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https://www.jisem-journal.com/ **Research Article**

Sensors in the Teaching of Physics: A Methodological Proposal for Teaching the Basic Concepts of Sound with the Use of BBC Micro: Bit, Cyberpi and Arduino

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ABSTRACT

This work presents the first research results of the proposal made with secondary and middle education students, in the areas of physics and technology, where didactic sequences focused on experimental activities mediated by technological tools such as Arduino, Cyberpi and BBC micro: bit, under the STEM approach are presented. This was done using the PBL methodology, as well as the physical analysis of the characteristics of the instruments used, and their respective programming and analysis of results, based on computational thinking tools. This proposal aims to provide teachers with tools to include technological tools such as sensors in the classroom and use them as didactic alternatives for learning key concepts of physics, technology and programming.

Keywords: Arduino, Cyberpi, BBC micro:bit, STEM, Project-Based Learning.

INTRODUCTION

In the vast and dynamic field of education, the integration of technological tools has become a fundamental element for pedagogical innovation and the improvement of the teaching-learning process. The teaching of physics, as a discipline that seeks to explain natural phenomena and the underlying principles that govern our universe, is no stranger to this educational revolution. In an increasingly digitized world, it is imperative that educators explore and leverage the technological tools available (simulations, microcontrollers, new laboratory devices, etc.) to enhance the understanding of complex physical concepts and stimulate scientific curiosity in new generations.

The research developed delves into the analysis and development of a didactic strategy that specifically addresses the teaching of waves, with a prominent focus on mechanical waves and wave phenomena. Waves are a fundamental part of the world around us, and understanding their behavior is essential to understanding a wide range of natural phenomena, from sound and waves in water to vibrations in mechanical structures. In this context, the use of technological devices (microcontrollers), such as Arduino, Cyberpi and Microbit, is presented as a valuable resource to enrich the teaching of these concepts, allowing students to explore, experiment and understand the underlying principles in a practical and participatory way through a STEM approach and project-based methodology.

This research work is structured around three specific objectives. First, an exhaustive analysis of the relevant curricular proposals for the teaching of wave types was carried out, evaluating the suitability of the aforementioned technological tools and exploring pedagogical methodologies that could facilitate effective learning. A series of devices were then designed and built, such as radars and proximity or motion detectors, which served as practical tools to illustrate and experiment with wave concepts, applied to instruments such as proximity detectors or radars that are not alien to students.

Finally, evaluation models were explored that allowed measuring the gains of this proposal, with the use of a test designed, reviewed by experts, and on which the learning gain model of Hake (2001) and the parameters of the Rasch model were applied, with the Pretest and Posttest tools, which yielded positive evidence regarding the use of this methodological strategy. At the same time, a satisfaction interview was applied through focus groups, which allowed to know the perception of the students, regarding the methodology and their opinion regarding the possibilities of improvement of the proposal and its evaluation parameters. For the qualitative analysis of the responses, ATLAS.ti software, which is commonly used in educational research to analyze and understand the responses of a focus group, was used. ATLAS.ti allows researchers to analyze data in a systematic and structured way, identify patterns and relationships between data, and develop new theories and concepts.

This article presents in the first instance a conceptual development that focuses the reader on the role that action research plays in the development of scientific proposals within the classroom, highlighting the critical reflection of the teaching work and the new challenges towards which students must be led to face the challenges of the twenty-first century (Olivos 2011). under the reference of Project-Based Learning, where the essential characteristics that these must have, their development and their evaluation process are mentioned, which is supported by concrete proposals that lead to the end of learning (Muñoz, Gómez 2017). Finally, within the conceptual pillars, the STEM approach is addressed, highlighting its scope and fundamental characteristics. In the second part of the article, reference is made to the research process developed, explaining in a concise way, the components that the work guides must have for the proper development of the proposal and its evaluation process. And finally, the article presents a development of the results and conclusions to which the development of the research led and which resulted in the interest to write this document.

Through this work, it seeks to contribute to the enrichment of physics teaching and promote the effective adoption of ICT as pedagogical resources in the classroom. In addition, it is intended to offer educators and students an innovative and motivating perspective to address a field of study that is often perceived as challenging but fundamental in our understanding of the world around us.

