as to understand the nature of science by experiencing how knowledge can be built, enhanced and validated through scientific investigation (Chin and Osborne 2008). Thus, and as highlighted by previous studies on science teaching and learning during the last decade, there has been a change in the science teaching paradigm in primary education towards an inquiry-based model (Harlen and Qualter 2009; Rönnebeck, Bernholt, and Ropohl 2016). Thus, in Europe, several projects, e.g. Fibonacci (www.fibonacciproject.eu), Pollen (www.pollen-europa.net) or Sinus-Transfer (www.sinus-transfer.eu), have been designed to spread inquiry learning in schools. Moreover, The European Commission Rocard Report underlines the importance of including new forms of learning, particularly of introducing inquiry-based activities in educational curricula throughout European countries (European Commission 2007). Learning science by inquiry in primary classrooms encourages students to, not only learn concepts, but also develop scientific skills by performing authentic scientific tasks (Harlen and Qualter 2009; Harlen 2013; Kirschner, Sweller, and Clark 2006). This entails that, in inquiry-based activities, children actively participate in developing their understanding by addressing questions, designing, performing and interpreting results of scientific investigations (Bell, Smetana, and Binns 2005; Harlen 2013; National Research Council [NRC] 2012).

Science skills play a key role in performing scientific inquiries and, consequently, developing these skills is often considered as a learning objective in primary science education (Durmaz and Mutlu 2016; Kruit, Oostdam, Van den Berg, and Schuitema 2018a). Many studies emphasize the importance of learning science skills at an early stage in order to enhance the student's understanding of science contents and general science literacy (Coil, Wenderoth, Cunninham, and Dirks 2010; Durmaz and Mutlu 2016). In the present study, the concept "science skills" (or "science process skills") is based on activities that reflect scientists' behaviour. Therefore, these skills address the

implementation of rules and principles needed to design and perform scientific research and interpret results (Harlen and Qualter 2009, Lederman and Lederman 2014; NRC 2012). A recent literature review shows that there is some diversity when defining and classifying the different specific scientific skills carried out during an inquiry process (Rönnebeck et al. 2016). However, despite the differences in the generic title of the different skills, there is considerable agreement about their objective (Harlen 1999). All of these definitions include, one way or another, skills related to *identifying research questions, formulating predictions and hypotheses, designing investigations, obtaining and interpreting evidence and drawing appropriate conclusions* in relation to the posed questions (Coil et al. 2010; Durmaz and Mutlu 2016; Harlen 1999; Rönnebeck et al. 2016).

Support for introducing inquiry-based activities in science primary classrooms. The case of video-worked examples

Introducing inquiry-based activities in primary classrooms is a challenging issue. Although some studies indicate that science skills can only be acquired through learning by doing (Dean and Kuhn 2007), recent research highlights the importance of providing students with instruction-assisted support and skills during inquiry for more effective learning (Durmaz and Mutlu 2016; Kruit et al. 2018a; Lazonder and Harmsen 2016). Primary education students usually lack experience, strategies and knowledge of the different science skills for performing effective scientific investigations. Moreover, children also present limited cognitive information-processing capacity that hinders the performance of a complex task such as an inquiry process (D’Costa and Schlueter 2013; Flavell 1992; Solé-Llussà et al. 2018). Thus, some authors emphasize that science process skills should be taught to students in an explicit and scaffolded way in that it provides them with assistance as well as further opportunities for mastering these abilities with the goal of improving student success in science classes (Klahr and Nigam 2004). In particular, much of the research that studies the use of supports and instructions when learning how to apply a control of variables strategy. For instance, Lazonder and Egberink (2014) and Chen and Klahr (2013) show how students improved on the implementation of this skill when providing them with guides and supports.

Among the different supports that can be offered to guide an investigation process, some studies give prominence to those that structure the investigation task and separate

it into several more manageable subtasks for students (Lazonder and Kamp 2012; Lazonder and Egberink 2014). Mulder, Lazonder, and de Jong (2014) also argue that it is not only important to facilitate order and structure for the inquiry task, but it is also essential to offer a very explicit vision of the skills included in that process. Understanding the aim of the different scientific skills and how they should be performed can lead to an improvement in the learning outcomes. Such support can come from the use of *worked examples* (Atkinson, Derry, Renkl, and Wortham 2000; Sweller and Cooper 1985).

Worked examples show a step-by-step expert solution to a problem. They are usually introduced in video format (hence and hereafter, video worked examples, video examples or videos), taking advantage of multiple visual resources that improve the presentation and clarification of the included content. When applied in an inquiry environment, video examples explain the structure of an investigation, or part of it, and demonstrate how to apply and perform the different abilities or skills usually involved in the corresponding process. Furthermore, since these examples intend to highlight the complex nature of scientific inquiry, they make special emphasis on the open and iterative structure of an investigation which does not exactly follow an algorithmic development. Worked examples not only exemplify an action sequence such as the generation of a hypothesis, experimental design or data collection, but also illustrate the reasoning underlying the choice and application of these abilities. This support helps to clarify processes related to a scientific inquiry in a way that textbooks and oral explanations cannot achieve (Rowley-Jolivet 2004). When learners are introduced to an inquiry, the introduction is designed to provide them with specific instructions at each stage, leading to a predetermined discovery (e.g. providing a problem to investigate, the procedure to follow, the materials needed, etc.) (Kruit et al. 2018a). From this point, as the students become more proficient with the approach, they learn to be more active and autonomous as the investigation process proceeds and can tackle increasingly complex inquiry activities. Thus, worked examples provide visual instructions, descriptions and embedded expert guidance which can be particularly helpful for novice learners who may need this kind of support to better structure and attune their inquiry activities according to their level of expertise and domain knowledge. In class, students can use these examples for support before or during the development of a training inquiry task on their own. The purpose is that students can transfer the inquiry outcomes provided by these worked

examples to the solution of other scientific investigations (Kant, Sheiter, and Oschatz 2017; Mulder et al. 2014).

The present study and objectives

To date, the use of video examples as support for inquiry learning activities has only been studied on secondary school students and has mainly focused on specific science skills such as control of variables and interpretation of results. In these studies, video examples have contributed to improving their inquiry skills. Kant et al. (2017) indicated that this support reduced the learners' mental effort and helped them concentrate on the necessary steps to solve the inquiry task. Results by Mulder et al. (2014) suggested that video worked examples had a positive influence on the students' systematic experimentation and enhanced the quality of their scientific explanations and models. In both cases, the support of video examples led students to create more advanced scientific investigations (Kant et al. 2017; Mulder et al. 2014).

