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The concept of pH and its logarithmic scale: A Micro Bit experience through inquiry, modeling, and computational thinking

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Abstract

The present work describes an educational experience carried out in a secondary school in Spain, where the case of Tinto River is presented as a learning scenario to understand the concept of pH and its logarithmic scale. Through the use and programming of controller boards (Micro Bit) and sensors, this study aims to address the underlying level of abstraction and alternative conceptions related to these topics. The intention is to provide practical examples for the development of a teaching-learning sequence based on inquiry, modeling, and computational thinking. This sequence addresses a current socio-scientific issue, while also considering students' comments, and considering the Spanish digital competence model. The analysis includes an evaluation of its strengths, weaknesses, opportunities, and threats. The results indicate that the sequence can be highly motivating in understanding the concepts presented and in acquiring digital competencies. However, it also reveals limitations in terms of time required and the complexity of its design.

Keywords: computer literacy, Micro Bit, science education, modeling, inquiry, computational thinking, pH, STEAM

INTRODUCTION

In today's digital society, the extensive use of technology in various aspects of life highlights the need for the educational system to adapt to this social reality. It's essential to incorporate a more contemporary and comprehensive approach to develop students' digital competencies in chemistry education. Digital technology can help improve chemistry teaching quality in technical, cognitive, and social aspects (Dewi et al., 2021). Digital competence is defined by Spanish education law as the creative, critical, and secure utilization of information and communication technologies to achieve objectives related to work, employability, learning, leisure time utilization, inclusion, and participation in society (LOE, 2020). In this context, educational technology applied to the model of digital competences of natural sciences plays a pivotal role in the emerging didactic model being proposed (**Table 1**).

Digital literacy encompasses not only scientific concepts but also cultivates critical thinking skills. This is because digital literacy emphasizes reading, writing, comprehension, evaluation, communication, and the utilization of information in various formats (Dewi et al., 2021). In this methodology, the active role of students and the guiding role of educators are key elements of the process. Contexts are presented as essential for generating learning situations that are crucial to the development of expected student behaviors (Lorca Marín et al., 2021).

To develop this digital competence, an experiential learning model has been implemented using sensors and microcontroller boards (such as Micro Bit), which are programmed through block-based programming using freely accessible software.

Effective and creative teaching in STEAM education (science, technology, engineering, arts, and mathematics) is essential to equip students with the ability to apply basic scientific theories to various

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Contribution to the literature

- This experience arises from the needs that the literature exposes related to the implementation of science teaching-learning sequences, where inquiry and modeling, widely validated (Couso et al., 2020) and considered ideal but rarely implemented in science classrooms, are carried out to develop scientific literacy.
- Likewise, the gap between technological evolution and formal education is growing wider, and concepts such as computational thinking (CT) or digital literacy are now seen as necessary.
- Developing experiences through socio-scientific issues (SSIs) focused on controversial heritages that consider the mentioned concepts provides a new way to approach science content and empower students to create, develop, and use their own digital tools to develop skills and science content that can help structure critical thinking. Thus, we provide a new sequence based on inquiry and modeling, combining it with CT that focuses on problematizing from learning situations aimed at addressing these needs.

Table 1. Digital competences model of Spanish citizens describes the key core of the competence areas, capacities, & performance levels of digital competences for Spanish population (PNCD, 2023)

Model of digital competences of Spanish citiziens	
Competence areas	Competences
1. Scientific information & literacy	1.1. Navigation, search, & filtering of information, data, & digital content related to corpus of scientific knowledge
	1.2. Evaluation of scientific information, data, &d content
	1.3. Storage & retrieval of information, data, & digital content
2. Communication & collaboration	2.1. Interaction through digital technologies
	2.2. Sharing information & digital content
	2.3. Online civic participation
	2.4. Collaboration through digital channels
	2.5. Netiquette
	2.6. Management of digital identity
3. Content creation	3.1. Development of digital content
	3.2. Integration & reworking of digital content
	3.3. Copyright & licenses
	3.4. Programming
4. Security	4.1. Device protection
	4.2. Protection of personal data & digital identity
	4.3. Health protection
	4.4. Environmental protection
5. Problem-solving	5.1. Problem-solving, both technological, & scientific
	5.2. Identification of needs & technological solutions
	5.3. Innovation and creative use of digital technology
	5.4. Identification of gaps in digital skills

technologies and understand their real-world applications from an engineering perspective. This necessitates the development of creative methods and tools, as well as the integration of innovative experiments, which extend beyond the traditional boundaries of STEAM education. It emphasizes the connections between STEAM fields and the relationship between educational theory and its practical application (Park & Ko, 2012).