CONCEPTUAL FRAMEWORK

Among the theoretical references on which the applied research proposal was based, there is a constructionist approach, Project-Based Learning, action research and the STEM approach.

The action research proposed by Stenhouse (1984) seeks to improve teaching practice through critical reflection and action (Gómez, 2016). In this proposal, the teacher becomes a researcher of his or her own educational practice, designing tools that allow him or her to identify difficulties in the classroom, posing challenges and interventions based on theory and evidence. These actions are implemented and evaluated through the measurement of the impact on the students and then the teacher uses this collected information to make decisions in the development of their micro-curricula. Action research requires a critical reflection on its own practice, and encourages teamwork collaboration between different teachers, exploring elements of interdisciplinarity and transdisciplinarity, ultimately, to achieve a constant improvement of teaching practice.

On the other hand, the student faces new ways of assimilating information, staging it in specific situations, agreeing to link technology in their development within the classroom and reflecting on their learning processes.

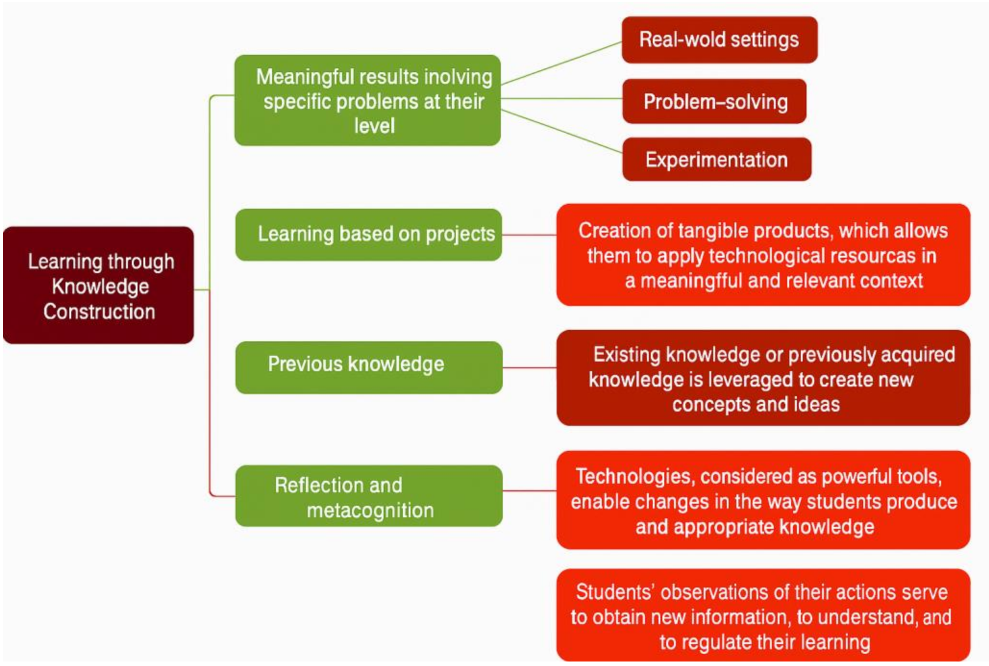


Fig. 1. Characteristics of constructionism Papert (1986).

Another reference is Project-Based Learning, where students work in groups to investigate a topic or problem of interest. These projects are often interdisciplinary and address real-world challenges, allowing them to apply knowledge and skills from various areas of the curriculum.

Projects are usually time-bound and divided into clear stages, including planning, research, implementation, and presentation of results. Its main characteristics are the significance that seeks to increase their motivation and commitment, the promotion of collaboration, autonomy and responsibility, the integration of knowledge from the use of the basic pillars of each subject to the development of concrete interdisciplinary elements that can be used to solve problems and achieve results.