However, the effectiveness of such video examples has not yet been explored on elementary education students, an educational level where supports for performing inquiry processes are greatly needed. Thus, in the present study, the focus of the research is on acquiring science skills through support and instructions provided by video worked examples in a primary science classroom. The present work builds on previous research on using video worked examples and analyses how this support contributes to understanding and applying each scientific skill involved in a whole inquiry task, from formulation of a researchable question to interpretation of the collected evidence. This information contributes to the current discussion on the importance of providing support to conduct effective scientific inquiries in primary education. On this line, the present paper addresses the following two main objectives:

- (1) To design and implement a learning strategy based on the use of video worked examples to support a scientific inquiry task.
- (2) To analyse the development of the participants' science process skills before and after the intervention supported by video worked examples through pre- and post- questionnaires.

Methodology

Research design

The present work is a case study based on a quantitative research approach. To analyse whether the didactic strategy implemented made a difference to the students' science process skills, we collected quantitative data from open-ended pre- and post-questionnaires (see details in section "Competence evaluation"). The research embeds qualitative data obtained from these questionnaires and also from audio and video recordings to better understand the impact of the classroom intervention and to support the quantitative results. This method design is helpful in that the researcher gains a broader perspective, rather than relying on the predominant method alone (Creswell 2014).

The present case study was conducted on 30 elementary school students in their fifth and sixth grade (16 female, age $M = 11.32$ years, $SD = 0.71$) from one rural school in Catalonia (eastern Spain). Participation in this study was voluntary and written informed parental and children's consent was obtained.

Students were encouraged to perform an inquiry on electrical circuits. The proposed training inquiry task dealt with phenomena observed in single-loop direct current circuits (hereafter, DC circuits). In particular, participants were asked to investigate the relationship between battery voltage and electric current in a DC circuit. Students therefore had to check how these parameters influence and interact with the components that can be found in a DC circuit (i.e. cable, light bulb and battery). The reason for choosing the topic of DC circuits for the training inquiry task was based on its inclusion in the elementary education curricula (Catalan Decree 119/2015) for fifth and sixth grade students. Prior to this study, the participants had not studied this topic yet, nor had students been introduced before to science and engineering practices.

In this paper, we introduce a didactic strategy based on the use of video worked examples to support the aforementioned training inquiry task. The goal of this strategy was to develop the scientific process skills of the participants. The process diagram in Figure 1 shows the sequence followed to complete this research: design of video worked examples, classroom implementation and quantitative analysis to check on the evolution of the students' scientific abilities.

Figure 1. Performed process to introduce worked example videos to support a training inquiry task.

Design of the didactic strategy based on the use of video worked examples

The design of the didactic strategy for this study was carried out by a group of seven experts including elementary school teachers and University lecturers involved in research projects on science didactics with over 10 years of teaching experience.

First, the experts designed and produced a set of video worked examples aimed at students with no experience of scientific inquiry. These videos structured, explained and exemplified, step by step, how to carry out an inquiry process about the same scientific topic as the one the students had to investigate (electrical circuits). As students would be involved in a complex scientific inquiry task, the experts decided to segment the task into more manageable smaller parts for helping students to better understand how an investigation may be organized. This segmentation of the inquiry process could help elementary pupils clarify the structure and performance of the scientific process skills involved and, in turn, lead to better performance for learners (Lazonder and Kamp 2012). Thus, three different worked example videos were produced. Each video focused on key challenging stages of the inquiry methodology: (1) context engagement and research question; (2) planning of the investigation following a control-of-variables strategy; and (3) interpretation of results and building of scientific explanations (Rönnebeck et al. 2016).

Table 1 shows the specific content for each of the three video worked examples, as well as their corresponding Internet address (with subtitles in English).

233

234 Table 1. Content description for video worked examples.

WEB ADDRESS	CONTENT
<p>CONTEXT</p> <p>http://hdl.handle.net/10459.1/66476</p>	<ul style="list-style-type: none">• Focuses students on the topic they will investigate and relates it with a real-life context• Introduction of concepts: electrical energy, natural electric properties of materials (conductors and insulators), components of electrical circuits (cable, light bulb and battery) and the conversion of batteries' electric energy into light in a DC circuit• The virtual <i>Physics Education Technology</i> simulator for electrical circuits (University of Colorado-Boulder) is presented (https://phet.colorado.edu/es/simulation/legacy/circuit-construction-kit-dc)• The following researchable question is proposed: <i>What is the relationship between battery voltage and circuit current?</i>
<p>PLANNING</p> <p>http://hdl.handle.net/10459.1/66497</p>	<ul style="list-style-type: none">• Presentation on how to plan an experimental inquiry attending to the research question and the corresponding initial ideas• Formulation of a hypothesis and predictions of possible relationship between battery voltage and circuit current is exemplified• Description of different types of experimental variables: current (dependent), voltage (independent) and how to control variables to improve the feasibility of results (battery internal resistance, light bulb resistance and circuit configuration).• Introduction to measuring tools for DC circuits: voltmeters and ammeters• Illustration of how to collect data: data range definition and organization of the current and voltage measurements
<p>INTERPRETATION</p> <p>http://hdl.handle.net/10459.1/66501</p>	<ul style="list-style-type: none">• Demonstration of how to construct graphs (by hand or using spread sheets) from the collected data• Tips and hints for interpreting the collected data: finding relationships and patterns among data (proportional increase of circuit current versus battery voltage, deduction of Ohm's law)• Support provided for building key ideas about DC circuits from measured data• Comparison with initial ideas and evolution of the corresponding scientific model based on collected evidence• Summary of the inquiry process and encouragement to address new DC circuit challenges

235

236 The video worked examples were produced taking into account additional
237 pedagogical and technical characteristics that could facilitate their introduction in an
238 elementary education classroom: for example, vocabulary was accurately adapted to the
239 students' appropriate academic level; everyday images familiar to the students were used;

and graphical elements such as icons, schemes and diagrams were introduced to clarify the presentation and organization of the information given.

Classroom intervention

The guided inquiry about DC circuits using video worked examples was carried out in three 75-minute sessions. Each session was focused on a different stage of the inquiry process: context, planning and interpretation. The video examples listed in Table 1 were introduced in consecutive sessions.

