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Solar Energy and Inquiry-Based Learning: A Pathway to Scientific Competencies in Secondary Education

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Abstract: The fundamentals of experimental science didactics have proven that compulsory education students need to develop skills such as critical thinking. Guided inquiry is a practical methodology for developing various science skills. Moreover, current legislation establishes a series of specific competencies that students must develop. This work presents research carried out with students aged 13–14 years. A project, based on the problem-based learning methodology, on a real-world topic close to the students was implemented to assess the development of critical thinking and specific competencies outlined in legislation. For this purpose, a teaching-learning sequence was developed, and the students' outputs were collected through questionnaires and teacher observation sheets. The results show that students can answer each of the problems encountered during the project, posing researchable questions and finding solutions through experimentation. Each of the sessions has demonstrated clear progress in several key areas such as the development of some of the required competencies and overall scientific skills, thereby facilitating overall development.

Keywords: electricity, solar cells, inquiry, problem- based learning (PBL), secondary education

1. Introduction

The low level of scientific literacy in society has been attributed to the reduced number of students pursuing scientific vocations. This topic was studied by several researchers in recent years [1]. This lack of literacy has broader implications, including diminished critical thinking abilities (crucial for daily decision-making) and a greater susceptibility to misinformation, among other challenges [2]. Scientific literacy is crucial in many everyday situations, making it vital to encourage genuine science education that incorporates increasingly advanced scientific and technological content, all within the framework of educating individuals within their social context [3].

Motivation and self-confidence are two key factors that significantly impact students' interest in science [4], and they also play a role in their academic performance in science-related subjects. According to Kurbanoğlu et al. [5] and Carroll et al. [6], young Europeans often exhibit low confidence in their ability to learn science, which in turn reduces their overall interest in the subject. Additionally, Awandia [7] highlights that the teaching methods employed in science education are crucial in shaping students' attitudes, which, in turn, affect their future interest in scientific fields. While considering these aspects is vital for designing effective science curricula, Touchet et al. [8] observe that such considerations are not yet widely implemented. Given this, it is clear that science classes should focus on sparking students' curiosity in scientific topics while ensuring they thoroughly understand the content taught by their teachers. In summary, this work has researched the development of specific competencies acquired by students along a teaching-learning sequence based on their science interests, which collaterally helps develop critical thinking.

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2. Literature Review

Studies have shown that students are generally more engaged when addressing problems related to their immediate surroundings. Framing scientific problems within their environment leads to increased interest from students [9–12]. In this regard, it is essential for teachers to assess whether students are acquiring the necessary scientific process skills. As a result, an effective teaching strategy could involve students generating their own questions or projects, based on their personal experiences and interests, and contextualized within their environment [13].

At the secondary school level, teachers are expected to teach not only theoretical content but also scientific procedures [14]. In this respect, researchers such as Pozuelo-Muñoz et al. [15], Bolger et al. [16], and Lestari et al. [17] argue that scientific practices like inquiry, argumentation, and modeling are highly effective ways to teach science. These practices are often utilized within problem-based learning (PBL) [18], which enhances students' research skills and aids in the assimilation of new knowledge. Haatainen and Askela [19], Navy et al. [20], and McKinney [21] further underline the value of PBL in fostering the inquiry practice necessary for experimental science.

PBL is an instructional approach that focuses on both developing problem-solving skills and acquiring content knowledge [22]. According to Hmelo-Silver [23] and Merrit et al. [24], the objectives of PBL are divided into (a) content knowledge (fostering a deep and adaptable knowledge base, academic achievement, retention of knowledge, and conceptual growth), (b) procedural knowledge (cultivating effective problem-solving abilities and lifelong self-directed learning), (c) productive collaboration, and (d) positive attitudes (including intrinsic motivation and active engagement in learning). Learning through solving real-world problems, integrating knowledge, and applying it to practical situations is at the heart of PBL [25], which helps to develop various skills and competencies [26]. The general framework of PBL, as examined by Drake and Long [27], typically comprises eight components: a problem or project, small group collaboration, an iterative student-driven inquiry process, resources, technology, community partnerships, communicating results, and teachers serving as facilitators. While research on the benefits of PBL in secondary science education is limited, some studies have shown promising outcomes, including the enhancement of critical thinking skills [28] and the promotion of scientific practices among both students and teachers [29].

