ENHANCING EPISTEMIC LEARNING IN ELEMENTARY SCIENCE THROUGH A BLACK BOX GAME

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Abstract

A key component of scientific literacy, the perennial objective of science education for a sustainable world increasingly permeated by science and technology, is epistemic knowledge, that is, the innovative meta-cognitive knowledge on how science and technology work and how scientists think and act to validate scientific knowledge. Teaching and learning epistemic knowledge is difficult due to its meta-cognitive feature, and especially for primary teachers and students; the cooperative serious games may have a role on overcome the difficulties and thus have been selected as the didactic tool for teaching epistemic knowledge in the elementary school. Games offer an authentic analogy of the scientific practice because they replicate science epistemological tenets and its cooperative and competitive aspects that authentically simulate the cooperation and competition among scientists (as sociology of science has put forward) and are flexible enough to allow evolutionary adaptation to students. This paper aims to innovate the training of science primary teachers through their involvement in developing teaching materials with the format of the black box game project to teach elementary students some epistemic contents. A real experience to teach students science research skills such as evidence-based observing, thinking, arguing and concluding on knowledge validation through a black box game project is presented. The methodological design and some preliminary products of student learning account for the specific experience developed on a school, as the work is still in progress. Finally, some preliminary conclusions for the continuity of the teacher training experience are discussed.

Keywords: epistemic learning, serious educational games, elementary science, black box game, teacher training.

1 INTRODUCTION

Scholars consider that epistemic knowledge (about how science and technology work and how scientists think and act to validate knowledge) is a key component of scientific literacy, which in turn is a renowned aim of science education to adequately prepare citizens for everyday life in a sustainable world increasingly permeated by science and technology [1].

Epistemic knowledge is a set of complex, multifaceted, interdisciplinary, evolving and changing, meta-knowledge about science (and technological) practices (functioning, methods, values, scientific community, science, technology, society relations etc.), which have been emerging from history, philosophy and sociology of science on scientific and technological practices [2].

However, teaching and learning epistemic knowledge is difficult, and especially for primary teachers and students, due to its innovative and meta-cognitive nature. The lack of teacher training and the lack of educational resources for teaching epistemic knowledge contents are the most prominent hindrances [3].

Educational games offer an authentic analogy of scientific practices to overcome those difficulties, as they allow authentically simulating the cooperation and competition among scientists when researching, and replicating some science epistemic tenets. The use of games as teaching material addresses the former difficulties, and especially in primary science education, where students’ motivation and interest are explicitly developed through playing the game for enhancing learning on these hard epistemic topics. Further, game design is flexible enough to allow developmental adaptation to students’ grade. This way games allow actually teaching students complex epistemic aspects about thinking and acting as scientists [4].

This communication aims to innovate the initial training of primary science teachers through their involvement in developing personal teaching materials with the format of cooperative serious games to teach students epistemic contents. Serious games to teach epistemic knowledge are usually sorted in the literature as puzzles, cubes, scenarios, black boxes, cards, etc. [5].
Thus, a real experience to train teachers and teach students epistemic knowledge through a serious game project by means of a black box game is presented. The general research question here is: is a black box serious game an appropriate tool to effectively teach epistemic contents in primary science?

The aim of this experiment is to give the scientist role to the students and to introduce the scientific method as a generic protocol for problem solving which has different components: reflective, interactive and manipulative. So it is not so important to know what happens inside, the objective is to provide opportunities to generate ideas and models, as it is the best way to stimulate students' creative and argumentative thinking to behave like a scientist [6].

2 METHODOLOGY

The methodological description involves the generic traits of a global black box game project and some specific features on a real black box game project for a school that is now starting to develop their project. In fact, the global experience is now in progress.

2.1 Instruments

The criteria for choosing a game were the following: the game should explicitly address a topic on epistemic knowledge and allow cooperative and reflective thinking (as scientists do on research) along the learning activities involved in playing the game. Purposefully, digital games were overlooked as most of them do not fit those conditions [2].

