

FUEL QUALITY ANALYSIS AS A TOOL FOR SCIENTIFIC LITERACY IN CHEMISTRY EDUCATION

ANÁLISE DA QUALIDADE DE COMBUSTÍVEIS COMO FERRAMENTA PARA A
ALFABETIZAÇÃO CIENTÍFICA NO ENSINO DE QUÍMICA

EL ANÁLISIS DE LA CALIDAD DE LOS COMBUSTIBLES COMO HERRAMIENTA
PARA LA ALFABETIZACIÓN CIENTÍFICA EN LA ENSEÑANZA DE LA QUÍMICA

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ABSTRACT

Chemistry education in Brazilian public high schools faces persistent challenges related to the abstract nature of scientific concepts, limited laboratory infrastructure, and students' difficulties connecting theoretical knowledge with everyday experiences. This qualitative study reports a university extension project developed by the State University of Rio de Janeiro (UERJ) that employed contextualized fuel quality analysis as a pedagogical strategy to promote scientific literacy and citizenship among 102 public high school students (ages 15–17) across two schools. Grounded in Ausubel's meaningful learning theory and Science-Technology-Society (CTS) frameworks, the four-week intervention integrated theoretical discussions, hands-on experimentation (ethanol content determination in gasoline via phase separation), and reflective debates on Brazil's energy matrix, fuel adulteration, sustainability, and consumer rights. Data were collected through participant observation, semi-structured field notes, and student written reflections, analyzed via thematic analysis. Results revealed three major themes: heightened scientific curiosity; conceptual understanding of molecular polarity, intermolecular forces, and solubility; and emerging citizenship awareness regarding consumer rights and scientific decision-making. Findings demonstrate that contextualized experimentation anchored in socially relevant issues can simultaneously advance conceptual learning and critical citizenship competencies.

Keywords: Chemistry Education. University Extension. Scientific Literacy. Scientific Citizenship. Fuel Quality. Contextualized Learning.

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RESUMO

O ensino de química nas escolas públicas brasileiras enfrenta desafios persistentes relacionados à natureza abstrata dos conceitos científicos, infraestrutura laboratorial limitada e dificuldades dos estudantes em conectar conhecimento teórico com experiências cotidianas. Este estudo qualitativo relata um projeto de extensão universitária desenvolvido pela Universidade do Estado do Rio de Janeiro (UERJ) que empregou análise contextualizada da qualidade de combustíveis como estratégia pedagógica para promover letramento científico e cidadania entre 102 estudantes de ensino médio público (15–17 anos) em duas escolas. Fundamentado na teoria da aprendizagem significativa de Ausubel e nos referenciais Ciência-Tecnologia-Sociedade (CTS), a intervenção de quatro semanas integrou discussões teóricas, experimentação prática (determinação do teor de etanol na gasolina via separação de fases) e debates reflexivos sobre matriz energética brasileira, adulteração de combustíveis, sustentabilidade e direitos do consumidor. Os dados foram coletados por observação participante, notas de campo semiestruturadas e reflexões escritas dos estudantes, analisados via análise temática. Os resultados revelaram três temas principais: curiosidade científica intensificada; compreensão conceitual de polaridade molecular, forças intermoleculares e solubilidade; e consciência cidadã emergente sobre direitos do consumidor e tomada de decisão científica. Os achados demonstram que experimentação contextualizada ancorada em questões socialmente relevantes pode simultaneamente avançar aprendizagem conceitual e competências de cidadania crítica.

Palavras-chave: Ensino de Química. Extensão Universitária. Alfabetização Científica. Cidadania Científica. Qualidade de Combustíveis. Aprendizagem Contextualizada.

RESUMEN

La enseñanza de química en las escuelas públicas brasileñas enfrenta desafíos persistentes relacionados con la naturaleza abstracta de los conceptos científicos, infraestructura de laboratorio limitada y dificultades de los estudiantes para conectar conocimiento teórico con experiencias cotidianas. Este estudio cualitativo reporta un proyecto de extensión universitaria desarrollado por la Universidad del Estado de Río de Janeiro (UERJ) que empleó análisis contextualizado de calidad de combustibles como estrategia pedagógica para promover alfabetización científica y ciudadanía entre 102 estudiantes de escuela secundaria pública (15–17 años) en dos escuelas. Fundamentado en la teoría del aprendizaje significativo de Ausubel y marcos Ciencia-Tecnología-Sociedad (CTS), la intervención de cuatro semanas integró discusiones teóricas, experimentación práctica y debates reflexivos. Los resultados revelaron tres temas principales: curiosidad científica intensificada; comprensión conceptual de polaridad molecular, fuerzas intermoleculares y solubilidad; y conciencia ciudadana emergente sobre derechos del consumidor y toma de decisiones científicas. Los hallazgos demuestran que la experimentación contextualizada puede simultáneamente avanzar aprendizaje conceptual y competencias de ciudadanía crítica.