By fusing CT instruction with STEAM disciplines, students can explore and apply CT skills within a more established and accessible STEAM context. In this way, STEAM can enhance CT learning (Weintrop et al., 2014).

As a learning situation, the study focused on the physicochemical characteristics of Tinto River, a river with red waters and a low pH level located in the Province of Huelva in the southwest of the Iberian Peninsula (Spain). This river presents an SSI as, despite its exceptional peculiarities and its interest as a controversial natural and scientific heritage, it is a polluted river that negatively affects the ecosystem. This fact represents an interest for classroom work as it raises conflicts of ideological, political, economic, and environmental nature that could lead students to reflect, form their own opinions, and critically analyze reality (Arroyo Mora & Cuenca López, 2021). Similarly, heritage education is not an end in itself but should be integrated into the educational process, providing relevant content for many other fields of action such as environmental education or scientific literacy (Cuenca López, 2014).

SSIs involve the use of science and are of interest to society, also raising ethical and moral dilemmas.

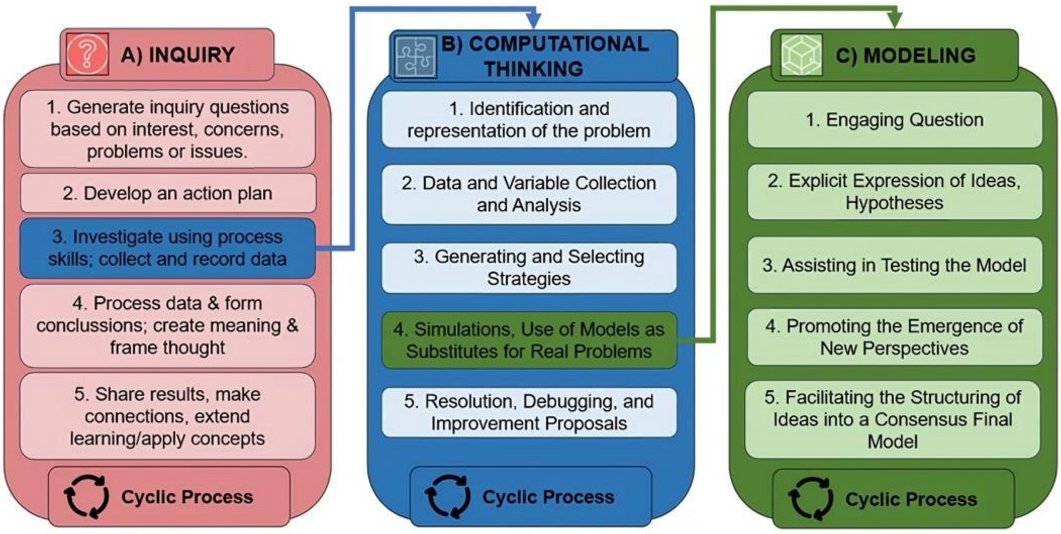

Figure 1. Sequence developed in the (A) inquiry learning cycle (adapted from Hammerman, 2006); (B) computational thinking cycle (Campina-López et al., 2023); & (C) modeling cycle (adapted from Campina-López et al., 2023 and Couso et al., 2020, illustrating process of experimental learning model created by authors)

Introducing such problems presents a significant and usually cross-disciplinary challenge to curriculum developers and teachers (Morris, 2014).

The concept of acidity, pH and the understanding of its logarithmic scale can pose a high level of complexity for many students. Studies like those by Kala et al. (2013) have found the existence of alternative conceptions about pH and pOH concepts among secondary school students, which should be taken into consideration by educators. For example, when converting the pH, which is a logarithmic scale, to a decimal expression, the students tended to think that it was a linear scale and that the addition of distilled water to an acidic solution should have produced a linear increase in the pH value (López-Banet et al., 2021). Furthermore, they think that neutralization always results in a neutral solution and have only a notion of the corrosive aspects of acidity (Lin & Chiu, 2007).