Projects are based on authentic and meaningful situations that have relevance to students, increasing their motivation and engagement, where students work in teams to research, solve problems, and develop products or solutions. Collaboration fosters teamwork, effective communication, and the development of soft skills, as well as having some autonomy to make decisions about your project, set goals, and manage your time. This promotes accountability and the development of self-regulation skills, allowing them to connect and apply knowledge and skills from different areas of the curriculum, thus fostering interdisciplinary learning. Finally, students present and share their projects with their peers, teachers, or even wider audiences. This promotes effective communication and the development of presentation skills.

Assessment in Project-Based Learning focuses on the quality and level of mastery of the skills and knowledge acquired. It involves the observation and analysis of students' actions, interactions, and products. It is used to assess aspects such as depth of understanding, analytical and synthesis skills, creativity, critical thinking, and problem-solving skills. Qualitative assessment may also include verbal or written feedback, descriptive rubrics, and individual or group reflections (Thomas *et al.*, 1999).

This evaluation involves different aspects, among which are formative evaluation, through continuous processes of feedback by the teacher in group or individual scenarios, as he or she considers appropriate; the evaluation of the final product through a prototype, without ignoring the evaluation of the process that led to this result, in addition to the evaluation of the skills and competencies that each of the members of the work team have developed, and finally the process concludes with the evaluation of peers, where students can also participate in the evaluation of the projects of their classmates. This promotes accountability and collaborative learning among students, who can be provided with the assessment criteria so they know what they should focus on when evaluating the work of others.

The third theoretical reference element focused on the STEM approach created by *The National Science Foundation* (USA) as an acronym for *Science, Technology, Engineering* and *Mathematics* with which general reference was made to events, policies, projects or programs alluding to these areas. This approach seeks to promote professional vocations in careers based on science, technology, engineering or mathematics, in order to promote the productivity and competitiveness of economies, preparing students to face the challenges of the 21st century, promoting a deep understanding of scientific and mathematical concepts, as well as the practical application of technological and engineering skills, being able to relate and transfer knowledge to real-world situations, developing the necessary skills to address complex problems, work in multidisciplinary teams and avoid disjointed curricula. This approach is characterized by being practical and project-based, in which students participate in activities that allow them to explore, investigate, and solve authentic problems by fostering creativity, innovation, and critical thinking (Bybee, 2013).

THE RESEARCH PROCESS

The general objective of the research work focused on measuring the level of learning gain, the skill parameters and in turn the impact caused by the Project-Based Learning methodology, mediated through the STEM approach, with the use of sensors controlled by Cyberpi, Microbit and Arduino for the appropriation of the basic concepts of sound. focused on the analysis of technological artifacts, and aimed at tenth grade students contributing to gender equity in science teaching.

The specific objectives were to analyze the contents, means and methodologies with which a didactic strategy can be developed mediated by an ICT tool such as Arduino, Cyberpi or Microbit. Methodologically construct the didactic strategy that will be carried out in the classroom by implementing the design and construction of devices (radar, distance meters and audio amplitude detectors) with the use of sensors for the teaching of types of waves, emphasizing mechanical waves and wave phenomena. To characterize the evaluation models by knowing the level of effective Hake gain, the skill parameters of the Rasch model in accordance with the use of pre-test and post-test.

The proposal was applied during the years 2022 and 2023 to a sample of 243 students where 119 belonged to the control group. These students were part of the last two years of secondary education in the city of Bogotá, Colombia, in a district educational institution, within the areas of physics and technology, within a total population of 2680 students.

The evaluation instrument used for the construction and application of the pretest and posttest was taken from the validated research work of Baniol & Zavala (2019), based on the "*Mechanical Waves Conceptual Survey* (MWCS)" test developed by Tongchai *et al.* (2009); from which 12 questions were taken and worked on that addressed the topics of Propagation (Sound Variables, Sound Wave Speed, String Wave Speed, Displacement of the Medium in Sound Waves); Superposition (Superimposition – Construction, Superposition – Destruction); Reflection (Reflection-Fixed End, Reflection-Free End) and Standing Waves (Transverse Standing Waves in Strings, Longitudinal Standing Waves in Sound). Below is the distribution and organization of the questions according to the author.