Each session was structured similarly. An introductory part was devoted to the collective visualization of the video-example, followed by a brief dialogue between teacher and students about its content. The teacher concluded the section with a few open questions and then launched the autonomous working part of the session. The autonomous part corresponded to the most extended activity period of the session and was conducted in collaborative groups of two or three students. At that point, students went on performing their training inquiry task about electrical circuits while having continuous access to the video worked examples (Figure 1 and Table 1). Learners followed the explanations and examples shown in the videos in order to apply the different science process skills needed to perform the proposed inquiry about electrical circuits. More specifically, each group of students managed the following material:

- (1) A PC-tablet where the group of students could autonomously visualize the videos. This device was available throughout the session. Participants could use it as many times as they considered necessary to guide their actions throughout the training inquiry task (Kant et al. 2017; Mulder et al. 2014). The use of this kind of mobile technology allows direct access to the videos and easy adaptation to different learning rhythms (e.g. some students only need to watch the video once while others prefer to stop the video at certain times and visualize the same segment several times).
- (2) A laptop on which students had access to a virtual laboratory where they could carry out the inquiry task related to DC circuits. This lab was available at the *Physics Education Technology* project from the University of Colorado-Boulder (<https://phet.colorado.edu/es/simulation/legacy/circuit-construction-kit-dc>).
- (3) A laboratory notebook where participants recorded their investigative actions as they progressed with their task: they wrote down the research question, proposed the corresponding predictions and hypotheses, described the planning of their

research, wrote down and organized the data derived from their experimentation, performed the corresponding graphic treatment and pointed out the conclusions derived from the interpretation of the collected evidence. It is important to highlight that students were encouraged not only to strictly reproduce all the skills exemplified in the videos. For instance, these videos motivated the students to formulate new hypotheses or collect more data on their own considering the examples shown. Participants did not receive a mark on the information reported in their laboratory notebook.

It is also important to highlight the role of the teacher during these sessions. During the autonomous working part, the teacher provided complementary support derived from the use of video worked examples: e.g. additional nuances to the concepts and skills presented in the videos, redundant aids on the procedures exemplified, encouragement of collaboration and group work and solutions to technical problems. This kind of complementary aid could be addressed to a specific group of students or openly to all participants in the classroom. At the end of each session, the teacher offered a short report summarizing difficulties and achievements. Although the role of the teacher lies beyond the scope of this paper and will be developed further in a future study, some of the teacher's contributions have been briefly discussed in the analysis of the results section.

The structure and organization of the strategy for this experiment (e.g. length of the sessions, number of students in each group, administration of the video examples, etc.) were adjusted during a pilot intervention conducted in a previous academic year on a group of 14 fifth and sixth grade students which were not part of the main study.

Scientific process skill assessment

A test inquiry task was designed to assess the students' ability to apply scientific process skills. Students performed this task before and fifteen days after the classroom intervention. The task consisted of a test whereby students answered a set of open-ended questions about how they would conduct a research process focused on the buoyancy of solids in water. In particular, six questions were formulated and each of them focused on the performance of a specific scientific skill. The use of a topic other than DC circuits was proposed in the test as a way to analyse the students' proficiency in scientific skills

when transferred and applied to other scientific contexts. This change in scientific contexts is a way to demonstrate a more robust learning of science process skills (Chen and Klahr 1999).

Here, we present an extract of the test inquiry task. The questionnaire begins by presenting a set of images with a brief description to contextualize students to the buoyancy topic; then, the following six questions are proposed: (1) based on the observation of the initial images, identify possible questions that could be investigated; (2) formulate predictions and hypotheses related to the proposed questions; (3) identify those variables that should be analysed to check the following hypothesis: “if an object is small, then it will float better” (the question is illustrated with a picture that shows wood cubes of different sizes; students can propose to investigate e.g. the influence of mass, volume, etc.); (4) describe an experimental design to obtain useful evidence for testing the aforementioned hypothesis; (5) following the previous hypothesis and using a virtual simulator, measure the volume under water of a set of wood cubes when they are immersed into a recipient of 100 litres. Collect the data, organize and represent them (students are provided with a picture of five different wood cubes with their corresponding mass and volume; they have access to the buoyancy virtual lab of *Physics Education Technology* from the University of Colorado-Boulder (<https://phet.colorado.edu/en/simulation/legacy/buoyancy>) for collecting the asked data; students are also provided with a graph paper); (6) from the collected results, propose possible scientific explanations linked to the formulated hypothesis. The design of this test inquiry task is based on similar evaluation instruments published in the literature (Kant et al. 2017; Kruit, Oostdam, Van den Berg, and Schuitema 2018b).

This instrument was validated by following two steps. Firstly, the validation was performed by the aforementioned group of experts who assessed the test items by applying the procedure described in Carrera, Vaquero, and Balsells (2011). This validation process responds to the following criteria: (1) the unicity, linguistic precision of each question for its understanding; and (2) the relevance, adequacy and relationship of each question with the object of evaluation. Definitions of “unicity” and “relevance” were provided to the group of experts before performing the validation task. After a few iterations of the test, the corresponding items were validated by the experts with an agreement rate of 80%. Secondly, the instrument was pilot tested with the aforementioned group of 14 students to adjust the conditions for its application, the time length for test

administration (75 minutes) and to identify words and sentences that students deemed difficult to understand.

Evaluation of the students' answers

The answers to the test were analysed by applying an existing rubric (Ferrés-Gurt and Marbà-Tallada 2018; Tamir, Nussinovitz and Friedler 1982) and available in: <https://indagacioprimariau.wixsite.com/misitio/assessment-instrument>. This rubric allows the assessment of the main scientific skills carried out in an inquiry process. Each scientific skill was evaluated by an ascending numerical grade, according to the level of skill. The skills were rated with a minimum of 0 and a maximum of 2 or 4 points, depending on the level of each skill. The attached rubric defines the requirement needed to reach each level of skill for every science process skill I. In Appendix 1, there are some examples about how this scoring model has been implemented during the assessment of the pre and post-tests (in the attached rubric, each skill level is exemplified with an answer obtained from the students' questionnaires which has been scored following the aforementioned procedure).

Two evaluators, both university lecturers involved in science didactics research, received separate training for the scoring of the test inquiry task. Evaluators were schooled using student answers from the pre- and post-tests. Twenty-five percent of the pre- and post-tests were scored by both evaluators. Interrater reliability was calculated by determining intraclass correlation (e.g. ICC, two-way random, absolute agreement). The ICC ranged from .93 to 1.00 and the tests were randomly distributed to be scored by individual evaluator. Each evaluator scored one question for all students before moving on to the next one in order to achieve more sensitivity to different performance levels for a particular scientific skill.