Understanding that the problem or project itself serves as the central focus in the learning process, as it drives students' motivation and engagement [30]. Therefore, projects or problems should be complex, reflecting real-life situations and allowing for open-ended exploration and discovery by students [24, 31]. Additionally, many authors advocate for granting students the autonomy to identify and resolve their own problems [30, 32]. Once a problem is established, students work together in small groups [22, 29, 31], focusing on an iterative inquiry process, which is a fundamental aspect of the PBL model [30].

The process of inquiry is a structured approach that aims to solve and diagnose problems by identifying assumptions, applying logical and critical thinking, and evaluating alternative explanations [33]. Pedaste et al. [34] outline the stages of inquiry, which include orientation, experimental design, investigation, conclusion, communication of results, and discussion. This method aligns with how scientists study the natural world and reach conclusions based on evidence gathered from their experiments [35]. Additionally, the questions posed during this process serve as triggers for organizing new knowledge [36] and nurturing curiosity, encouraging individuals to reflect on their own understanding and learning [16]. Although we haven't analyzed the development of critical thinking in detail, these types of projects, in which students ask themselves questions and seek answers, should help develop it. According to Ennis [37, 38] and Facione [39], it would appear that effective teaching must include strategies for building intellectual character rather than relying exclusively on strengthening cognitive skills, which will ultimately help develop critical thinking, as long as students are willing to do so.

Hodson [40] notes that students prefer to have a clear grasp of their activities; while uncertainty may be unsettling, they find intellectual challenges enjoyable when they can answer questions independently. Consequently, it is important to design tasks that afford students enough control and independence to ensure their learning progress remains unimpeded.

Furthermore, we must not forget that compulsory education students must achieve knowledge that can be evaluated according to the criteria of the regulations in force. According to current legislation [41], students must achieve specific skills that have to be evaluated. Attending to the previously stated and to facilitate the development of these specific competencies (which are specified in the following section), an interdisciplinary project was designed to evaluate their development in a project-based-learning context based on guided inquiry of the students.

Therefore, the objective of this work is to investigate to what extent the developed project favors the development of the specific skills and competencies necessary according to current legislation.

3. Research Methodology

3.1. The project-based learning context (PBL)

An interdisciplinary project was designed between the subjects of technology and physics-chemistry around a common topic: electricity. The project was developed with 30 students aged 13–14 years old throughout the 2023–24 academic year. The research was developed in an urban private school with a medium-high socioeconomic level.

The students were grouped into mixed groups of boys and girls, before being presented with the research question they had to answer, which was: "How is it possible to make our own solar cells?"

To answer the question posed, the teacher designed a teaching-learning sequence based on seven stages. Each of these stages had expected objectives, so that in the total development of all stages, the normative competencies will be worked on. In Table 1, the stages are presented with the expected objectives of each of them. An informed consent was requested from the students and their legal tutor.

Table 1
Activities developed in each session and the expected objectives of each

Session	Activity	Expected Objectives
1	Search information	Analyze critically the proposed information. Discuss as a group and be able to decide the most appropriate options by consensus.
	Compare the list of available materials with project needs	Analyze the feasibility and needs related to a project. Adapt a project to existing resources. Develop group negotiation skills.
	Propose a solar cell design	Discuss the viability of a project within a group and reach agreements on the design.
2	Build a solar cell with CDs	Critically analyze your own project throughout the process and develop the ability to adapt it to real contexts. Put electricity concepts into practice such as voltage, resistance, voltage, conductive and insulating materials, and electric current.

