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Inquiry-Based Teaching of Acids and Bases in Basic Education: A Contextualized, Low-Cost Approach Grounded in the Three Pedagogical Moments

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Abstract

This study analyzes a pedagogical intervention addressing the teaching and learning of acids and bases, conducted within the scope of the Institutional Teaching Initiation Scholarship Program (PIBID) at a public full-time high school in São Luís, Maranhão, Brazil. In response to the limited availability of fully equipped school laboratories, a thematic workshop was developed based on the Three Pedagogical Moments and Critical Meaningful Learning Theory. Aqueous extracts of red cabbage (Brassica oleracea var. capitata f. rubra) and black beans (Phaseolus vulgaris) were used as natural acid-base indicators and compared with universal pH test strips. Formative assessment and teacher-mediated inquiry were used to monitor students' hypotheses, observations, explanations, and conceptual development throughout the intervention. The activities enabled students to reconsider intuitive conceptions, particularly the association of acidity exclusively with corrosiveness, and to establish relationships between observable phenomena and scientific concepts such as pH, neutralization, and the chemical properties of everyday substances. The findings highlight the feasibility and pedagogical potential of inquiry-based experimentation using low-cost materials, particularly when integrated with structured pedagogical approaches and continuous teacher mediation in public-school science education.

Keywords: Chemistry teaching; Acids and bases; Didactic sequence; Three pedagogical moments; Natural pH indicators; Critical meaningful learning; PIBID.

1. INTRODUCTION

Chemistry teaching in basic education frequently faces systemic and structural challenges, including the prevalence of passive, lecture-based instruction, extensive curricula disconnected from students' everyday experiences, and limited access to adequately equipped school laboratories. Such conditions may reduce student engagement and hinder the development of scientifically grounded conceptual understanding [1,2].

To address these limitations within a public high school located in an economically vulnerable community in São Luís, Maranhão, this intervention was grounded in the theory of meaningful learning proposed by Moreira [1]. From this perspective, learning becomes meaningful when new knowledge is related in a non-arbitrary and substantive manner to the learner's existing cognitive structure. In science education, this perspective is particularly relevant because students' prior conceptions and everyday experiences can serve as important starting points for the construction and restructuring of scientific knowledge.

The teaching of Acids and Bases is particularly challenging because it requires students to move between macroscopic observations, submicroscopic explanations, and symbolic representations. [3] At the macroscopic level, students encounter observable phenomena such as color changes in acid-base indicators, whereas the submicroscopic level requires them to reason about unobservable entities and processes involving ions, molecules, and chemical equilibria. At the symbolic level, these phenomena must be represented through chemical formulas, equations, and other formal representations. Coordinating these different levels can pose substantial conceptual challenges for students and may contribute to difficulties in understanding abstract chemical concepts, such as acidity, basicity, pH, ionization, dissociation, and neutralization therefore require pedagogical strategies capable of connecting observable phenomena with theoretical and symbolic representations.

In this context, experimental activities can provide an important pedagogical bridge between observable phenomena and scientific explanations. Rather than functioning merely as demonstrations, inquiry-based experiments can encourage students to formulate hypotheses, observe and interpret evidence, construct explanations, and relate experimental observations to chemical concepts. This approach is particularly relevant in public-school contexts where conventional laboratory infrastructure may be limited, as low-cost and alternative materials can expand opportunities for meaningful experimental learning [2,4].

The topic of Acids and Bases offers an especially productive context for this approach because of its ubiquitous presence in everyday life, including human physiology, food chemistry, household products, and socio-environmental processes. Its teaching can therefore connect scientific concepts with familiar situations while providing opportunities for students to investigate phenomena and develop explanations grounded in chemical knowledge. The use of experimental activities also creates opportunities to move from concrete observations toward the conceptual and symbolic representations required for understanding chemical processes. [2,3]

To organize this learning process, the intervention employed the Three Pedagogical Moments proposed by Delizoicov, Angotti, and Pernambuco [5], comprising Initial Problematization, Knowledge Organization, and Knowledge Application. This framework provides a structure through which students' everyday experiences and prior conceptions can be problematized, scientific knowledge can be systematically organized, and the newly constructed knowledge can subsequently be applied to situations beyond the initial problem. Such an organization is consistent with a meaningful learning perspective because it creates opportunities for students to establish relationships between new scientific concepts and their existing cognitive structures. [1,5].

In addition to the construction of conceptual knowledge, the assessment of students' learning requires attention to how knowledge develops throughout the instructional process. Assessment should not be restricted to the measurement of final performance but can also serve as a means of monitoring and regulating learning, allowing teachers to identify students' difficulties and adjust pedagogical interventions accordingly. [5] In this sense, the analysis of students' responses throughout the workshop can provide evidence of changes in their conceptual understanding and of the ways in which the proposed activities contributed to the learning process.