Statistical analysis

Once the initial and final questionnaire scores were established for each participant, the Wilcoxon test allowed determining whether there was a statistically significant difference between the levels for the initial and final performance for each scientific skill. Data were analysed statistically with the IBM SPSS Statistics 24.0 software (IBM SPSS Inc. 2016). The results were evaluated at a significance level of $p < 0.05$.

Finally, it is interesting to note that audio and video of the classroom sessions were recorded from a non-participant perspective. Although a systematic and comprehensive

analysis of these recordings was not performed, some of this evidence has been used to support and enhance the discussion derived from the quantitative data.

Results

This study analyses to what extent the introduction of a didactic strategy based on the use of video worked examples makes a difference to the science process skills of fifth and sixth grade students.

Concerning the first objective of this paper, Figure 2 shows the results obtained from the tests performed before and after the classroom intervention. This figure represents the number of students distributed according to the score obtained for each science process skill analysed. In addition, Table 2 summarizes the results derived from the Wilcoxon test, and these results indicate for which science process skills there was a statistically significant difference between the pre- and post-tests.

386

387 Figure 2. Quantitative evaluation of student science process skills based on pre- and post-
388 test.

389

390 We used the Wilcoxon test to determine whether the intervention guided by video
391 worked examples made a difference on the post-test results. Results obtained from the
392 first phase of intervention are shown in Table 2 and reveal that there is a statistically

significant difference in favor of the post-test inquiry in identifying study variables, collecting, organizing, representing and analyzing data to draw conclusions.

Table 2. Wilcoxon test from pre- and post-test results.

SCIENCE PROCESS SKILLS	<i>p</i>	
1. Identify research questions	.022*	400
2. Formulate previous ideas: hypothesis and predictions	.377	401
3. Identify variables	.059	402
4. Plan an investigation	.678	403
5. Collect, organize and represent data	<.001**	404
6. Analyse data and draw conclusions	.001**	405

The following discussion considers this set of data, and contains an exposition of the evolution, improvements and difficulties observed on the six science process skills.

Discussion

From a general perspective, the results of this study (Figure 2) suggest that the performed intervention with video examples facilitated a general acquisition of the scientific process skills involved in an inquiry. These data confirm that offering a structured setting and explicit instruction in the primary science class provides an opportunity to practise skills and improve their application, in line with previous studies (Dean and Kuhn 2007; Kruit et al. 2018a). Results also show that the didactic strategy introduced facilitated the transfer of skills between the different scientific domains proposed in both the inquiry task and the assessment questionnaire. This implies that the intervention helped learners to not only use the scientific skills but also understand how they can be applied, a difficult aspect to be achieved in a classroom setting according to previous studies (Klahr and Li 2005).

Next, there will be a discussion on the development of each science process skill before and after the intervention supported by video examples, highlighting the aspects

where the didactic strategy has contributed the most and where participants showed more difficulties.

The results of the pre-test show that, on one hand, 15 out of 30 learners were not able to properly address the identification of research questions (scoring 0 points) (Figure 2). These students either left the first question blank or made general descriptions of the concept to be investigated without formulating any specific question. On the other hand, 13 of the participants proposed some kind of question in the pre-test, but this was supported only by simple observations that did not lead to any actual inquiry planning. After the classroom intervention, a statistically significant change was observed in this scientific ability (Table 2). Specifically, post-test results showed an increase from 2 to 10 students who could formulate proper research questions. In these cases, we observed how students posed questions that were appropriately contextualized in the corresponding inquiry topic and even included suitable study variables. These improvements seem to be directly related to the work that participants conducted in the first classroom session (Figure 1). In this session, students worked with the *Context* video example that introduces the research topic and proposes a specific question to be investigated in the following sessions: “*What is the relationship between battery voltage and circuit current?*” (Table 1). It is important to emphasize that this first video only exemplifies the formulation of a research question based on previous contextualization and does not explain the specific features that a good researchable question could present. At this point, the teacher played a crucial role by relying on the video content to offer students supplementary assistance. The teacher highlighted those characteristics that contribute to make investigable the question presented in the video. This combination of supports – from both the video worked example and the reflection promoted by the teacher – might have positively contributed to the better results observed in the post-test. Participants who improved in this scientific ability were able to successfully transfer the ideas and assistance provided by the video and the teacher during the training inquiry task (about electrical circuits) to other scientific contexts like the one proposed in the test (buoyancy). In the pre-test, for example, non-researchable questions were given as answers, such as “*Why do the stones remain in the middle of a glass full of water?*” (scoring 1 point) and these evolved into researchable ones in the post-test, such as “*Will an object float the same in hot water as in cold water?*” (scoring 2 points). Despite an improvement obtained from this skill, results indicate that asking good researchable questions was still challenging for learners (18 students failed to formulate proper researchable questions,

Figure 2). This result confirms previous studies which emphasize that this science process ability requires higher cognitive skills for integrating complex and differing information from various sources as well as a better knowledge of the inquiry topic. Thus, a greater amount of classroom support is needed at this stage for enhancing their capacity to explore ideas from their daily experiences and formulate proper investigable questions (D'Costa and Schlueter 2013; Rönnebeck et al. 2016; So 2003).

With regard to formulation of previous ideas (hypothesis and predictions), 23 participants scored 2 or less points in their pre-test (Figure 2). This group of students either proposed hypotheses or predictions without any connection to the research problem or they confused this science process skill with the formulation of an investigable question. The rest of the participants (7 out of 30) were able to suggest suitable predictions or hypotheses for the proposed problem scenario, while including some study variables that could be tackled a subsequent research (scoring 3 points). After the classroom intervention, this kind of answer value increased to 12 students (Figure 2). Students worked on hypothesis formulation during the second classroom intervention while using the second video worked example for support. This video stresses the importance of proposing previous ideas in an inquiry process to test them later on and exemplifies it by formulating cause-effect structures directly related to the introduced research question (e.g. *"If voltage increases, the current will become higher"*, as seen in Table 1). Once again, the role of the teacher was relevant during classroom work because the teacher relied on the examples shown on video to emphasize the objective and structure of hypotheses and predictions. This type of classroom intervention seemed to lead to a slight improvement in the post-test results. Although some students raised meaningless hypotheses or predictions in the pre-test (e.g. *"Fruit floats because it is an element of nature"*, scoring 0 points), after the intervention, they provided answers that were better focused on the problem scenario, even including possible study variables (e.g. *"Fresh water will hold light objects, while saltwater will hold heavier objects"*, scoring 3 points). It appears that students moved the structure of hypothesis and prediction visualized on video to their post-test answers. However, data indicate that there is still room for improvement regarding this scientific ability. The difficulties to propose hypotheses in primary science classrooms has been previously studied in the literature (Solé-Llussà et al. 2018). Similar to the formulation of investigable questions, the lack of knowledge about the topic at hand usually hindered the proposal of testable hypotheses and predictions (Harlen 2013; Kruit et al. 2018a). In this work, the topic of the test inquiry

task, buoyancy, was not well known to all of the participants. The lack of knowledge about possible factors that could influence on the buoyancy phenomenon may have prevented better results in the formulation of hypothesis and predictions (Harlen 2013; Harlen and Qualter 1999). A better outcome could probably be obtained by providing a greater diversity of examples, as well as more details about the nature of hypothesis and prediction in the video example (Rowley-Jolivet 2004).