Palabras clave: Enseñanza de Química. Extensión Universitaria. Alfabetización Científica. Ciudadanía Científica. Calidad de Combustibles. Aprendizaje Contextualizado.



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INTRODUCTION

Chemistry education in Brazilian public high schools confronts persistent pedagogical challenges that compromise both conceptual understanding and the development of scientific citizenship. The abstract nature of chemical concepts, particularly molecular structure, intermolecular forces, and solution chemistry, creates significant barriers for adolescent learners attempting to construct meaningful connections between classroom instruction and lived experience (Santos & Schnetzler, 2015). This disconnect is exacerbated by systemic constraints including limited laboratory infrastructure and teacher training that often emphasizes content transmission over inquiry-based pedagogy (Chassot, 2018). Consequently, many students perceive chemistry as an isolated body of decontextualized facts rather than a powerful lens for understanding sociotechnical issues in their communities.

Contemporary frameworks for scientific literacy emphasize that effective science education must transcend disciplinary knowledge acquisition to cultivate critical competencies for informed citizenship (Bybee, 1997; OECD, 2015). Scientific literacy encompasses not only conceptual understanding but also the capacity to evaluate scientific claims, participate in evidence-based decision-making, and recognize the reciprocal relationships among science, technology, and society (Hodson, 2014). In Brazil, where fuel adulteration represents a widespread consumer protection issue with direct implications for environmental sustainability and public health, fuel quality analysis offers a pedagogically rich context for integrating chemical concepts with citizenship development.

The present study reports a four-week university extension intervention that employed contextualized fuel quality analysis to promote scientific literacy among public high school students. The intervention was grounded in Ausubel's meaningful learning theory, which emphasizes connecting new knowledge to students' existing cognitive structures through relevant contexts (Ausubel, 2000), and Science-Technology-Society (CTS) approaches, which position scientific learning within broader social, economic, and ethical dimensions (Aikenhead, 2006). By integrating hands-on experimentation with reflective discussions on Brazil's energy matrix, regulatory standards, consumer rights, and environmental sustainability, the intervention sought to simultaneously develop conceptual understanding and critical citizenship competencies.

Research Objectives. This study aimed to: (1) implement and evaluate a contextualized fuel quality analysis intervention grounded in meaningful learning and CTS frameworks; (2)

examine how hands-on experimentation influences students' conceptual understanding of molecular polarity, intermolecular forces, and solubility; and (3) investigate the development of scientific citizenship competencies, including critical awareness of consumer rights, environmental sustainability, and evidence-based decision-making.

THEORETICAL FRAMEWORK

Meaningful Learning Theory

Ausubel's meaningful learning theory posits that learning is meaningful when new information is substantively and non-arbitrarily connected to relevant concepts already present in the learner's cognitive structure (Ausubel, 2000). Three conditions facilitate meaningful learning: the material must be logically structured and relatable to prior knowledge; the learner must possess relevant prior knowledge as cognitive anchors; and the learner must adopt a meaningful learning disposition rather than rote memorization. Fuel quality analysis satisfies these conditions by anchoring abstract chemical concepts, molecular polarity, intermolecular forces, phase separation, in students' everyday experiences with gasoline and ethanol. When students can relate new chemical concepts to familiar contexts, they construct cognitive bridges that facilitate both initial comprehension and subsequent application. The phase separation experiment leverages this principle by providing a concrete, observable phenomenon that students can connect to abstract molecular-level explanations.

Science-Technology-Society (CTS) Education

CTS education examines the complex interrelationships among scientific knowledge, technological development, and societal contexts (Aikenhead, 2006; Santos & Mortimer, 2002). CTS approaches emphasize that scientific literacy requires not only conceptual understanding but also critical awareness of how science and technology shape, and are shaped by, economic interests, political decisions, environmental constraints, and ethical values. Fuel quality represents an exemplary CTS issue: it involves chemical principles (solution chemistry, molecular interactions), technological systems (fuel production, quality control), economic dimensions (consumer protection, fraud), and environmental implications (emissions, renewable

energy). By situating chemical learning within this multidimensional context, CTS pedagogy cultivates students' capacity to analyze sociotechnical controversies and participate as informed citizens in democratic deliberation.