Therefore, the primary objective of this paper is to analyze the development of high school students' conceptual understanding during an inquiry-based thematic workshop on Acids and Bases, structured according to the Three Pedagogical Moments and implemented using low-cost, alternative experimental materials in a public-school context.

2. THEORETICAL-METHODOLOGICAL FRAMEWORK

2.1 The Three Pedagogical Moments (3PM)

The instructional design was organized according to the Three Pedagogical Moments proposed by Delizoicov, Angotti, and Pernambuco [5], comprising three interconnected stages:

- Initial Problematization: Real-world situations and questions were presented to challenge students and elicit their prior knowledge, conceptions, intuitive explanations, and questions concerning acids and bases.
- Knowledge Organization: The scientific knowledge required to understand the problems raised during the initial stage was systematically developed through guided discussion and theoretical formalization.
- Knowledge Application: Students applied the newly organized scientific knowledge to experimental situations and new problems, using evidence obtained from the activities to evaluate their initial hypotheses and construct scientifically grounded explanations.

2.2 Formative Assessment and Regulation of Learning

In contrast to an assessment approach focused exclusively on final performance, the intervention incorporated formative assessment throughout the instructional process. [6] Students' learning was monitored through their participation in discussions, formulation and revision of hypotheses, written records in the experimental worksheets, interpretation of experimental observations, and argumentation during the activities. These elements provided opportunities to identify difficulties, monitor the development of students' conceptual understanding, and regulate the learning process.

Diverging from traditional summative assessment, this study adopted a formative assessment model. [6] Student progress was monitored continuously, focusing on the regulatory mechanisms of learning: observing active participation, analyzing written hypotheses in lab worksheets, and evaluating argumentation during experimental trials.

3. METHODOLOGICAL PROCEDURE

The intervention was conducted with second-year high school students at Centro Educa Mais Dayse Galvão de Sousa, a public school located in São Luís, Maranhão, Brazil. The thematic workshop was structured according to the Three Pedagogical Moments and developed through three interconnected phases. [5]

1. Initial Problematization - The workshop began with questions intended to stimulate students' prior knowledge and problematize their everyday conceptions of acids and bases, including: *"What defines an acid or a base?"* and *"Are all acids and bases inherently corrosive?"* Students were encouraged to discuss their initial ideas and record their hypotheses before the theoretical and experimental activities.

2. Knowledge Organization - The subsequent stage involved the systematic organization of the scientific knowledge necessary to interpret the phenomena investigated in the workshop. The teacher-mediated discussions addressed the Arrhenius concept of acids and bases, pH and pOH, acid-base indicators, and the relationship between chemical properties and everyday substances. Examples included hydrochloric acid associated with gastric juice, citric acid in citrus fruits, and sodium hydroxide in caustic soda.

3. Knowledge Application–Inquiry-Based Experimental Workshop - In the final stage, students worked in small groups and investigated the acid-base properties of accessible materials using low-cost experimental resources (Figure 1). The materials included:

- Natural indicators: aqueous extracts prepared from red cabbage and black beans, used to investigate color changes under different chemical conditions;
- pH reference: universal pH test strips, used as a comparative reference for the natural indicators;
- Everyday acidic and basic samples: citrus fruit juice, household vinegar, carbonated soft drink, and a diluted sodium hydroxide solution prepared from commercial caustic soda;
- Experimental containers: transparent plastic cups and laboratory glassware for holding and comparing the samples;
- Additional materials: plastic bottles and other low-cost containers used for preparing, storing, and handling the indicator extracts and solutions.

Students systematically tested the selected substances with the natural indicators and universal pH strips, recorded the resulting color changes, compared the responses obtained with the different indicators, and interpreted the observations based on the concepts developed during the Knowledge Organization stage. The students were also encouraged to compare their experimental evidence with their initial hypotheses and to justify their conclusions using appropriate scientific concepts.

Figure 1. Materials and experimental resources used in the inquiry-based acid-base workshop.

4. RESULTS AND DISCUSSION

4.1 Deconstruction of Alternative Conceptions

During the Initial Problem-Posing phase, students expressed intuitive conceptions about acids and bases, including statements such as “An acid is anything that corrodes or burns” and “A base is something I cannot define.” These responses revealed that students’ initial understanding was strongly associated with the observable effects and everyday uses of chemical substances rather than with their chemical properties.

The teacher’s mediation was essential in transforming these initial statements into opportunities for conceptual development. Instead of immediately correcting the students’ responses, the instructor introduced counterexamples and posed additional questions, such as whether the citric acid naturally present in fruits produces the same corrosive effects commonly associated with strong mineral acids. This strategy encouraged students to reconsider their initial assumptions and establish distinctions between the concepts of acidity, chemical reactivity, concentration, and hazardousness.