Next, the experimental design was analysed. In particular, the study focused on two key elements: first, the identification of study variables; second, the elaboration of a reliable experimental plan or procedure, including suitable material and measuring instruments for tackling the research problem. The *Planning* video example shows how to perform, step by step, these science processes to solve the suggested inquiry about electrical circuits (Table 1). Compared to the other discussed science skills, these processes are explained and demonstrated with higher precision in the corresponding video example, which means that students could work more autonomously in the classroom. The role of the teacher was, therefore, limited to answering specific questions raised by students during the training inquiry task.

First, many of published studies in elementary education about the benefits of supports and instructions on inquiry focus on the control of variables (Chen and Klahr 1999; Dean and Kuhn 2007; Klahr and Li 2005). In particular, and despite having been applied at higher educational levels, the use of video examples has demonstrated their effectiveness with this science skill in previous works (Kant et al. 2017). In the pre-test, 19 participants obtained a score of 2 or less (Figure 2); they were not able to identify study variables or if they proposed any, it was not related to the research question and the considered hypothesis (e.g. for the hypothesis – small objects will float more: “*I will fill the glass with water and I will put in two different cubes to see if they float.*”, scored 2 points). In the post-test, students improved on this skill and could identify more accurately independent and/or dependent variables relevant for the research problem. It is especially important to highlight an increase of up to 9 students who reached a maximum score of 4. This group of learners not only identified relevant variables correctly, but they also incorporated in their answers systematic and detailed descriptions as presented in the video example. These students specified that, in order to test the corresponding hypothesis, they had to choose one appropriate variable that had to change along the investigation and another one that they measured to check the effect of that change. For

example, *“To check if small objects float, the variable I change is how big or small the object is. Then, I will measure how much it has sunk”*. The obtained results are in agreement with previous research that highlights how instructions can help pupils to learn and transfer the control of variables skill (Chen and Klahr 1999). These are encouraging results for a scientific skill with which students tend to show frustration and/or reluctance. Although students perform better the control variables strategy immediately after the provided support, it might be interesting to evaluate the retention or transfer of this skill over a longer time in primary education (Dean and Kuhn 2007).

Second, focusing on experimental planning, 21 students were able to describe their pre-test procedures related to the research topic, highlighting the steps to follow, the material and the instruments to use (12 students scored 2 points and 9 students scored 3 points, Figure 2). Indeed, it appeared that the learners had some familiarity with describing experimental processes, probably due to the traditional way in which practical laboratory activities are implemented (Lazonder and Egberink 2014). These experimental procedures could not be evaluated with the maximum score, however, because they were incomplete: i.e. they did not integrate study variables, and they did not consider control variables that must be kept constant throughout the investigation to obtain reliable results (e.g. *“We add water in a vessel. Then we put in a big wood cube and a small wood cube and see if they float or not”*, scored 2 points). In the post-test, slight improvements in this scientific ability appeared, as a small number of participants enhanced in their descriptions of experimental procedures by starting to include control variables: 11 participants scored 3 points and 1 participant scored 4 points, Figure 2 (e.g. *“We add two litres of water in a vessel and we put in the large object. Carefully, we measure with a ruler the portion that has sunk and the portion that floats. Then, with the same amount of water, we put in the small object and compare the results”*, scored 4 points). As results suggest, most students did not yet consider the factors that needed to be controlled during the experimental phase to achieve reliability. This may be due to the fact that the corresponding video example does not specify control variables as precisely as independent and dependent variables. Chen and Klahr (1999) emphasize the need to provide appropriate instructions to students and remind them of the importance of performing unconfounded experiments. It is also interesting to note that 5 students’ post-test answers contained simple theoretical descriptions about how to perform experimental planning by paraphrasing some of the explanations presented in the video (e.g. *“First we*

559 *take into account the variables, then we select the material and measuring instruments.*
560 *After that, we organize the data and we will try to make a graph”).* Although the student’s
561 acquisition of this scheme is valued, these answers received a minimum score, which has
562 contributed to the relatively poor quantitative results in the post-test. In short, it seems
563 necessary to stress elaboration on experimental design strategies, an ability whose
564 development seems to improve with age (Chen and Klahr 1999).

565 Finally, skills related to data processing and construction of the corresponding
566 scientific conclusions will be considered. The *Interpretation* video focuses on these
567 processes, providing recommendations and demonstrating how to build a scientific model
568 based on evidence collected during the performed inquiry about electrical circuits (further
569 details in Table 1). The illustrative and sequential nature of this third video means that,
570 in general, students gain autonomy when using it as a support during the performance of
571 this inquiry stage in the classroom.

572 Regarding the collection and processing of data, it should be noted that this is not
573 a common skill in literature and, therefore, has become a challenging issue for elementary
574 students (Garcia-Mila, Marti, Gilabert, and Castells 2014). In the present work, this
575 scientific skill was a statistically significant difference between the pre- and the post-test
576 results (Table 2). Initially, 23 participants scored 1 or less (Figure 1) because they did not
577 organize the collected data (e.g. using data tables) or did not represent them graphically,
578 perhaps due to the novel nature of this task for the students. Only 5 learners were
579 successful in drawing a graph, but nobody added a title or measurement units to the data
580 represented in each axis or numbers were not evenly spread on axes (scored 3 points,
581 Figure 1). This evidence suggests that, although participants were familiar with the use
582 of tables and graphs through their textbooks, they lacked practical experience in the use
583 of these tools (Durmaz and Mutlu 2016). After the classroom intervention, an important
584 advance was observed: 28 students were familiar with the use of tables for organizing
585 data, and 19 students could draw a graphic representation of that data. In this last group,
586 5 participants obtained the maximum score because they successfully presented the graph
587 correctly labelled as they identify the data represented in each axis. This seems to indicate
588 that learners adequately integrated the instructions and examples presented in the video.
589 In fact, they were able to transfer the same types of tables and graphs shown on the video
590 about electrical circuits to other scientific contexts, such as buoyancy to the test inquiry
591 task. As observed in previous studies, organizing data (for instance, using tables) can be

an essential bridging tool for understanding the essence of the data and its graphical representation (Garcia-Mila et al. 2014). The creation of a graph involves following a particular sequence of steps and, in this respect, the video examples seem to have greatly contributed to understanding and implementing this skill, as the successful results indicate.