Scientific Literacy and Citizenship

Contemporary scientific literacy frameworks define scientific literacy as encompassing conceptual knowledge, procedural competencies (inquiry, experimentation, data analysis), epistemic understanding, and critical citizenship dimensions including socioscientific decision-making and civic engagement (Bybee, 1997; OECD, 2015; Hodson, 2014). The integration of meaningful learning and CTS frameworks in this intervention reflects this multidimensional conception: hands-on experimentation provides concrete experiences that anchor abstract concepts, while reflective discussions on fuel adulteration, regulatory standards, and consumer rights position chemical knowledge as a tool for informed citizenship.

METHODOLOGY

Research Design and Context

This qualitative study employed a descriptive case study design to examine the implementation and outcomes of a four-week university extension intervention focused on fuel quality analysis. The research was conducted in two public high schools in Rio de Janeiro, Brazil, during the second semester of 2023. Both schools serve predominantly low-income communities and face typical infrastructure constraints including limited laboratory facilities. The schools were selected through UERJ's existing extension partnerships, ensuring institutional support and teacher collaboration.

Participants

Participants comprised 102 students (ages 15–17) enrolled in second-year high school chemistry courses across four classes (two per school, with class sizes ranging from 24 to 28 students). The intervention was implemented by a university extension team consisting of one

faculty supervisor (the third author), three graduate students, and three undergraduate students in Chemistry Teacher Education from UERJ. All team members received training in CTS pedagogy, meaningful learning principles, and qualitative data collection methods prior to implementation.

Intervention Design

The four-week intervention integrated theoretical instruction, hands-on experimentation, and reflective discussions structured around fuel quality analysis. Table 1 summarizes the weekly activities and pedagogical objectives. The intervention followed a coherent progression: Week 1 activated prior knowledge and established social relevance; Week 2 developed conceptual foundations through interactive instruction; Week 3 engaged students in hands-on ethanol content determination; and Week 4 facilitated reflective discussions connecting chemical knowledge to citizenship dimensions.

Table 1

Four-Week Intervention Structure: Activities and Pedagogical Objectives

Week	Focus	Core Activities	Pedagogical Objectives
1	Introduction and Contextualization	Guided discussion of fuel experiences; fuel adulteration data; Brazil's energy matrix and ANP standards	Activate prior knowledge; establish social relevance
2	Conceptual Foundations	Molecular polarity, intermolecular forces, and solubility; visual models and demonstrations	Develop conceptual understanding underlying phase separation
3	Hands-On Experimentation	Ethanol content determination via phase separation; data collection; comparison to regulatory standards	Apply concepts; develop inquiry competencies; practice quantitative reasoning
4	Reflection and Citizenship	Reflective discussions on consumer rights, environmental sustainability, and energy policy; written reflections	Connect chemistry to citizenship; foster critical awareness

Experimental Procedure

The ethanol content determination was performed according to the Brazilian standard ABNT NBR 13992, referenced by the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) for the determination of anhydrous ethanol content in automotive gasoline. The method is based on the extraction of ethanol from gasoline by an aqueous sodium chloride

solution followed by phase separation and volumetric measurement. Students worked in groups of 3–4 using a graduated cylinder, gasoline samples, and the aqueous extraction solution. After mixing the phases according to the standard procedure and allowing complete phase separation, the volume increase of the aqueous phase was measured and used to calculate the ethanol content in the gasoline sample. The obtained values were compared with the specifications established by ANP for commercial gasoline. This low-cost procedure was selected because it can be safely implemented in school environments without requiring specialized laboratory equipment.

Data Collection

Data were collected through three complementary methods. First, participant observation was conducted by the extension team during all activities, with attention to student questions, experimental engagement, and spontaneous connections to everyday experiences. Second, semi-structured field notes were maintained by each team member and compiled in weekly debriefing sessions. Third, student written reflections were collected at the end of Week 4, responding to prompts about chemistry, citizenship, and personal application of scientific knowledge.

Data Analysis

Data were analyzed using Braun and Clarke's (2006) thematic analysis approach through six phases: familiarization; initial coding; theme development; theme review and refinement; theme definition and naming; and final interpretation in relation to the theoretical framework. Analysis was conducted collaboratively through iterative cycles of independent coding, comparison, and consensus-building to enhance interpretive rigor. Representative excerpts from student reflections were selected to illustrate each theme, with pseudonyms assigned to protect anonymity.

RESULTS AND DISCUSSIONS

Thematic analysis revealed three major themes: (1) heightened scientific curiosity and engagement with sociotechnical issues; (2) conceptual understanding of molecular interactions and solution chemistry; and (3) emerging citizenship awareness regarding consumer rights and

evidence-based decision-making.

Theme 1: Heightened Scientific Curiosity and Engagement with Sociotechnical Issues

Students demonstrated marked increases in scientific curiosity, evidenced by spontaneous questions extending beyond the experimental procedure to broader sociotechnical dimensions of fuel quality, energy policy, and environmental sustainability. These inquiries suggested that the contextualized intervention successfully activated intrinsic motivation to understand the complex relationships among chemistry, technology, and society.