(*Continued*)

Table 1
(*Continued*)

Session	Activity	Expected Objectives
	Check the operation of homemade panel, measuring and connecting elements	Use the multimeter to measure voltage and intensity provided by the panel, and train work capacity with electrical elements, connecting a light bulb, fan, and pump. Develop the capacity for analysis, preparing a document of conclusions.
3	Build a panel with commercial cells and check its operation	Put electricity concepts into practice such as series and parallel circuits, voltage, tension, resistance, amperes, connections, and motors. Manipulate electrical material with skill. Analyze phenomena related to electricity: the connection of pump, light bulb, and fan. Analyze the behavior of solar panels under different incident light conditions and connected elements, comparing their performance with a traditional power source (battery).
	Prepare a document with the main conclusions	Agree with the group on the most important points learned during all sessions. Work on the ability to analyze and be concrete. Develop skills to search for information.
4	Panel solar builder's visit	Develop the ability to ask questions and raise doubts in a group.
5	Visit to a solar park	Know a real installation and associate acquired knowledge.
6	Final work	Answer questions to evaluate the teaching-learning process of the project.
7	Presentation of the final work	Explain/expose their learning to the community.

Note: * List of sessions, type of activities, and expected objectives.

In summary, throughout the project, the students were tasked with answering the research question. To do this, they first had to create a solar cell using CDs, based on the provided instructions. They had to collect reflections on the quality of the information and the manufacturing process that would help them in the second stage. During this second stage, they had to consider the materials required to create a viable solar cell, in addition to testing whether it functioned properly and applying concepts learned in the two subjects (technology and physics-chemistry). After this, they received a visit from experts on the subject. A solar cell manufacturing company agreed to visit the classroom to address questions and reinforce concepts. Since the institute has a solar cell park, we visited it, reviewing all its parts in detail, to try to relate what was worked on in the project with a real assembly in optimal operation. And finally, to work on the skills associated with transferring the generated knowledge and communication skills, the project's results are presented to the entire institute in a special session specifically designed for this purpose.

3.2. Assessment

As described in the objective, throughout the project, the extent to which the project facilitated the development of the competencies established by legislation was evaluated. These competencies are listed in Table 2 [41].

Table 2
Competencies to develop along the project

	Specific Competency
1	To search and to select appropriate information from various sources in a critical and safe manner, applying research processes and product analysis methods and experimenting with simulation tools, to define technological problems and initiate processes of creating solutions from the information obtained
2	To address technological problems with autonomy and a creative attitude, applying interdisciplinary knowledge and working cooperatively and collaboratively, to design and plan solutions to a problem or need in an effective, innovative, and sustainable way
3	To apply different interdisciplinary techniques and knowledge appropriately and safely, using operators, technological systems, and tools and taking into account prior planning and design, to build or manufacture technological, sustainable solutions that address needs in different contexts.
4	To describe, represent, and exchange ideas or solutions to technological or digital problems, using appropriate means of representation, symbols, and vocabulary, as well as the instruments and resources available, and valuing the usefulness of digital tools, to communicate and disseminate information and proposals
5	To make responsible and ethical use of technology, showing interest in sustainable development, identifying its repercussions, and valuing the contribution of emerging technologies, to identify the contributions and impact of technological development on society and the environment

Note: * List of competencies by number and description.

4. Results

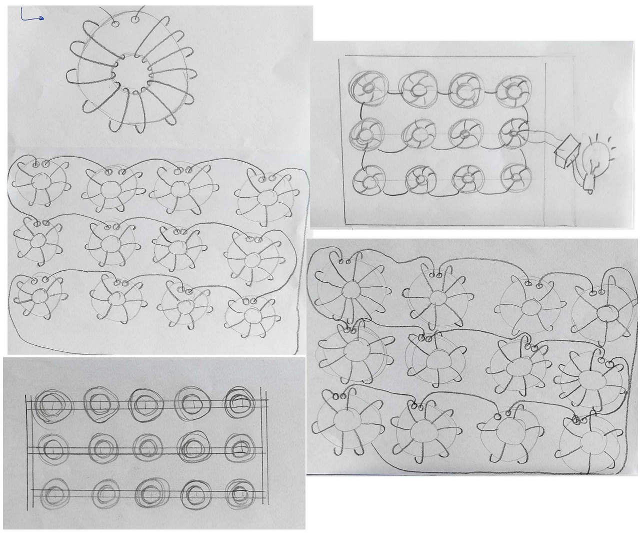
Below, we describe each of the activities carried out, linking their development with the skills to be developed.