Topic	Subtopic	Question	Concept Evaluated
Propagation	Sound variables	1	Interpretation of amplitude and frequency.
	Speed of sound waves	2	Speed in air independent of frequency.
	Speed of sound waves	3	Speed in air independent of frequency and amplitude.
	Speed of sound waves	4	Speed proportional to tension and independent of changes in hand movement.
	Speed of sound waves	5	Speed proportional to velocity and tension.
	Medium displacement in sound waves	6	Longitudinal oscillation of disturbed air particles.
		7	Increase in frequency.
		8	Increase in amplitude.

		9	Superposition of two waves during overlap.
Superposition and reflection	Superposition – construction	10	Superposition of two waves after overlap.
	Superposition – destruction, Reflection	11	Total reflection.
		12	Partial reflection.

Fig. 2. Topics addressed in the Tests and their distribution

The learning guides based on the concept of didactic unit highlight having a structure, for the development of activities and experiences in the classroom, a logical sequence with introduction, or contextualization of the topic, followed by exploration, explanation, practice and application activities and includes a series of key elements, such as learning objectives, the contents to be taught, the pedagogical strategies, the educational resources, the evaluation activities and the estimated time for each of the stages. These guides present the following application methodology based on the proposal of Jonassen (1997), cited by Martin & Martínez (2018).

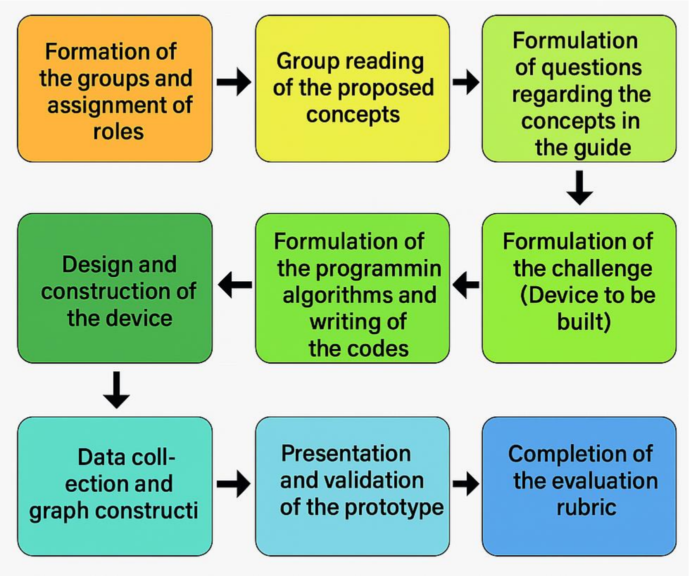


Fig. 3. Methodology for the application of the learning guides.

The elaboration of the guides has a complex framework that starts from the description of the concepts, the presentation of different sources and resources for consultation and deepening, not only of the physical concepts implicit for the corresponding activity, but also involves the theory around the technological applications, characteristic analysis, operation and experimental theoretical foundations of the devices used. especially of the sensors of each experimental object. On the other hand, the guides describe the mechanical and electrical modeling of the experimental constructions and, of course, the programming indications for the different microcontrollers that were found as a resource inside the classroom. It is important to note that, according to the expertise of each of the groups, the students chose to program with Arduino through open source or with Micro: bit or Cyberpi through blocks, allowing the students to adapt better to the process and not find in programming a problem when carrying out their experimental process. This programming stage includes the description and explanation of the variables with respect to the modeling equations.

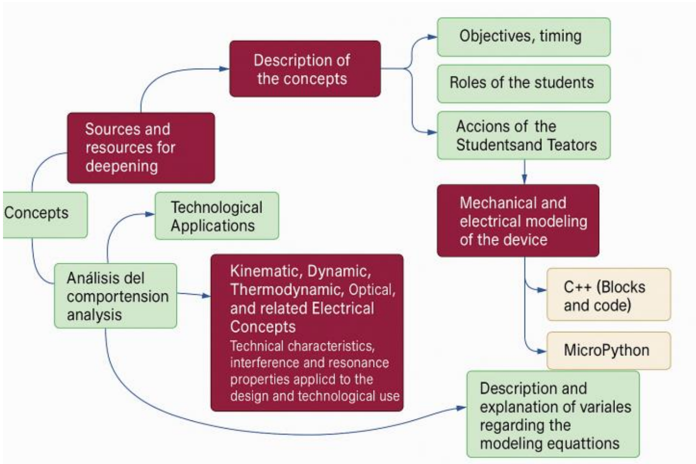


Fig. 4. Structure of the teaching units.