Inquiry, Modeling, & Computational Thinking as Teaching & Learning Models

This experiential learning model combines these three teaching approaches: inquiry, CT, and modeling (**Figure 1**). To carry out an inquiry learning cycle, the process should focus on questions that are of interest to students and that harness the wonder we aim to foster in them (Hammerman, 2006). Thus, the student needs to take ownership of the question, express, justify, and discuss their ideas using different languages, design the search for evidence to contrast their ideas (Martínez-Chico et al., 2017).

CT method helps us solve complex problems with its central focus on developing skills such as abstraction, simplification, and decomposition to generate problem-solving strategies and optimize the process. It enables students to think differently, express themselves through a variety of media, solve real-world problems, and analyze everyday issues from a different perspective (Bocconi et al., 2016). On the other hand, modeling is the learning approach that accompanies research with models in order to apply them, revise them, modify them, and even replace them with different ones if necessary (Justi & Gilbert, 2002). Modeling it's a strategy that enhances conceptual understanding and students' levels of success, helping to eliminate existing misconceptions and generating a positive attitude towards the course and learning (Benzer & Unal, 2021).

With teaching and learning based on models being coherent with personal and social constructivist theories of learning, focusing on students, and where all learning depends on language and communication (Treagust et al., 2004).

Although the sequence of the cycles presented here aids in the design of teaching and learning sequences, it is important to note that it is not necessary to strictly follow the order to carry them out.

Objectives

Within the proposed approach, there is a dual purpose that we can outline in the form of main objectives. Firstly, the goal is to design teaching-learning sequences based on inquiry, modeling, and CT. These sequences are intended to align with the national digital competence plan (**Table 1**) proposed by the Ministry of Economic Affairs and Digital Transformation of the Government of Spain. Additionally, they aim to facilitate the exploration of STEAM content and competencies, where sensors can demonstrate variables related to acidity, pH, and pOH in accordance with known theoretical concepts.

The second objective is to evaluate sequence implemented by participating students, using a SWOT analysis as primary evaluation tool. It will particularly focus on the compilation and analysis of the students' comments and impressions, which were recorded in their field notebooks. The most common observations from these notes will be used to construct SWOT table. This approach allows for a detailed understanding of students' experiences and perceptions, providing insights into strengths, weaknesses, opportunities, and threats associated with learning sequence.

METHODOLOGY

Participants

The proposal was carried out with 26 students from 4th year of compulsory secondary education at María Auxiliadora School in Valverde del Camino (Huelva, Spain), comprising 15 females and 11 males. The design, implementation, and evaluation of the proposal are contextualized within the subjects of biology, chemistry, geology, and physics. Throughout the process, students analyzed and studied specific topics to construct and define the main domains and their implications in the physicochemical content inherent to the subject. This work was done in teams, enabling students to progressively and engagingly acquire the content related to the concepts of acidity, pH, and pOH as covered in secondary education.

Design

Starting point

The proposal stems from a project examining Tinto River at various levels: biological, geological, physical, chemical, and historical. Its exceptional physicochemical properties, characterized by red waters and a unique ecosystem, mark it as a globally unique heritage. The river, with high metal concentrations, low oxygen, and an extremely acidic pH of around 2.5, has sparked debate over its restoration and preservation. These features also attracted NASA for astro-biological research in environments similar to Mars, through the MARTE (Mars astrobiology Rio Tinto experiment) campaign (NASA, 2018). Furthermore, these characteristics make the river an apt context for pH learning, among other educational aspects.

But why is this so? Has it been this way since its origin? How do its waters affect the ecosystem? Is it a polluted river? Why? How would it affect us? These were some of the questions raised by the students themselves and, apart from being the starting point of their investigation, it was also considered, with the guidance of the teacher, that they needed to explore the physico-chemical characteristics necessary to characterize river waters, considering their units of measurement and the instrument used for measurement. Can we build our own measuring instruments? The teacher would present the possibility of constructing and programming their own tools to measure river characteristics using sensors and taking water samples at different points in the river's source (with special attention to its first two tributaries) and along its course.