4.1. Session 1

The students watched the videos provided by the teacher and had to agree on the necessary information they should extract to design a plan for homemade solar cells. At the end of this session, they deliver a report with the justified decisions and the design carried out. The questions that guided this session were: What construction elements are repeated in the videos? Which of them do you consider essential? Is the number of CDs important? Can a solar cell be made with a single CD? How are CDs joined together? How do we place the CDs in the holder? How do we connect the board to the elements we want to plug in? What other details do you think are important?

Some of the representations of the students are shown in Figure 1.

Figure 1
Students' representations of solar cells hand-made with CDs



According to the inquiry methodology carried out, learning is guided through questions. These questions are not only asked by the teacher, but the students themselves, as an indication of the learning carried out, should ask themselves questions based on what is happening throughout the project, and they should look for instruments to solve these questions. In this first session, the students asked themselves numerous questions, see Table 3.

4.2. Session 2

In this session, the students had all the materials that they themselves believed were necessary to build a solar cell with CDs and check its operation. The materials were enough CDs, a copper coil, a cardboard sheet, aluminum foil, insulating tape, a multimeter, a light bulb, and a silicone gun. Some of the assemblies they carried out are shown in Figure 2.

The students built boards using 4 to 12 CDs. Those who used more CDs justified it to *"get more voltage."* The students expressed some difficulties in construction such as the connections between CDs. Some of them solved the connections using copper wire, while others used aluminum strips. And all of them performed series and parallel connection tests before deciding on the final assembly. They checked the conduction of current with a battery-battery-bulb holder. They tested each CD independently, finding that no CD conducted electricity. The students then performed current conduction tests on aluminum, finding that it did conduct. This led them to the fact that the copper wires had some problems, so they did not conduct current. They tried a shorter piece of copper wire, with several wires intertwined to achieve more sections, with finer copper wire to see if it was a problem with the resistance of the material. In the end, it was concluded that it could be due to a coating on the copper wire. They peeled the ends, did tests, and saw that it did conduct electricity.

4.3. Session 3

In this session, the students had a solar cell. They had to measure voltage and intensity, build a circuit with a light bulb or motor (fan), and check if it worked, justifying the answer.

Taking into consideration the knowledge they had acquired in sessions 1 and 2, the students were able to link the different elements and to construct a viable panel. They placed their cells in the sun; however, none of them managed to activate the motor (1.5V) or turn on the light bulb (LED). After measuring voltage, they found very low voltages (1 mV) and concluded that the reasons could be *"the board was not of quality"; "they didn't have enough silicon"; "there wasn't enough sun, or we haven't left it long enough"; "The elements need more tension than the plate can provide*.

As a conclusion of this session, the students collected possible reasons to ask the experts. This means the students had totally focused their doubts, which is a really important step in the learning process.

4.4. Sessions 4 and 5

To find an answer to what has happened and resolve the questions to which the students have not found answers with the experimental tests, we invited professionals from a solar cell assembly and installation company (see Figure 3). In this session, students

Table 3
Developed competencies along each session

Session	Evidence	Developed Competencies
1	*"Can the turns that the CDs make with the copper interfere with the voltage they provide? Does it matter if the copper wire runs in front or behind the CD, or if we only place it on the side exposed to the sun? The darker the panel, the more thermal energy it will absorb? Is it necessary to use copper to conduct electricity? How can we check in the laboratory if copper or aluminum are conductors? Does it matter if you connect the CDs series or in parallel?"*	1, 2, 3, 5

(*Continued*)

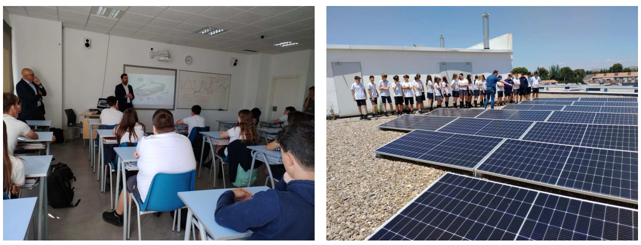
Table 3
(*Continued*)