Some authors were tracked for games that fulfill the former inclusion criteria through puzzles, cubes, scenarios, black boxes, cards, etc. A black box serious game project was selected for training teachers to teach students epistemic topics. The aim of black box serious game spins about predicting the content of the black box, using rough observations and applying technologies to intruding the box along some gradual steps. Students work in small groups to respond to: what may contain the box? Along the project steps searching for answers, students are softly introduced to the main aspects of practices carried out by scientists to validate knowledge [5].

2.2 Procedure

The teachers participate in a workshop, where they are introduced to the black box serious game project, the main goals, and the adaptation to their classes on the difficulty of the experiments, the methodology and the evaluation criteria.

The teachers prepare the lesson plan for the black box serious game, adapt its epistemic contents for teaching their students, lead classroom teaching, collect students’ reflections and arguments through paper organizers and help the students drawing conclusions on the epistemic knowledge involved in the black box game project.

Teachers work to design the teaching learning sequence and lesson plan for the black box game and to appropriate the contents and the pedagogy following the didactic model of the 7E’s. A synthesis of the most important aspects of the teaching-learning sequence about the black box includes the general description, the learning standards, the relations of the game with the curriculum contents, the logical connection between evidence, scientific explanation and theoretical models, and the students’ activities (check the optional proposal for the whole project in the Annex at the end of text).

The general educational objectives for teaching the game to students are the following …

- Practice/engage in accountable and constructive discussion between each other
- Share content understanding
- Build on each other’s science content understanding
- Push each other to address science misconceptions
- Encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize scientific practice.

Finally, the teachers will share their experiences on teaching about the black box in a forthcoming joint session of reflection and analysis on the activities carried out and the results achieved by their students to complete their training on epistemic knowledge. Teachers considered the experience with a black box serious game effective to teach epistemic contents and appreciated the merits of the black
box game for their flexibility to satisfy multiple adaptations on epistemic topics and for their ability to foster students’ motivation and interest toward playing.

2.3 Participants

Six Spanish teachers prepared and applied the black box serious game to their grade 6 (12-year-old) students. The rationale of the implementation stems from the development of the content block #1 (the activity of scientists) of the Spanish primary school science curriculum.

The students receive a closed box which contains lots of objects and they have to figure out what is inside. The students observe the box, look for evidences, gather data, reason about the evidences to reach conclusions based on valid thinking about the accepted evidences, etc. The students will be allowed to manipulate the box, to make observations from their senses and to do any experiments they want but without breaking or opening the box (initially).

Students must also handle the data collection (observation, experiments...), use the collected information to create a hypothesis, design and implement a test to explore their hypothesis, collect data and make predictions of their models and conclusions. They must not throw away their previous hypotheses. They will use it to demonstrate their team’s thinking process from the start to the end.

It is expected the students, based on observations and reasoning, construct hypothesis, discuss about hypothesis and predictions, understand scientific methodology, and link the scientific research and the social issues.

The students respond initial questions (How do scientists work? How would you describe a scientific investigation?) and develop some individual, whole-class and small-group activities, such as exploring the black box, writing observed data, proposing hypothesis and explanations, elaborating and discussing explanations and supporting data, and arguing conclusions. A final whole-class activity discusses all the answers to reach the conclusions of the project.

3 RESULTS

As noted above the project is now on process, so the results presented here are some anticipation of the first initiatives to start the development of the black box game project around the participants.

The teacher develops the black box game project getting their students active to elaborate answers to some questions through individual, small group or whole-class tasks. The set of tentative questions to propose to students’ elaboration is the following (check the whole project in the Annex):

- How does the box sound? (stone, metal…)
- Is one of the element heavier/bigger that the rest?
- Do they roll? In all the directions? (Sphere, tube…)
- Move the box and listen the sounds: Can you estimate size, kind of materials?
- May the box have an internal structure? How can you check it?
- Can you write down reasoning about confirm / disconfirming the hypothetical structure of your guess?
- Identify the tools you will need to proceed deeper in the research.
- Think to identify some variables you are considering in determining the unknown elements. Why do you consider each to be important?
- Write your hypothesis about the box and explain how you came up with it.
- What else do you need in order to make workable your hypothesis?
- Push students to re-examine the original test or experiments if they have trouble making their hypothesis.
- Can you write down reasoning about confirm / disconfirming your hypothesis?
Can you reflect on the way you have developed until now? Would you change some of your decisions at any point of the procedure?