Concerning the construction of scientific models and drawing conclusions, a statistically significant difference was also found after classroom intervention. The corresponding video example stresses this skill by explaining and exemplifying how to identify patterns from the collected data, taking into account the modelled graphs, to build a scientific model about electrical circuits (Table 1). According to previous research, elementary students often fail to provide data for their own claims and fail to rebut or counterclaim when they should (Ryu and Sandoval 2012). Justifying the relationship between claims and data is particularly difficult for pupils as evidenced in the present study. When interpreting their results and building arguments, students needed more assistance from the teacher to clarify some of the processes shown on video (mainly related to understanding graphs, which leads to analysing the relationship between voltage and current and ultimately obtaining Ohm's Law, Table 1). However, teacher intervention appeared to involve better coordination between the experimental data and the explanations at the end of the inquiry process. Some students started to include rebuttals to some of their initial ideas based on gathered data. Thus, in the pre-test, 21 participants drew conclusions without paying attention to any collected evidence (e.g. *"The wooden objects float better"*, scored 1 point). Subsequently, in the post-test, 18 students started to include systematic and causal patterns in their scientific reasoning: e.g. *"I searched for patterns among the results and I observed that buoyancy does not just depend on weight (...). If the volume increases, the object floats too. Then, I have to check the hypothesis and I see it is not true that small objects float better"* (scored 3 points). As can be seen, some of the participants' answers included instructions and hints provided by the video to develop this scientific ability. It seems that the video example helped learners to build a problem-solving schema that could reduce mental effort and benefit the performance of this scientific practice (Kant et al. 2017). However, only 3 students, in the post-test answers, used more advanced scientific models by combining empirical evidence with theoretical justifications. Although the video example demonstrates the construction of an advanced model for electrical circuits, it was difficult for students to

transfer this reasoning level to other scientific contexts such as the one proposed in the test inquiry task. The video example appeared to help students integrate a set of good practices that could be useful for drawing conclusions derived from their investigation process. However, to achieve more advanced reasoning, prior knowledge about the inquiry topic was deemed necessary, as well as an important metacognitive load (Piekny and Maehler, 2013; Valanides et al. 2014). In any case, and despite the positive results obtained with this particular skill, the practice of interpretation and argumentation requires interventions performed over longer periods of time for changing the classroom discourse. Some authors highlight the need of scaffolds embedded within ongoing activity in order to better understand the underlying rationale of the scientific arguments and explanations (Ryu and Sandoval 2012).

Conclusions and final considerations

The use of support to develop school inquiry is frequently required, given the difficulties that this methodology usually presents, especially for novice learners. Although several technological tools have been explored as support for developing investigation tasks, the use of video to promote the inquiry skills in elementary education has not been studied as yet in depth. Therefore, the present study lays out a new didactic strategy based on the use of video worked examples for supporting an inquiry about electrical circuits in a primary school classroom. These videos exemplify, step-by-step, how to solve this inquiry by demonstrating how to perform several science process skills. The findings show that they structure the investigation task and separate it into more manageable tasks for students. During the class, students were provided with a PC-tablet to watch, autonomously or in groups, these videos to obtain assistance that could be implemented during the execution of their inquiry activity. The present work, on the one hand, depicts the first research focused on analysing the effectiveness of this didactic strategy at an early educational level. On the other hand, it provides evidence about how this intervention, supported by video worked examples, successfully contributed to developing the students' inquiry skills. The results provide new insights into how primary students understand and implement the different science skills and highlight those skills that could be specifically benefited by introducing such digital support.

In this way, the didactic strategy introduced in this work based on the use of video examples has proved to be useful in improving the inquiry behaviour in a primary

science classroom. This approach rendered new possibilities for understanding and practising science skills for students who had little experience and/or were unfamiliar with inquiry processes. Once the intervention finished, it became clear that a significant difference was observed in the following abilities: identifying research questions; collecting, organizing and representing data; analysing data and drawing conclusions. For instance, some students posed investigable questions that were more contextualized with the subject under research; they started using tables and graphs to organize and represent the data collected; they also began to incorporate empirical evidence into their scientific explanations and conclusions at the end of the inquiry process. Learners seemed to integrate several of the instructions and tips demonstrated in the video examples, which had a positive effect on the aforementioned students' science process skills performance. However, this study also reveals that certain problems remain, even after applying science process skills. In particular, problems derived from formulating hypotheses and designing experimental skills were lower than problems derived from other abilities. Thus, students found difficulties in elaborating hypotheses and predictions related to the research questions proposed; or they did not integrate control variables in their planning to obtain reliable results. Probably these skills are more related to domain knowledge and are less transferable between scientific contexts. It would therefore be necessary to conduct a broader study based on more classroom interventions supported by new video worked examples that stress these abilities.

It is also worth noting that the role of the teacher lies beyond the scope of the present work. Nevertheless, teacher mediation is an important factor also to be considered for further understanding about how the use of video-worked examples have contributed to improving students' inquiry skills. The interaction between the teacher and the digital support has a clear and positive influence on a wide variety of guides, instructions and supports provided to the students. Analysing how teachers interact and adapt to technology should provide useful pedagogical knowledge for promoting inquiry in technologically-rich environments. Therefore, our future studies could fruitfully explore this issue further.

Notwithstanding, the present findings provide useful information on effective ways to support the understanding and application of science process skills for primary students. Despite the limitations of this study – such as small sample size, the lack of analysis of long-term student outcomes, the comparison of the experimental group against

control group or the aforementioned analysis of the impact of video examples in specific guides provided by the teacher (all of which will be considered in future studies) – it should be noted that this study shows the potential for this type of didactic strategy to promote and develop students’ science process skills in primary education.