As a concrete example, a practice was carried out that consisted of the construction of a radar, addressing the concepts of mechanical waves, sound and ultrasound, concept of frequency, wavelength, amplitude and speed of propagation. Along with these concepts, ideas regarding transducers and their applications in technology, industry and medicine were worked on. On the other hand, the modeling of the propagation velocity equation of a wave through code in C++ was worked on, from the previous ideas of pulse generation for firing the piezoelectric of the HCSR04 sensor, and finally to obtain graphs of emitted and reflected waves for their corresponding mathematical physical analysis.

Below is an outline of the contents of the example guide.

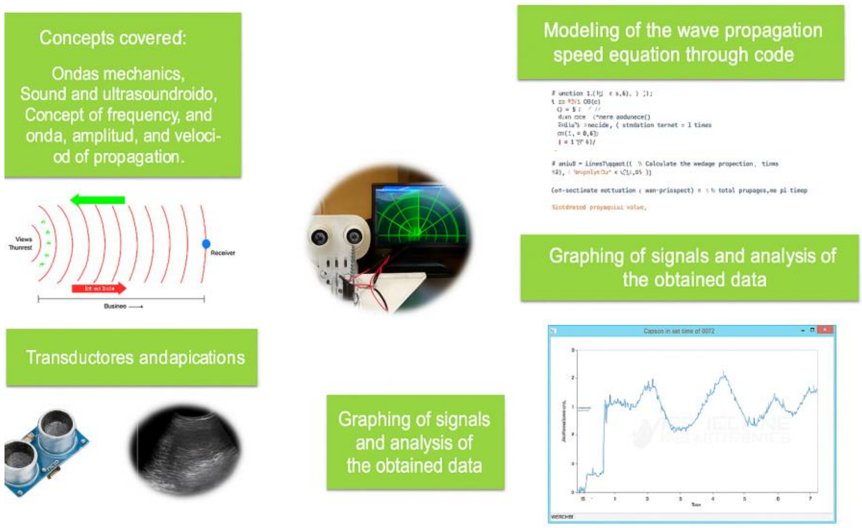


Fig. 5. Example of the elements addressed in the ultrasound guide.

Each of the stages of the experimental work by the students is evaluated through an evaluation rubric provided by the educational institution for the area of science and technology, where the process, teamwork, management of concepts, programming skills, design skills, etc. and prototyping and data collection, representation and analysis.

RESULTS

Through the statistical analysis of Hake's gain factor, it was sought to measure the learning evolution of a population of students divided into two groups, the control group and the group that experienced the intervention and application of the research work, allowing to determine if the teaching and learning methodology was effective for the students. Learning gain (g) is defined as the ratio of the increase of a pre-test and a post-test with respect to the maximum possible (Hake, 1998).

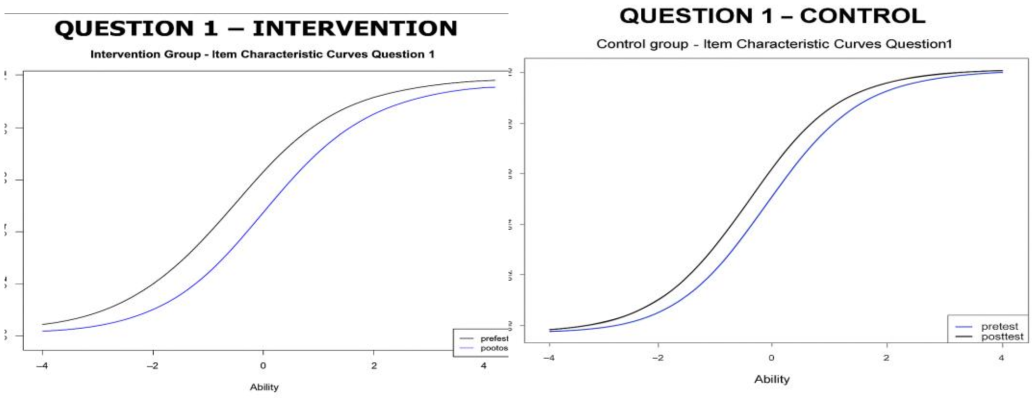
$$g = \frac{postest(\%) - pretest(\%)}{100 - pretest(\%)}$$