The observed transition is consistent with the perspective of meaningful learning proposed by Moreira [1], in which new knowledge is constructed through relationships with elements already present in the learner’s cognitive structure. In this process, the teacher does not simply replace an incorrect conception with a scientifically correct definition. Rather, the teacher creates conditions in which students can examine the explanatory limits of their initial conceptions and reorganize them in light of new evidence and conceptual relationships. [7,8]

4.2 Low-Cost Experimentation as an Inquiry Tool

During the experimental activities, the red cabbage extract exhibited pronounced color changes under different chemical conditions, ranging from pink/red in acidic media to green/yellow in basic media. The black bean extract was used as a complementary natural indicator, allowing students to compare the responses of different plant-derived pigments. Universal pH test strips provided an additional reference for comparing the qualitative color changes observed with the natural indicators.

The pedagogical value of this activity extended beyond the simple observation of color changes. Students were required to compare evidence obtained from different materials, identify patterns, and relate these observations to the concepts discussed during the Knowledge Organization stage. The comparison between natural indicators and universal pH strips therefore created an opportunity to connect macroscopic observations with chemical explanations and symbolic representations, an important aspect of chemistry learning. [5]

Importantly, the effectiveness of the experimental activity cannot be attributed solely to the use of low-cost materials. The materials became pedagogically meaningful because the teacher structured the activity around questions, hypotheses, observations, comparisons, and explanations. Thus, the experiment functioned not merely as a demonstration but as an inquiry tool mediated by teacher intervention. [7]

During the chromatic testing, the red cabbage extract demonstrated sharp color transitions (pink/red in acidic media; green/yellow in basic media). The black bean extract served as a parallel comparative element for scientific validation. By cross-checking the color shifts of natural indicators against the quantitative scale of the universal pH paper, students verified the qualitative reliability of plant-derived pigments. This comparative trial reinforced their understanding of the scientific method as a rigorous process of hypothesis testing and empirical verification. [4]

4.3 The Teacher as Mediator: Beyond Scientific Knowledge

One of the most significant aspects observed during the intervention was the role of the teacher as mediator between students, experimental phenomena, and scientific knowledge. [9] The activity demonstrated that effective teaching requires more than mastery of the scientific content itself. The teacher must also know how to select examples, formulate questions, anticipate students' difficulties, interpret their responses, organize interactions, and determine when to intervene and when to allow students to construct explanations independently.

This dimension can be understood through Shulman's concept of Pedagogical Content Knowledge (PCK), which emphasizes the specific knowledge required to transform subject matter into forms that are accessible and meaningful to learners [10]. From this perspective, knowing the chemistry of acids and bases is necessary but insufficient for teaching the topic effectively. The teacher must also understand how students are likely to interpret concepts such as acidity, pH, corrosion, and neutralization, and must select representations, analogies, questions, experiments, and explanations capable of addressing these difficulties. PCK therefore constitutes a form of professional knowledge situated at the intersection of scientific content, pedagogy, and knowledge of learners.

The intervention also highlighted the relational dimension of teaching. Unlike professional activities in which interactions with clients or users may be brief or highly variable, school teaching is characterized by sustained and repeated interaction with the same group of learners. The teacher works with students not only through isolated encounters but through an ongoing process of coexistence, dialogue, observation, feedback, and adjustment. Tardif and Lessard conceptualize teaching precisely as a profession of human interactions, in which the relationship with students is not peripheral to the work but constitutes one of its central dimensions. [9]

This aspect became particularly evident during the experimental activities. Students did not respond uniformly to the same questions or observations. Some groups required additional questioning to move beyond descriptions of color changes, while others were able to formulate explanations with less intervention. The teacher therefore had to continuously adjust the level and type of mediation according to the responses emerging from each group. Such adjustment requires not only knowledge of chemistry and pedagogical strategies but also familiarity with the students and sensitivity to their ways of communicating, reasoning, and participating.

Consequently, teacher mediation should not be understood as the simple transmission of scientific information. It involves a dynamic process in which the teacher interprets students' ideas, identifies conceptual difficulties, creates productive cognitive challenges, and regulates the progression from everyday explanations toward scientific reasoning. The experiment provides the empirical context, but the teacher's intervention determines, to a considerable extent, whether students merely observe a phenomenon or use that phenomenon as a basis for constructing an explanation. [7-10]

4.4 Interdisciplinary Connections and Process-Oriented Assessment

The hands-on activities also promoted connections beyond the immediate content of Chemistry. In Biology, discussions addressed physiological pH regulation and the role of acidic environments in processes such as digestion. In relation to health and everyday life, the activity provided an opportunity to discuss the risks associated with handling corrosive household products, particularly sodium hydroxide-based caustic soda. The discussion therefore extended the chemical concepts beyond the laboratory context and connected them with situations that students could recognize in their daily lives.