How do you think scientists make workable their hypothesis in a real life science problem? Consider using examples and hypothetical situations you may imagine or know to answer this question.

The scientific method is a process. Do you agree or disagree? Explain your answer using examples and diagrams.

A technological teacher provided the following description about his specific preparation of the the black box game project for their students, who were engaged on curriculum development lessons about basic components of computers (table 1).

The mysterious box was more complex as the teacher divided the box into three independent parts. One part contained a computer motherboard, the second one about twenty metallic coins and the third part was filled with several different pieces of the case of an old computer. The box had two holes, kind of small windows that allowed limited watching in the parts that contained the motherboard and the pieces of the case.

<table>
<thead>
<tr>
<th>Stages</th>
<th>The mysterious box</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The first step was the preparation of the box.</td>
</tr>
<tr>
<td>2</td>
<td>Since it was for 6th grade students, we have designed a little bit complex black box with three parts inside.</td>
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<tr>
<td>3</td>
<td>The children were assigned to small working groups, into teams of three students.</td>
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<tr>
<td>4</td>
<td>The students were presented the challenge of discovering the content of the black box.</td>
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<tr>
<td>5</td>
<td>A person from each group is picked up and told to write down about the content of the box, without touching the box.</td>
</tr>
<tr>
<td>6</td>
<td>The second group was offered the opportunity to shake the box and hearing the sounds. They exchanged on what they thought the box may contain.</td>
</tr>
<tr>
<td>7</td>
<td>The third group was allowed to watch and touch through a small hole. They see the black pieces of the casing.</td>
</tr>
<tr>
<td>8</td>
<td>Again a hole is opened for the first group that allows looking at the plate the flashlight and the motherboard.</td>
</tr>
<tr>
<td>9</td>
<td>At the end, they are joined by groups and they are asked to comment on what the black box contains.</td>
</tr>
<tr>
<td>10</td>
<td>The conflict presented is that each person in the group has observed a part of the box. One has heard the coins, others have observed the part of casing and others the motherboard.</td>
</tr>
<tr>
<td>11</td>
<td>Then the box was opened. The students observe the content and contrast their predictions, the missed elements and the unknown elements (shells and motherboards).</td>
</tr>
<tr>
<td>12</td>
<td>As we were in the computer room, the students proceed to observe the environment to compare and discover the elements of the black box in the real computers.</td>
</tr>
<tr>
<td>13</td>
<td>Let's look and check the computer for searching the pieces of the box... the students discover the sides of the casing, the similar pieces, and a partial look at a part of the motherboard that seems similar to that of the box. Lastly, the students find a similar plate and check the strong similarity.</td>
</tr>
</tbody>
</table>

The pictures below show the mysterious box in the hands of the students when developing the activities about hypothesizing and discovering the content of the box. The students in Figure 1 are trying to open the box to check their hypotheses and conclusions about the box contents as obtained through hypotheses and discussions with classmates.
The students in Figure 2 perform observation and comparison activities between two computer motherboards, one of them extracted from the mysterious box and the other one extracted from a real computer in order to make decisions about their similarities and differences and, thus, their identity as they correspond to the same or different objects.

Finally, a sample of the students’ hypotheses about the contents of the mysterious box is presented, as extracted from their notebooks. The Spanish written hypotheses in figure 3 expose the following students’ hypothesis about the box contents:

- …there can be nothing inside
- …there cannot be a dinosaur because it is very big
- …there is air because it is everywhere
– …there can be something dead
– …there can be a paper photocopier because it is written on the box
– …there can be the results of the examination

The hypothesis allows verifying how the students are quite coherent with their observations, as they read the labels of the box that corresponded to a printer. On the other hand, they also propose the elimination of less likely hypotheses, the dinosaur hypothesis, and so on. Students must learn the difficulty of formulating accurate hypotheses to account for observations, and it is expected to learn this scientific skill when they engage in defining more precise and more adjusted ideas about what it is intended to depict observations, explanations or discovering.