Through quantitative processes, the level of Hake's learning gain was measured, where on average a result of g = 0.72% was obtained for the entire experimental group, with an average of 84.5% of correct answers in the post-test compared to 45.6% in the pretest, which shows a significant improvement after the application of the methodological proposal.

It should be noted that questions 3, 7, 8, 9 were cataloged by Baniol & Zavala (2019), with a high level of difficulty where in that study, the population obtained 40 or less of correct percentage, and that in this study according to the statistical factor, they ended up at a medium level of gain. It is also noted that the validated test included question 6, but that, for this study, it had a gain of 0.77% for a high level.

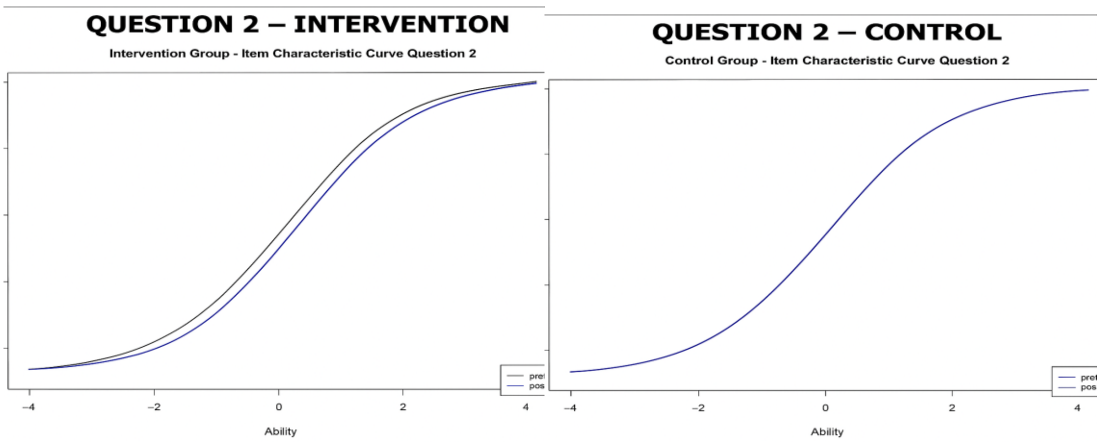
Question Number	**Percentage of Correct Answers in the Pretest**	**Percentage of Correct Answers in the Posttest**	**Hake Factor**	**Gain Level**
1	50.4	86.7	0.73	High
2	40.0	92.4	0.87	High
3	48.0	79.5	0.60	Medium
4	46.35	89.3	0.80	High
5	55.8	91.4	0.81	High
6	52.5	89.1	0.77	High
7	48.1	77.3	0.56	Medium
8	34.6	76.3	0.64	Medium
9	41.3	72.4	0.53	Medium
10	49.2	87.5	0.75	High
11	37.1	87.3	0.80	High
12	43.5	84.4	0.72	High
Average Values (%)	**45.6**	**84.5**	**0.72**	**High**

The skill parameters were also measured for each of the questions, where comparing the analysis curves it is concluded that there was a clear advance in the level of probability of answering the questions correctly for the post-test phase, however, the individual numerical record of the students' progress is kept in the lists of ease parameters. which were obtained with the Rasch() function of the LTM library, and which were then used to make the graphical representation in the form of the curves of the same items of the test, for the pre-test phases, and for the post-test, where individual analyses must be carried out to find the variables and associated factors for each of the students where the study is to be deepened. The graph for question 1 is shown as an example below, corresponding to the interpretation of the concepts of amplitude and frequency.