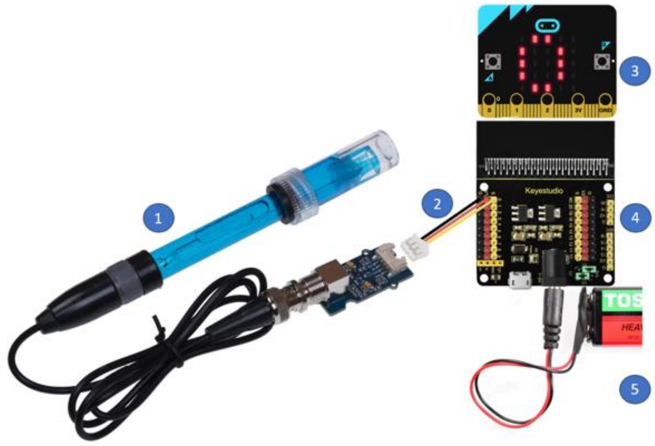

Figure 2. Setup diagram of pH measurement device: (1) pH sensor with probe & sensor module; (2) Three-pin power cable; (3) Micro Bit board; (4) External device connection extender board for Micro Bit; & (5) Battery or power source (Source: Authors' own elaboration)

Resources & Materials: Micro Bit, pH Sensor, & Art Supplies

The use of microcomputer based laboratory sensors or data acquisition equipment allows students to complete activities that are difficult to implement, as well as enabling them to study chemical phenomena outside the educational center (Aksela, 2011). These sensors cover a variety of measurements, allowing the exploration of different aspects of the secondary education curriculum (Caamaño, 2011). For the project's development, one session was devoted to handling Micro Bit boards and the pH sensor (**Figure 2**), as well as MakeCode programming environment.

Hardware

Micro Bit is an open-source hardware system based on ARM designed by BBC for use in computer education in the United Kingdom. Its low cost and small size were crucial factors in its selection. In our case, we used the V2 model.

As for the digital pH sensor, it's the "0vfz2rqcnx" model, which incorporates the pH sensor module and the pH probe consisting of a pH glass electrode and a silver chloride reference electrode.

Software

MakeCode is an open-source programming platform for creating computer science learning experiences. It enables programming with blocks or text (JavaScript).

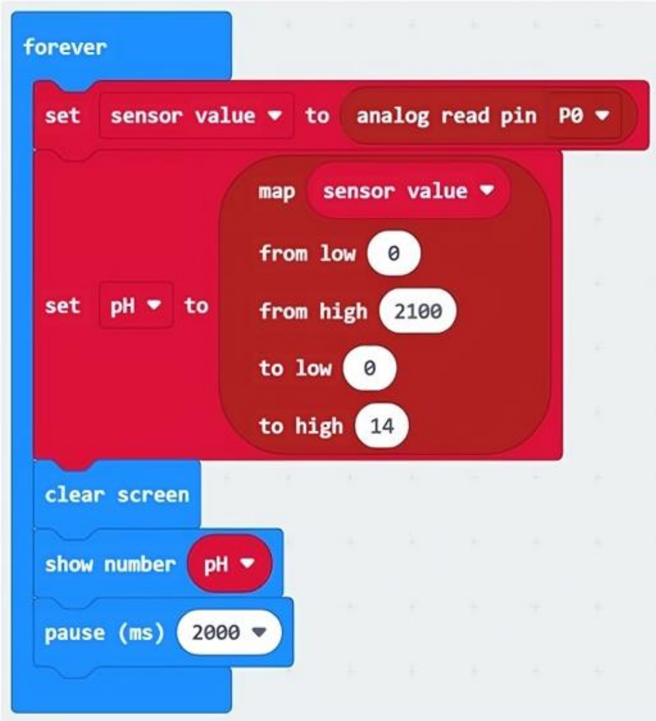

Figure 3. Block programming sequence of pH sensor through MakeCode (Source: Authors' own elaboration)

As shown in **Figure 3**, the process begins by creating the "sensor value" variable to read the analog input of the sensor, in our case, pin 0. A "pH" variable is created to map the value from zero to 2100 (depending on the sensor) to a value between zero-14. The screen is cleared, the pH value is displayed, and a two-second pause is introduced. It's important to clarify these sensors are not highly accurate, and the use of pH test strips is advised to verify the obtained data. Calibration of the probe with control substances and, if necessary, adjusting the sensor's potentiometer until the expected value is reached is required. Materials for model construction: The creation of a model primarily required carpenter's glue, newspaper, acrylic paints, plastic bottles, silicone, brushes, and aluminum foil.

Sequence

The design of sequence (see **Table 2**) involved initial review of sequences inherent in inquiry, modeling, and CT approaches. Part of the innovative contribution of this proposal is based on using a STEAM context to introduce experimental science content and SSIs through students' engagement in scientific practices.