![Figure 3. Sample of hypotheses about the content of the mysterious box, as drawn from the notebooks of the students.](image)

The technological teacher draws the following conclusions from the experience of his students with the challenge of the computer-oriented mysterious black box:

- In the process of finding explanations about the objects, the students spontaneously accepted all opinions, in spite of being corrected or discarded later on.
- The most surprising finding is that the students did not fight or quarrel to impose their views; rather they tried to reach consensus in spite of having quite different ideas.
- It is also worth noting the students tried to change and adjust their views to the new facts when new evidence arose along the exchange and arguments.

The data presented here are just preliminary information that has been provided by the teacher who first started the activity on the black box project. The experience is still in progress until the end of school year, according to the agendas and possibilities of the primary teachers involved.

4 CONCLUSIONS

The innovative experience of teacher training and student learning on epistemic knowledge described here must be contextualized bearing in mind that it was the first innovative step of the primary teachers toward including epistemic knowledge in science education. The research question is achieving a positive answer as the aims for teachers’ training and students’ learning are going adequately in progress. Further, teachers are displaying some professional enjoyment when teaching epistemic contents through games [7].

The experience of the black box project is simple to allow the teachers getting a balanced and calm training on these innovative and complex epistemic issues for them. As games contribute to overcome the complexities of epistemic knowledge by means of analogical simplification, games display a limited, yet affordable, image of scientific practices, which is useful and practical for teachers and
students. Then, teachers can sustainably increase the complexity of their professional development on epistemic issues, through experiencing less simple games. In fact, the teacher whose results are displayed decided by their own construct a complex black box with some internal structure teachers and some of them are planning to try working on more complex games for the next training step [5].

Further, playing games manifestly promote scientific and critical thinking skills, namely, asking (and answering) questions, seeking data, observing, comparing and classifying, making decisions, sharing ideas, arguing on evidence, discussing results, and communicating conclusions [1].

The preliminary results shown here involve satisfaction of the primary teachers involved and motivation and interest of the students after playing the black box game and activities. We are looking for encouraging teachers to continue their epistemic training through deepening the complexity of the game next year on the basis of the positive results displayed here.

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REFERENCES


ANNEX. TEACHING LEARNING SEQUENCE: THE BLACK BOX EXPERIMENT PROJECT

JUSTIFICATION / GENERAL DESCRIPTION (summary)

The objective of science is the acquisition and validation of new knowledge. In this project the student assumes the role of scientist, who seeks knowledge at the level of the students, to practice with the experiment the norms and processes of science. The project offers an example that has different components of scientific processes: argumentation, planning, reflection, cooperation and manipulation. Students can manipulate a closed box (black), to make observations with their senses and plan and perform any experiment they believe, but without breaking or opening the box (initially). The most important thing is not only to know what happens inside the black box, but to provide opportunities for students to build their own arguments, data and models, and stimulate students' decision-making and creative thinking.

RELATIONSHIP WITH THE CURRICULUM

C 1. Introduction to scientific activity

OBJECTIVES

Content Objectives: Students will be able to ...
- Create reflective and detailed hypotheses based on observations and research
- Argue with evidence about the nature of science and the importance of predictions
- Understand that the scientific method is an endless and sometimes cyclic process
- Link scientific research and social issues

Pedagogical objectives: Students can also ...
- Practice / participate in a responsible and constructive debate between them
- Cooperate to share content and understanding of each other
- Cooperate to address new and erroneous ideas and concepts

Epistemic objectives: Students will be able to ...
- Develop thinking and research skills (observe, measure, classify, hypothesize, check, reason, argue with evidence, design, ...)
- Develop attitudes and dispositions that characterize science, such as curiosity, openness to new ideas and data, skepticism and others.