The formative assessment process operated simultaneously with these activities. Rather than being restricted to a final measurement of achievement, assessment was incorporated into the ongoing interaction between teacher and students. Students' hypotheses, questions, experimental records, explanations, and oral arguments provided evidence that could be used to identify difficulties and guide subsequent interventions. In this sense, the teacher's questions served not only to stimulate inquiry but also as instruments for monitoring students' conceptual development.

As emphasized by Perrenoud [6], formative assessment can assume a regulatory function when information about students' learning is used to adapt teaching to their needs. In the present intervention, this regulation occurred through real-time mediation: the instructor did not immediately provide answers when students encountered difficulties, but instead used guiding questions and peer discussion to encourage students to reconsider their interpretations and justify their conclusions with experimental evidence.

The results therefore suggest that the pedagogical effectiveness of the workshop resulted from the interaction among three elements: accessible experimental materials, a theoretically structured instructional sequence, and continuous teacher mediation. None of these elements should be considered independently. Low-cost materials increased the feasibility of experimentation, the Three Pedagogical Moments organized the progression of learning, and teacher mediation connected students' observations and prior conceptions with scientific knowledge.

5. CONCLUSION

The implementation of the thematic activity demonstrated that the absence of a fully equipped chemistry laboratory does not necessarily constitute an insurmountable barrier to inquiry-based science teaching. The deliberate pedagogical use of accessible materials, including red cabbage and black bean extracts, enabled students to investigate acid-base phenomena through direct observation, comparison, and discussion. When integrated into the Three Pedagogical Moments, these activities provided opportunities for students to relate everyday experiences to scientific concepts and to reconsider their initial conceptions.

The findings also indicate that the pedagogical value of low-cost experimentation cannot be attributed to the materials themselves. Their educational potential emerged from the way in which the teacher organized the experimental situations, formulated questions, interpreted students' responses, and mediated the transition from everyday explanations to scientific reasoning. In this sense, the teacher's role extends beyond scientific content knowledge to encompass pedagogical content knowledge, classroom interaction, formative assessment, and the continuous adaptation of instructional strategies to students' responses.

The relational dimension of teaching is equally relevant. The intervention illustrates that teaching is a profession grounded in sustained interaction with learners, in which knowledge of students is progressively constructed through dialogue, observation, feedback, and shared classroom experiences. The teacher's familiarity with students and with their ways of reasoning and participating can therefore become an important pedagogical resource, allowing interventions to be adjusted in real time and making scientific knowledge more accessible and meaningful.

Finally, this study highlights the contribution of teacher-initiation programs such as PIBID to teacher education. By placing future teachers in sustained contact with the realities of public-school education, such programs can provide opportunities to develop not only scientific and pedagogical knowledge but also the relational and reflective competencies required for teaching practice. The experience described here suggests that meaningful science education depends not simply on access to equipment or on the adoption of innovative methodologies, but on the capacity of teachers to integrate scientific knowledge, pedagogical strategies, assessment, and sustained dialogue with learners.

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REFERENCES

[1] Moreira MA. Aprendizagem significativa: a teoria e textos complementares. São Paulo: Livraria da Física, 2012.

[2] Santana SLC, Freitas MR, Rocha JS, et al. O ensino de ciências e os laboratórios escolares no Ensino Fundamental. VITTALLE 2019; 31(1): 15-26

[3] Johnstone, A.H. Why is science difficult to learn? Things are seldom what they seem. Journal of Computer Assisted Learning, 1991; 7: 75-83.

[4] Monteiro, P.; Rodrigues, M.; Santin Filho, O.; Batista, M. Ácidos e bases no cotidiano: uma proposta de experimento investigativo para o ensino médio. Revista Prática Docente. 2019; 4. 227-241.

[5] Delizoricov D, Angotti JA, Pernambuco MM. Metodologia do ensino de ciências. São Paulo: Cortez 1990.

[6] Perrenoud P. Avaliação: da excelência à regulação das aprendizagens entre duas lógicas. Porto Alegre: Artmed 1999.

[7] Farias, RF. Química, Ensino e Cidadania: pequeno manual para professores e estudantes de prática de ensino. 2ª. Ed. São Paulo: Edições Inteligentes, 2005.

[8] Pavan, R. F.; Freitas, M. R.; Rocha, J. S. Oficina temática sobre ácidos e bases: uma proposta para construção do conhecimento científico. Revista Brasileira de Ensino de Química, 2019; 11, 2, 45-56.

[9] Zabala, A. A prática educativa: como ensinar. Porto Alegre: Artmed, 1998.

[10] Shulman, L. Those who Understand: Knowledge Growth in Teaching. Journal of Education. 2017: 193. 1-11.