Table 2. Summary outline of work sequence undertaken with students (adapted from Lorca-Marín et al., 2021)

Session	Activity	Development of activity
Session 1 (one hour)	1. Observation & questioning activity. Main question: Why is there no visible life in river?	Purpose of school science is to make sense of phenomena occurring around us. Students should be capable of seeking answers to questions posed by their environment. With this activity, we aim to incorporate scientific content into students' reality, contextualized within a real-world situation, & encouraging them to engage in explaining known phenomena that make sense to them.
	2. Hypothesis generation activity	They search some information about river with websites we provide. Starting from alternative conceptions that students may have, as identified in scientific literature (e.g., concepts or calculations of pH as noted in Kala et al. (2013) & Susilaningsih et al. (2020), our aim is to encourage them to verbalize their thoughts, make predictions, & justify their ideas. Hypothesis - "pH is affecting & hindering development of life in river." - "River is polluted." - "I would not put my hand in river because it melts." Questions Why do they say river has a high level of acidity? What is acidity? What is pH? & pOH? How can we measure pH? Why is polluted? What polluted does mean? Is it natural or anthropogenic pollution?
	3. Explanation activity: Do their explanations clarify what happens? Another situation can be posed by modifying variables.	We reflect as a group, & once their models have been explicitly formulated to explain what they believe happens & why, we proceed to seek evidence. Focus is on designing a plan of activity & handling variables. Questions If it had different pH values, could there be life? How does pH level change along course of river? If we could change pH, How could we vary pH level? Answers - "By adding water with a higher pH." Question How will we know when pH is changing? Answers - "By putting a fish in" (this option was discarded). - "Using a pH meter."

Table 2 (Continued). Summary outline of work sequence undertaken with students (adapted from Lorca-Marín et al., 2021)

Session	Activity	Development of activity
Session 2 & session 3 (two hours)	4. Tool or measurement instrument design & testing activity	Students are asked to suggest different ways of measuring variables. After hearing their proposals, we dedicate two sessions to teaching them about available digital tools, as well as how hardware & block programming work. We start with simple examples that gradually become more complex, making them think of ways to solve processes optimally. They build, test, & calibrate pH sensor with acidic & alkaline substances in their first interaction with electronic devices & substances of varying pH levels (**Figure 4**).
Session 4 (≈one hour)	5. Data collection activity: How can they determine if their hypothesis matches reality?	A visit to Tinto River source involves collecting samples from it & its first two tributaries. In-situ measurements are taken using sensors constructed & programmed by students & verified with pH test strips (**Figure 5**). This activity shows them that river starts with a pH around 3.2, & its first tributary from a mining dump has a pH of 2.4. What pH would river have when mixed with water from its first tributary? Question generated many doubts, & it was observed that one of the most common misconceptions is thinking that product of mixing different pH values follows an arithmetic scale, assuming an average between 2.4 & 3.2. Second tributary has a pH of 5.4. When measuring pH resulting from mixing water with this second tributary, it was observed that pH had hardly changed, remaining below three. Why?
Session 5 (one hour)	6. Graphical interpretation of data activity & need for model construction & design: Students observe outcomes, analyze results, & form new hypotheses	After gathering data, new questions arise that need answers. Collected samples are brought to classroom, & a session is dedicated to designing a model of river's source. Model is discussed & agreed upon as a group, not only regarding its design but also materials to be used for representing terrain & water channels. It helps understand, on a small scale, how pH levels vary (**Figure 6**). Students can experiment by adding water with different pH values. Using a logarithmic scale as reference, obtained data is represented & estimated to understand quantities needed to change concentration of H^+ & why the pH of river hardly changes along its course.
Session 6 (one hour)	7. Synthesis & conclusion activity	Evidence obtained from data can contribute to revising their explanations and/or models. In doing so, they compare their hypotheses with newly obtained data & construct new knowledge in a meaningful way
	8. Reflection & generalization activity: What have they learned & felt? Should a river with such characteristics be conserved? How would it impact us?	A reflection on learning takes place, where emotions related to process are considered crucial for generalization & development of critical thinking. Classroom discussions cover these characteristics, & conservation or restoration of river is proposed. This includes holding a class debate on managing a river, understanding its physicochemical characteristics, & their impact on ecosystem, recognizing it as a natural heritage for its unique landscape, & a scientific one due to studies by NASA & other research groups interested in its peculiarities.
Session 7 (one hour)	9. Dissemination activity	A podcast is created to summarize all that has been done & learned, alongside a presentation using an online software for creating animated & interactive presentations "*genially*" & a website on Google Sites created by groups to explain process & their conclusions.