Session	Evidence	Developed Competencies
2	The students addressed technological problems with autonomy and a creative attitude, applying interdisciplinary knowledge and working cooperatively and collaboratively. They applied different interdisciplinary techniques and knowledge using operators, technological systems, and tools.	2, 3
3	They build a circuit with a light bulb or motor (fan) and check if it works, justifying the answer. *"The board was not of quality"; "they didn't have enough silicon"; "there wasn't enough sun, or we haven't left it long enough." "The elements need more tension than the cell can provide."*	1, 2, 3, 4, 5
4, 5	They searched and selected appropriate information from various sources, in a critical and safe manner, applying research processes. They made responsible and ethical use of technology, showing interest in sustainable development.	1, 5
6	They were able to describe, represent, and exchange ideas and solutions to technological or digital problems, using appropriate means of representation, symbols, and vocabulary.	1, 4
7	They presented and explained their functional projects.	1, 4, 5

Note: * List of sessions, evidence collected, and number of competencies developed.

Figure 2
Construction of the solar cells made with CDs

Figure 3
Visit of the professionals (left) and visit to the photovoltaic park (right)



contrast classroom learning with reality; that is, it helps them generalize the knowledge acquired in the classroom.

After the visit of the professionals, we visited the photovoltaic park that the institute has on the roof, with special dedication to the operation of the software, which clarified (according to the opinions of the students) some of the doubts that they still had (see Figure 3).

4.5. Sessions 6

Finally, the students had to answer a series of reflection questions, which helped the teacher evaluate their learning on the topic.

Some of the questions and answers are the following:

- Why didn't the CD panel work as a solar cell? *"Because it lacked semiconductor material" and "because it lacked silicon for electron movement."*
- How do you explain the transformation from light to electrical energy? You can use drawings to help you. Figure 4 shows a scheme of one of their responses. *"The photons collide with the solar cells, and a flow of electrons called electric current is formed. Then the electric current is directed to an external circuit." "Photovoltaic cells convert sunlight into electricity in the form of direct current and with a rating that varies between 380 and 800 volts."*
- What happens to the intensity and voltage with the installation of the cells in series and parallel? Explain what was happening with the fan in the workshop. *"If we install cells in series, the intensity is maintained, but the voltage is added, and if we install cells in parallel, the intensities of the solar cells are added, but the voltage is maintained. What happened with the fan was that it needed more intensity than the series cells had; therefore, it did not work." What happens with the intensity and voltage of the cells in series is that the volts increase, but, for example, with the fan, which had 6 volts, it did not work, because it used less intensity. Then in parallel they only gave 6 volts, but the fan worked, because it had more intensity."*
- What problems can a solar cell have? *"During the night, there is no energy production, so you have to take energy from the grid. Unless it has batteries, otherwise all the energy you produce and do not consume is demanded from the grid." "The degradation of efficiency, the accumulation of dust and dirt, corrosion, and deterioration, among other factors."*

4.6. Sessions 7

In this last session, the students presented the project, both to the rest of the students at the institute (see Figure 5), that is, a peer presentation, and to the parents and adults who wanted to attend; that is, they presented their research to the community, thus transferring their knowledge to their closest community.

In Table 3, we have collected the evidence (questions and comments) of the development of every competence.

Figure 4
Picture explaining the luminal to electrical energy transformation according to some students