REQUIREMENTS

None; the teacher adjusts and adapts the content, the questions to be asked and the activity guides to the age of the students.

ACTIVITIES (Student / Teacher) (Add, modify, improve, revise, adapt, specify ...)

ENGAGEMENT Introduction-motivation

Observation / electricity is a black box; We do not know what's within the cable, but turn on the light bulb ...

Search information about aircraft black boxes

ELICITING Previous knowledge

To answer the question / How many things do you use daily without knowing what there is inside?

Development activities

EXPLAIN Content

Free

EXPLAIN Procedures

Execute and record the results of ... / Teacher explains ...
Observe, move and listen (the box):
- How it sounds? (Metal…)
- Is one of the elements heavier than the rest?
- Roll? In all directions? (Sphere, tube …)

Predict:
- Can you predict the size, mass, shape, material and other properties of the object in the black box?
- What do your tests tell you about the black box itself?
- What is the structure of the box? What do you think the object is?
- How can you check it?

Develop a hypothesis about the contents of the box / Explain hypothesis concept
- Explain how you came up with your hypothesis.
- What is needed to make a viable hypothesis? is yours viable?
- How do you think that scientists make viable hypotheses in a real problem of life sciences?
- Why do you consider it important?

EXPLAIN Attitudes
Effort / Open minds, curiosity, truthfulness (no cheating, no lies …), deep thinking, arguing conclusions, imagination and creativity...

EXPLORE Consolidation
Meta-cognition:
Review of correctness / errors in hypothesis and research planning / Explain successes / errors and the experimental design; clarifies the conclusions, results and explanations and models created by the students

What could have you led to erroneous conclusions?
How could I have carried out the experiments differently to reach better conclusions?

Experiment / Research project
Before starting to write the design, review the objective of the experiment. A well-stated goal (hypothesis) is essential to the writing process and the reader’s understanding of the report.

Suggestions: Consider using examples and hypothetical situations to answer these questions.
Identify the tools that are needed to proceed in the investigation.
Identify some of the different variables to consider in determining the elements

Meta-cognition on research
4. Analyze your experimental design in detail.
4.1. What will you measure?
4.2. How is it going to be measured?
4.3. How will you collect the information and how will you work with it (tables, graphics…) ?.
4.4. Number of tests planned. Justify why.
4.5. What will calculate, for example, the average of all measurements.

5. Construct a conclusion, model, explanation on the classification of objects.

Students write their reports presenting procedures, results and explanations in a clear, concise and logical way, and focusing on being convincing about the explanations and conclusions reached, justifying them with the data obtained (argumentation).
EVALUATE
Instruments (select instruments to evaluate)
Present the guides and organizers / Rubric to evaluate each guide and organizers
Participation in group and class work / checklist of contributions
Criteria / indicators
Observation guide / organizer / quality of observations
Guide / organizer of hypotheses (decisions) / number, coherence and justification of hypotheses
Guide / prediction organizer / number, coherence, justification of predictions
Design document of experimental work / quality design
Document of the experimental data observed / quality of the presentation of the data
Participation in group and class work / frequency and quality of contributions

EXTEND Reinforcement activities
Each group presents its results to the whole class / Teacher rules and clarifies the presentation and explanations of each group
Discuss incoherent conclusions among themselves / Teacher rules and clarifies the debate
Class group conclusions / systematized the conclusions of the experience

EXTEND Recovery activities
Performs the recovery activities assigned by the Teacher / T. decides the necessary recovery activities

EXTEND Extension activities
Electricity was used for years without knowing its true nature (black box) / History of electricity from its discovery to justify its nature (electrons travelers by a driver)
History of the atom as a black box (what's inside?) / The bombardment with alpha particles showed its divisibility and structure
History of the telescope as a black box opener instrument what is beyond the Moon? What is beyond the solar system?
What organisms are in a drop of water? What is inside our skin?
Elaborate a story highlighting observations, hypothesis, results and models
Prepare an alternative story about a black box whose study could be applied to the method used…