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References

- Atkinson, R. K., Derry, S. J., Renkl, A., and D. Wortham. 2000. “Learning from examples: Instructional principles from the worked examples research.” *Review of Educational Research*, 70(2), 181–214. <https://doi.org/10.3102/00346543070002181>
- Bell, R., Smetana, L., and I. Binns. 2005. “Simplifying inquiry instruction.” *The Science Teacher* 72 (7): 30–33.
- Carrera, X., Vaquero, E., and M. Balsells. 2011. “Instruments for assessing digital competencies of at-risk adolescents.” [Instrumento de evaluación de competencias digitales para adolescentes en riesgo social]. *Edutec: Revista Electrónica de Tecnología Educativa* 35: 1–25.
- Chen, Z., and D. Klahr. 1999. “All other things being equal: Acquisition and transfer of the control of variables strategy.” *Child development* 70 (5): 1098–1120. <https://doi.org/10.1111/1467-8624.00081>
- Chin, C., and J. Osborne. 2008. “Students' questions: a potential resource for teaching and learning science.” *Studies in science education* 44 (1): 1–39. <https://doi.org/10.1080/03057260701828101>
- Coil, D., Wenderoth, M. P., Cunningham, M., and C. Dirks. 2010. “Teaching the process of science: faculty perceptions and an effective methodology.” *CBE—Life Sciences Education* 9: 524–535. <https://doi.org/10.1187/cbe.10-01-0005>
- Creswell, J. W. 2014. *Research design: Qualitative, quantitative, and mixed methods approaches*. 4th ed. Los Angeles, CA: Sage.

- 723 D'Costa, A. R., and M.A. Schlueter. 2013. "Scaffolded instruction improves student
724 understanding of the scientific method & experimental design." *The American*
725 *Biology Teacher* 75 (1): 18–28. <https://doi.org/10.1525/abt.2013.75.1.6>
- 726 Dean, D. and D. Kuhn. 2007. "Direct instruction vs discovery: The long view." *Science*
727 *Education* 91 (3): 384–397. <https://doi.org/10.1002/sce.20194>
- 728 *Catalan Decree 119/2015, 23rd of June, school teaching ordinance [Decret 119/2015,*
729 *de 23 de juny, d'ordenació dels ensenyaments de l'educació primària]*. Document
730 Oficial de la Generalitat de Catalunya (DOGC), núm. 6900, de 26 de junio de
731 2015, 119–121. Retrieved from
732 [http://ensenyament.gencat.cat/web/.content/home/departament/publicacions/colle](http://ensenyament.gencat.cat/web/.content/home/departament/publicacions/colleccions/curriculum/curriculum-educacio-primaria.pdf)
733 [ccions/curriculum/curriculum-educacio-primaria.pdf](http://ensenyament.gencat.cat/web/.content/home/departament/publicacions/colleccions/curriculum/curriculum-educacio-primaria.pdf)
- 734 Durmaz, H., and S. Mutlu. 2016. "The effect of an instructional intervention on
735 elementary students' science process skills." *The Journal of Educational*
736 *Research* 110 (4): 433–445. <https://doi.org/10.1080/00220671.2015.1118003>
- 737 European Commission. High Level Group on Science Education, European Commission.
738 Science, and Economy. 2007. *Science education now: A renewed pedagogy for*
739 *the future of Europe*. Vol. 22845. Office for Official Publications of the European
740 Communities.
- 741 Ferrés Gurt, C., and A. Marbà Tallada. 2018. "Problems students experience with inquiry
742 processes in the study of enzyme kinetics." *Journal of Biological Education* 52
743 (1): 113–120. <https://doi.org/10.1080/00219266.2017.1285801>
- 744 Flavell, J. H. 1992. "Cognitive development: Past, present and future." *Developmental*
745 *Psychology* 28 (6): 998.
- 746 Garcia-Mila, M., Marti, E., Gilabert, S., and M. Castells. 2014. "Fifth Through Eight
747 Grade Students' Difficulties in Constructing Bar Graphs: Data Organization, Data
748 Aggregation, and Integration of a Second Variable." *Mathematical Thinking and*
749 *Learning* 16: 201–233.
- 750 Harlen, W. 1999. "Purposes and procedures for assessing science process skills."
751 *Assessment in Education: principles, policy & practice* 6 (1): 129–144.
752 <https://doi.org/10.1080/09695949993044>
- 753 Harlen, W., and A. Qualter. 2009. *The Teaching of Science in Primary Schools*. Oxon,
754 OX: Routledge.
- 755 Harlen, W. 2013. "Inquiry-based learning in science and mathematics." *Review of*
756 *science, mathematics and ICT education* 7 (2): 9–33.
757 <https://doi.org/10.26220/rev.2042>
- 758 IBM Corp. 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, New York:
759 IBM Corp.

- 760 Kant, J. M., Scheiter, K., and K. Oschatz. 2017. "How to sequence video modeling
761 examples and inquiry tasks to foster scientific reasoning." *Learning and*
762 *Instruction* 52: 46–58. <https://doi.org/10.1016/j.learninstruc.2017.04.005>
- 763 Kirschner, P. A., Sweller, J., and R. E. Clark. 2006. "Why minimal guidance during
764 instruction does not work: An analysis of the failure of constructivist, discovery,
765 problem-based, experiential, and inquiry-based teaching." *Educational*
766 *psychologist* 41 (2): 75-86. https://doi.org/10.1207/s15326985ep4102_1
- 767 Klahr, D., and J. Li. 2005. "Cognitive research and elementary science instruction: From
768 the laboratory, to the classroom, and back." *Journal of Science Education and*
769 *Technology* 14 (2): 217-238. <https://doi.org/10.1007/s10956-005-4423-5>
- 770 Klahr, D., and M. Nigam. 2004. "The equivalence of learning paths in early science
771 instructions: Effects of direct instruction and discovery learning." *Psychological*
772 *Science* 15 (10): 661-667. <https://doi.org/10.1111/j.0956-7976.2004.00737.x>
- 773 Kruit, P. M., Oostdam, R. J., Van den Berg, E., and J. A. Schuitema. 2018a. "Effects of
774 explicit instruction on the acquisition of students' science inquiry skills in grades
775 5 and 6 of primary education." *International Journal of Science Education* 40 (4):
776 421-441. <https://doi.org/10.1080/09500693.2018.1428777>
- 777 Kruit, P. M., Oostdam, R. J., van den Berg, E., and J. A. Schuitema. 2018b. "Assessing
778 students' ability in performing scientific inquiry: instruments for measuring
779 science skills in primary education." *Research in Science & Technological*
780 *Education* 36 (4): 413-439. <https://doi.org/10.1080/02635143.2017.1421530>
- 781 Lazonder, A. and A. Egberink. 2014. "Children's acquisition and use of the control-of-
782 variables strategy: Effects of explicit and implicit instructional guidance."
783 *Instructional Science* 42: 291–304. <https://doi.org/10.1007/s11251-013-9284-3>
- 784 Lazonder, A. W., and R. Harmsen. 2016. "Meta-analysis of inquiry-based learning:
785 Effects of guidance." *Review of educational research* 86 (3): 681-718.
786 <https://doi.org/10.3102/0034654315627366>
- 787 Lazonder, A. W., and E. Kamp. 2012. "Bit by bit or all at once? Splitting up the inquiry
788 task to promote children's scientific reasoning." *Learning and Instruction* 22 (6):
789 458-464. <https://doi.org/10.1016/j.learninstruc.2012.05.005>
- 790 Lederman, N., and J. Lederman. 2014. "Research on Teaching and Learning of Nature of
791 Science". In *Handbook of Research on Science Education*, 2, edited by S. K. Abell
792 and N. G. Lederman, 600-620. Abingdon: Routledge.
- 793 Mulder, Y. G., Lazonder, A. W., and T. de Jong. 2014. "Using heuristic worked examples
794 to promote inquiry-based learning." *Learning and Instruction* 29: 56–64.
795 <https://doi.org/10.1016/j.learninstruc.2013.08.001>
- 796 National Research Council. 2012. *A framework for K-12 science education: Practices,*
797 *crosscutting concepts, and core ideas*. Washington, DC: The National Academies
798 Press.