Figure 4. Students calibrating & testing pH sensor with bleach & vinegar (left) & students learning block programming (right) (Source: Authors' own elaboration)

The sequence consisted of seven sessions (approximately one hour each) during which some sessions were spent in the field collecting samples, and others were used for designing and constructing a scaled model of the river's source with its first two tributaries.

ANALYSIS & RESULTS

The results recorded by the sensors must align with the theoretical approach, allowing the complexity of the studied phenomena to engage students, thus stimulating the search for justification for such results.

Student participation was consistent throughout the activity. Through observation, results analysis, and modeling, they gained an understanding of complex concepts like H3O+ concentration, acidity, basicity, and

Figure 5. Students collecting pH data from first tributary originating from a mining dump (left) & source of Tinto River (right) (Source: Authors' own elaboration)

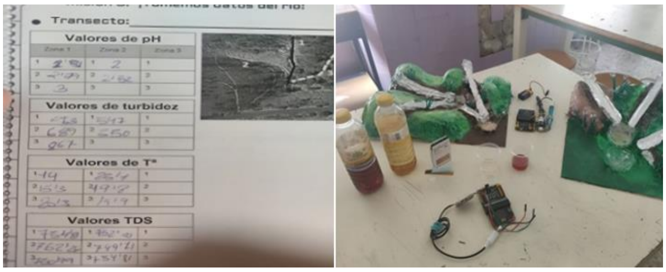

Figure 6. Physicochemical data of river taken at outlet with a diagram of area (left) & models created in class on schematic of Tinto River source for in-class experimentation with collected samples, showing pH strips, pH sensor, & total dissolved solids sensor (developed in project) (right) (Source: Authors' own elaboration)

pH and pOH scales. This was achieved by mixing waters with varying pH levels collected locally, making the logarithmic pH scale more comprehensible and functional to them. Students noted how minor changes in H_3O^+ concentration significantly affect pH, illustrating the logarithmic nature of the pH scale. They also worked with other physicochemical characteristics (not developed and explained in this paper, but also considered for the complete physicochemical characterization of the river) using sensors for temperature, turbidity, and conductivity. These relationships between different variables enabled a better characterization of the river and its environment.

SWOT analysis conducted in this study reveals insights into students' perceptions and interests regarding the instructional sequence, with a particular emphasis on the technological aspects used in the sequence. This feedback suggests that the integration of tools such as Micro Bit played a significant role in shaping students' engagement and perceptions of the learning process.

In its preparation, the opinion of the students was also considered through a post-test about the sequence and in the research notebooks, where they shared their evaluations and opinions regarding this project, which helps us in its analysis through a SWOT table (**Table 3**). The students' feedback, which included their views on both the appealing and challenging aspects of the activity, highlighted several key points. The following examples, extracted from their notebooks, reflect their perspectives on what they liked, disliked, and the problems they encountered during the activity they carried out:

> "It was super cool to program because it was very easy" (student 1 [strength]).
>
> "We understood the river's science when we measured it with the tools" (student 5 [strength]).
>
> "Building our own scientific tools was an amazing experience" (student 7 [opportunity]).
>
> "We loved painting and making the river model, and then measuring with the pH meter" (student 8 [opportunity]).
>
> "At first, I did not like it because it was very confusing with everyone working at the same time on a website, but then it went well" (opportunity).
>
> "My tablet always froze, and I had to start over again and again and I did not have enough time to finish" (student 17 [weakness]).
>
> "The internet was always going out and was very slow" (student 14 [weakness]).
>
> "We had to wait for the teacher to come over because the other teachers did not understand anything" (student 20 [threat]).

SWOT table highlights mostly positive aspects, which are closely related to the motivating and engaging way of introducing children to scientific approaches through new technologies. Similarly, it shows that facing something so new can become frustrating for many students. It is considered necessary for the process to be properly guided from the early stages of the sequence as well as in the initial contact with sensors and Micro Bit boards.

Collaborative work has been a weakness because students were not accustomed to working together in a coordinated manner. This aspect has evolved positively when they have seen their projects and models succeed.