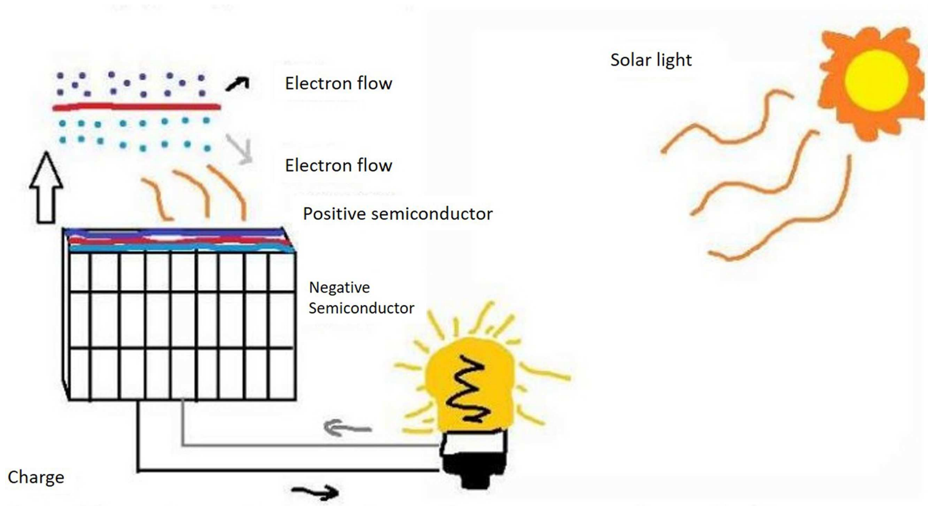


Figure 5
Project presentation

5. Conclusion

The main objective of this work was to investigate to what extent the development of this project favors the acquisition of the specific skills and competencies necessary according to current legislation. Attending to the results, the whole of the competencies expected were developed within the activities' sequence.

The interdisciplinary project carried out with 13–14-year-old students demonstrated, in a real classroom context, that inquiry-based and problem-focused learning supports the acquisition of the specific competencies required by current legislation. Throughout the seven sessions, students showed autonomy, creativity, and collaboration; applied knowledge to design, build, and evaluate prototypes; and contrasted their learning with professionals and authentic settings. This sequence not only strengthened their understanding of technological processes related to solar cells but also fostered transversal skills such as critical thinking and problem-solving in practical situations.

By specifically analyzing which competencies have been worked on in each session, we can say that:

In session 1, the students had to apply critical criteria to search for valid information and discuss it in groups until deciding on the most appropriate information. In session 2, the students had to solve the technological problem of constructing a solar cell with CDs, with autonomy and a creative attitude, applying interdisciplinary knowledge and working cooperatively and collaboratively. Once constructed, they had to check that it worked. In session 3, the students put into practice the knowledge mobilized in the previous sessions. In sessions 4 and 5, the students had the opportunity to resolve their specific doubts. This is very important; they were not general doubts but specific doubts generated in the construction process of the previous sessions. In session 6, the students had to put what they learned in writing by answering several questions, that is, verbalize the knowledge model built throughout the previous sessions. In session 7, the students had to present the project in front of classmates and adults.

However, the study presents important limitations: the assessment of competencies relied on teacher observations and student products without standardized rubrics, no quantitative pre-/post-measures or systematic analysis of critical thinking development were conducted, and there was no in-depth evaluation of the sustainability of the proposed solutions. These shortcomings restrict the generalizability of the findings and point to the need for future studies with larger samples, more rigorous evaluation instruments, and long-term analysis of specific competencies.

Despite these limitations, the experience highlights the pedagogical value of inquiry projects in secondary education. Integrating real problems and contexts familiar to students, alongside interaction with experts and authentic resources, appears to be an effective way to develop scientific and technological competencies, increase motivation, and lay the groundwork for more critical and autonomous learning in experimental sciences.

For future improvements, we plan to consider explicitly discussing the ethical implications and sustainability of technology to deepen students' understanding of these important issues.

Ethical Statement

This study involving human participants was reviewed and approved by the Ethics Committee of the University of Zaragoza. The students participating in this study and their families were informed of the data collection through a formal informed consent.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data that support this work are available upon reasonable request to the corresponding author.

Author Contribution Statement

Jorge Pozuelo-Muñoz: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Esther Cascarosa Salillas:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Elena Calvo Zueco:** Conceptualization, Software, Validation, Formal analysis, Investigation, Resources, Visualization, Supervision, Project administration. **Ester Sánchez Sánchez:** Conceptualization, Software, Validation, Formal analysis, Investigation, Resources, Visualization, Supervision, Project administration.

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