- Organization for Economic Cooperation and Development [OECD]. 2016. *PISA 2015. Assessment and analytical framework: Science, Reading, mathematics and financial literacy*. Paris: OECD.
- Piekny, J., and C. Maehler. 2013. "Scientific reasoning in early and middle childhood: The development of domain-general evidence evaluation, experimentation, and hypothesis generation skills." *British Journal of Developmental Psychology* 31 (2): 153–179. <https://doi.org/10.1111/j.2044-835X.2012.02082.x>
- Rönnebeck, S., Bernholt, S., and M. Ropohl. 2016. "Searching for a common ground—A literature review of empirical research on scientific inquiry activities." *Studies in Science Education* 52 (2): 161-197. <https://doi.org/10.1080/03057267.2016.1206351>
- Rowley-Jolivet, E. 2004. "Different visions, different visuals: A social semiotic analysis of field-specific visual composition in scientific conference presentations." *Visual Communication* 3 (2): 145–175.
- Ryu, S., and W. A. Sandoval. 2012. "Improvements to elementary children's epistemic understanding from sustained argumentation." *Science Education* 96 (3): 488-526. <https://doi.org/10.1002/sce.21006>
- So, W. W. M. 2003. "Learning science through investigations: An experience with Hong Kong primary school children." *International Journal of Science and Mathematics Education* 1 (2): 175-200. <https://doi.org/10.1023/B:IJMA.0000016852.19000.af>
- Solé-Llussà, A., Aguilar, D., Ibáñez, M., and J.L. Coiduras. 2018. "Communication analysis of inquiry experiences presented in science conferences aimed to Preschool and Primary Education students." [Análisis de la comunicación de experiencias indagadoras presentadas en congresos de ciencias dirigidos a alumnos de educación infantil y primaria]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias* 15 (1): 1302. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2018.v15.i1.1302
- Sweller, J., and G. A. Cooper. 1985. "The use of worked examples as a substitute for problem solving in learning algebra." *Cognition and instruction* 2 (1): 59–89. https://doi.org/10.1207/s1532690xci0201_3
- Tamir, P., Nussinovitz, R., and Y. Friedler. 1982. "The development and use of a Practical Test Assessment Inventory." *Journal of Biological Education* 16: 42–50.
- Valanides, N., Papageorgiou, M., and C. Angeli. 2014. "Scientific investigations of elementary school children." *Journal of Science Education and Technology* 23 (1): 26–36. <https://doi.org/10.1007/s10956-013-9448-6>

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0. Does not propose or identify predictions or hypothesis, or poses them without meaning.

1. Formulates predictions and hypothesis without relation to the question or objectives.

2. Poses ambiguous hypothesis and predictions, but related to the research topic.

3. Poses at least one hypothesis or prediction that fits the research question and includes possible study variables.

- The hypothesis or prediction fits the research question correctly proposed by the student *“Does the concentration of salt influence the buoyancy of objects?”*
- The hypothesis or prediction includes possible study variables (concentration of salt as an independent variable and buoyancy as a dependent variable).

4. Poses more than one hypothesis or prediction that fit the research problems and include possible study variables.

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853 **Appendix 1.**

854 *Example of scoring in the formulation of hypothesis or predictions*

855 *“Fresh water will not hold light objects; while saltwater will”*

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857 **Goal:**

The students were able to suggest at least one suitable prediction or hypothesis for the proposed research question. Students include some study variables (independent and dependent variables) which could be tackled in subsequent research.

Example of scoring in planning an investigation

'We add two liters of water in a vessel and we put in the large cubic object. Carefully, we measure with a ruler the portion that has sunk and the portion that floats. Then, with the same amount of water, we put in the small cubic object and compare the results'

Goal:

The students were able to plan an investigation to obtain experimental evidence to test their predictions or hypotheses. Students include study variables (control, independent and dependent), materials and instruments needed and the steps to follow.

0. No experimental design is proposed.

1. The experimental design has no relation to the researchable question and does not allow the verification of the hypotheses or predictions.

2. The experimental design is related to the considered hypotheses, but its description (use of materials, instruments, steps to follow) is incomplete and does not state the control variables.

3. The experimental design allows the verification of the hypothesis and predictions, with an adequate description, but with incomplete control variables.

4. The experimental design allows the verification of the hypothesis and predictions in a reliable way, presenting appropriate control variables.

- *The experimental design allows the verification of prediction: 'if an object is small, then it will float better'*
 - *The amount of water in the vessel is presented as a control variable which denotes that it is not evident for kids that this variable could not influence on the object buoyancy.*
 - *The size of the cubes (small and large) is the independent variable while the portion of the cube above water level is the dependent variable (determined by the quotient between height above water and the total height).*
 - *The material and instruments are properly described: the cubic objects, the vessel, the water volume and the ruler to measured heights.*
 - *The steps to follow are detailed*
-