The lack of time is a weakness that is related to the complexity of the sequence itself and is considered to be something that can be addressed with the proper collaboration of teachers from different areas in the preparation, design, and joint development of the project.

The threats relate to ensuring good internet connectivity, maintaining the sensors (with the pH sensor being quite fragile and complex to maintain, especially in terms of cleaning after use), and unsatisfactory collaboration between teachers, as they,

Table 3. Summary SWOT (strengths, weaknesses, opportunities, & threats) table analysis of experience

Variable	Values
Strengths	• No need for complex prior training • An engaging and fun way of learning • A way to learn to program from scratch • Intuitive and easily accessible tools • They create their own measuring tools • They learn science content with a level of abstraction in a meaningful way & developing computer skills
Weaknesses	• Lack of resources in schools • Fear of academic failure • Initially complex due to something entirely new and unfamiliar • Not accustomed to working in groups in multiplatform system • It can become frustrating and stressful at the beginning • Lack of time
Opportunities	• To be able to compare and learn from models to understand reality • It is a positive and motivating experience to promote scientific and technological vocations in students • Understanding the fundamental value of science • Promote collaborative work • Development of artistic/creative skills
Threats	• Need for good connectivity • Adequate maintenance • Limited collaboration among the teaching staff

despite assisting in the classroom, lacked knowledge about block programming or sensor usage.

Micro Bit boards and sensors were embraced with enthusiasm, serving as an additional motivation for the development of the unit, which, in its more traditional version, tends to be laden with passivity and student boredom. Its development and management could respond to the digital literacy needs demanded by today's society. These are carried out in a safe, responsible, and civic manner, covering the five competency areas related to the digital competence model presented in **Table 1**. However, it is also important to emphasize them as a threat because, despite the fact that the devices used do not have a very high price, not all educational centers have the financial and material resources to afford them.

CONCLUSIONS

Learning processes, phenomena, concepts, etc. through experimentation using inquiry and modeling approaches, where students combine theory with empirical data, could potentially constitute moments of rich learning. The joint development of these methods with CT, along with the construction and programming of measurement tools, appears to have been highly motivating, as suggested by the enthusiasm highlighted in students' field notebook comments. Particularly, the use of web applications, as well as the programming and utilization of sensors, were aspects most emphasized by students in their reflections.

Students had the opportunity to compare their initial conceptions of acidity and logarithmic scale variation, realizing that mixing pH values does not correspond to a linear scale. This was part of addressing the alternative conceptions mentioned in the introduction of this work. Through hands-on activities, their understanding was enhanced by constructing and programming digital tools for pH measurement and creating a small-scale Tinto River model. These activities emphasized the complexity of changing H3O+ concentration and proposed an engaging way to explore pH and pOH, set against the backdrop of Tinto River's scientific controversy regarding its preservation or restoration.

In terms of digital competence, the students worked on and processed scientific data and content through digital environments, creating their own data collection tools, which they shared and developed collaboratively. Additionally, they programmed the processes of their tools in blocks to address socio-scientific and environmental problems, identifying the need for technological solutions. All these activities would support the acquisition of a certain level of digital competence.

The combined use of three learning methods (inquiry, CT, and modeling) could become more relevant when applied in SSI contexts engaging with controversial topics or areas. This approach appears to stimulate students' engagement through questions they formulate, encouraging reflection and freedom in hypothesis testing. It seems that this method allowed for the assessment of students' argumentative skills and critical thinking and might have helped them understand complex natural phenomena and the role of physicochemical variables.

Implementing this method suggests that students took an active role in their learning, possibly enhancing understanding through reflection and exploration. The use of these resources seems to have facilitated data acquisition and broadened applicability to pH-related phenomena. Additionally, the selection of Tinto River as a learning context supports the idea that controversial heritages can serve as excellent settings for STEAM projects, demonstrating the educational value of integrating complex real-world issues into the curriculum.

Future analyses of video and audio recordings from this project might provide more insights, potentially helping to determine the depth of students' understanding and identify areas for improvement, thereby shaping future research to enhance teaching and learning sequences.

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Ethical statement: The authors stated that the study was approved by the institutional ethics committee of Universidad de Málaga on date October 30th, 2023 (Approval code: CEUMA: 98-2023-H) Written informed consents were obtained from the legal guardians of the participating children. The authors further stated that confidentiality and anonymity was ensured for all data collected during the study.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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