A. B.

For question 2 referring to the topic of frequency-independent air speed, the following curves were obtained:



The results are visually encouraging, even if, for example, in question 2 a large increase is not visualized, for the other questions, the increase was noticeable since there is a progress that can be considered significant between the CCI curves of the pretest and the CCI of the posttest.

In terms of the categories found through the analysis with the ATLAS.ti software, we want to highlight the following conclusions around the main codes:

Enthusiasm for Technology: Most of the responses express a remarkable level of enthusiasm and fascination for the use of Microbit, Cyberpi and Arduino in addressing the issue of sound.

Hands-on Learning: A general appreciation for the hands-on approach offered by Microbit and Arduino is highlighted. The students value the opportunity to directly apply the theoretical concepts, indicating that this facilitates the understanding and retention of sound-related topics.

Technological Empowerment: A feeling of empowerment emerges among students when using devices such as Microbit, Cyberpi and Arduino. The ability to program and build their own devices has led to a significant increase in participants' confidence in their technological skills.

Creativity and Customization: The ability to customize sound-related projects using Microbit and Arduino has been highlighted repeatedly. Students appreciate the freedom to express their creativity and tailor projects to their individual interests, which has contributed to a more meaningful learning experience.

Emerging Thematic Nuclei:

Motivation and Active Participation: Most participants manifest an increase in motivation to participate in sound-related activities when Microbit and Arduino are incorporated. This factor has led to more active participation compared to traditional methods.

Development of Technological Skills: There is a general consensus on the significant development of technological skills. The students feel that the experience with Microbit and Arduino has provided them with an understanding. ATLAS.ti's analysis reveals that students express a positive receptivity to the use of Microbit and Arduino in the teaching of sound. Enthusiasm, appreciation of hands-on learning, technological empowerment, and the ability to personalize emerge as key factors that contribute to a richer educational experience. These findings support the effectiveness of integrating technologies in physics teaching, highlighting the importance of innovative approaches to foster student participation and interest in learning scientific concepts.

CONCLUSIONS

We can suggest that the proposed strategy becomes an important didactic methodology for this case study. In turn, the impact caused by the PBL methodology, mediated through the STEM approach, can be given as a conclusion, and point of discussion, the following elements to be considered:

The integration of technologies such as Arduino, Cyberpi and Microbit offered a valuable contribution to improving the teaching-learning processes in physics for children. These platforms enabled practical and interactive experiences, allowing students to build and program devices, and on them to carry out an analysis of properties and physical characteristics of devices, which in turn contributed to Active and Participatory Learning. The visualization of abstract concepts, such as sound waves, was facilitated, and the linking of physics with technology provided practical applications, increasing the interest of the students, evidenced in the answers offered in the interviews carried out through the different focus groups. In addition, the development of technological skills from an early age prepares students for future STEM careers, while the versatility and adaptability of these technologies allow for a personalized approach. Together, these advantages not only motivate and engage students, but also transform physical education, making it more relevant, exciting, and preparing them for the technological world of the future. The application of didactic units with the Project-Based Learning (PBL) methodology and under the STEM approach, emerges as a highly effective alternative to improve the understanding of the physical concepts of sound in the context of the application of research work, evidenced in the results of the ICFES saber tests of the years 2022 and 2023 in the areas of science, specifically with regard to the subject of physics in its own concepts of sound. By contextualizing these principles in real-world projects, students actively participated in the construction of devices, connecting theory with practical applications and evidencing the concepts, and appropriating them in a better way as they evidence the contrast between the pre-test and post-test application tests. The interdisciplinarity of PBL, together with collaboration between students, fostered a more complete and connected understanding of sound phenomena. The creativity and personalization inherent in the projects increased motivation and commitment, while the comprehensive evaluation addressed both theoretical knowledge and practical application when testing their knowledge and also collaborative work. In addition, ABPr developed key skills such as problem-solving and critical thinking, preparing students to face challenges in innovative ways.

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