One student reflected: “I never thought about where gasoline comes from or why we mix ethanol in it. Now I understand it’s not just chemistry, it’s about the environment, the economy, and politics. I want to know more about how these decisions are made” (Student A, School 1). This excerpt illustrates how contextualized experimentation can catalyze curiosity that transcends disciplinary boundaries, aligning with CTS frameworks (Aikenhead, 2006; Santos & Mortimer, 2002).

Another student expressed nuanced environmental awareness: “Ethanol comes from sugarcane, which is renewable, but gasoline comes from petroleum. This makes me think about sustainability. But I also wonder about the land used for sugarcane, could it be used for food? These are complicated questions, and science doesn’t always have simple answers” (Student D, School 2). This reflection demonstrates emerging capacity for critical analysis of competing values and interests (Zeidler *et al.*, 2005).

Theme 2: Conceptual Understanding of Molecular Interactions and Solution Chemistry

Students developed substantive conceptual understanding of molecular polarity, intermolecular forces, and solubility, demonstrating capacity to explain phase separation using appropriate chemical reasoning. Written reflections revealed that students could articulate why ethanol (polar) preferentially dissolves in the aqueous salt solution rather than remaining in nonpolar gasoline, referencing the “like dissolves like” principle and hydrogen bonding.

One student explained: “Before this project, I memorized that polar dissolves polar, but I didn’t understand why. Now I see it’s because molecules have to interact. Ethanol has OH groups that form hydrogen bonds with water, so it moves to the water layer. When I saw the two layers

form in the cylinder, it all made sense” (Student B, School 2). This reflection exemplifies meaningful learning as conceptualized by Ausubel (2000): the experimental context provided a concrete anchor enabling students to construct substantive connections between abstract molecular concepts and observable phenomena.

Another student articulated metacognitive awareness: “I used to think chemistry was just about memorizing formulas. Now I understand that properties of substances depend on molecular structure. This is powerful because it means I can predict behavior if I understand structure” (Student E, School 1). This reflects sophisticated understanding of chemistry’s epistemic foundations, aligning with scientific literacy frameworks emphasizing how scientific knowledge is constructed (Hodson, 2014).

Theme 3: Emerging Citizenship Awareness Regarding Consumer Rights and Evidence-Based Decision-Making

Students articulated emerging awareness of their rights and responsibilities as consumers and citizens, recognizing that scientific knowledge empowers informed decision-making. Many expressed newfound confidence in their capacity to evaluate fuel quality claims and detect potential adulteration.

One student stated: “Now I know I can test the gasoline myself if I suspect something is wrong. I don’t have to just trust what the gas station says. Science isn’t just for scientists—it’s a tool that regular people can use to protect themselves” (Student C, School 1). Another connected the intervention to broader civic responsibilities: “Being a good citizen means being informed, asking questions, and using evidence to make decisions. When I hear politicians making claims about energy, I need to think critically about whether they have evidence” (Student F, School 2).

These findings align with and extend prior research on contextualized chemistry education in Brazil (Silva & Marcondes, 2010; Wartha & Alário, 2005). The present study contributes systematic qualitative evidence that such interventions also cultivate citizenship competencies. The university extension model offers a scalable approach for overcoming infrastructure barriers in under-resourced schools while providing authentic pedagogical experiences for pre-service educators.

CONCLUSION

This study demonstrates that contextualized fuel quality analysis, implemented through a university extension partnership grounded in meaningful learning and CTS frameworks, can simultaneously advance conceptual understanding and critical citizenship competencies among public high school students. Students developed substantive comprehension of molecular polarity, intermolecular forces, and solution chemistry, while cultivating scientific curiosity extending to sociotechnical issues including energy policy, environmental sustainability, and consumer protection.

These findings carry significant implications for chemistry education in Brazil and similar contexts. First, they affirm that infrastructure limitations need not preclude meaningful experimental learning; the phase separation method requires only basic materials yet provides rich opportunities for conceptual development. Second, they underscore the value of university-school partnerships as mechanisms for enhancing educational quality. Third, they demonstrate that scientific literacy, encompassing conceptual knowledge, procedural competencies, and citizenship dimensions, can be effectively cultivated through approaches integrating disciplinary learning with critical examination of science-society relationships.

The study's limitations include the short intervention duration (four weeks) and the absence of longitudinal data. Future research should employ longitudinal designs to examine long-term effects and investigate mechanisms that support sustained impact. Additionally, future studies should investigate how such interventions can be institutionalized within regular curriculum structures to ensure broader access and sustainability.

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