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Research Article

Integrating Environmental Education into Petroleum Engineering: A Global Framework with Insights from the Colombian Case

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Abstract

Environmental education is essential in the training of Petroleum Engineers, posing a significant challenge for current academic dynamics. This article aims to develop an innovative curriculum proposal to integrate environmental education into Petroleum Engineering programs in Colombia. The study, which is qualitative in nature, draws on Hugo Biagini's alternative thinking and Edgar Morin's complex thinking, applying the Systematic Inquiry Pedagogical Approach (EPIS). Documentation from universities and regulatory bodies was analyzed, and opinions from students, faculty, alumni, employers, and communities were gathered through interviews, observations, and surveys.

The findings reveal a general interest in integrating environmental education into engineering training, although it is currently limited to fragmented courses. The proposal advocates for a transdisciplinary environmental education that promotes ethical, political, and socio-environmental responsibility, focusing on critical reflection and the integral development of the engineer as a social subject. The proposed education aims to transcend traditional instruction, fostering research, critical thinking, and teamwork through innovative strategies and a systemic approach to addressing the petroleum sector's environmental and technical challenges.

Introduction

The mission of Petroleum Engineering programs at Colombian universities is to prepare competent professionals capable of operating in the field of energy sustainability through hydrocarbons while promoting a commitment to the socio-economic objectives of the country and the petroleum industry. However, so far, the environmental commitment during academic training has been addressed in a fragmented manner through supplementary courses, which do not fully meet the needs and challenges of the professional field, leading to inconsistencies between energy and environmental sustainability. The Professional Council of Petroleum Engineering has noted a decline in the acceptance of Petroleum Engineering, not due to technical failures, but because of low standards of empathy within communities that reject petroleum activities, as well as competition from other professions in the sector that are occupying the traditional job market for petroleum engineers (CPIP, 2021).

Law 20 of 1984 establishes the guidelines for the professional practice of Petroleum Engineers in Colombia, but it does not include explicit environmental guidelines. The Engineering Code of Ethics, regulated by Law 842 of 2003, provides general ethical references and some environmental guidelines but lacks a direct relationship with the specific activities of each engineering discipline. According to Article 33, it is the responsibility of engineers to thoroughly assess environmental impacts and select the most suitable alternatives to contribute to sustainable development. This research aims to build a strategy to integrate environmental education into the training of Petroleum Engineers, based on pedagogical approaches of complexity, alternative thinking, and systematic inquiry. This strategy aspires to become a guiding document for educators, promoting interdisciplinarity [1], ethics, and social responsibility. An exhaustive analysis of integral education in higher education was carried out, characterizing the pedagogical practices inherent to environmental education and proposing an innovative training strategy for Petroleum Engineers that represents a significant contribution to science, technology, and the socio-environmental field.

The issue addressed in this article focuses on the "need for integral education" Nova [2] that contributes to fulfilling the university and program teleology [3], where education transcends the epistemic, pedagogical, axiological, and methodological [4], in response to curricula with limited environmental content, unarticulated connections between petroleum operations and the environment, and lacking evidence of the exploration of hidden curriculum, transdisciplinary components, knowledge of legal environmental commitments, and the perception of training subjects towards environmental commitment, particularly from educators, students, alumni, employers, and society. The issue of the lack of environmental culture [5] in the training of Petroleum Engineers, or at least the social perception of it [6], highlights the urgent need for environmental education, where integral education and values serve as the structural axis that not only educates professionals but also shapes citizens who transcend beyond their profession and become sources of values in society [7].

The development of the research began with the establishment of the research problem, focusing on the research lines of the PACA and GIPE groups (educational approaches for building an environmental culture, and environment and petroleum operations, respectively) at the Universidad Surcolombiana. Through these groups, the process of defining the importance and relevance, and the definition and appropriation of the objectives were carried out. Subsequently, as a strategy for conceptual strengthening, the state-of-the-art and theoretical framework was developed, involving the definition of conceptual structures, the analysis of training structures in Petroleum Engineering, identifying their educational trends and curricular processes around Environmental Education. The methodology focused on achieving the objectives, with clear strategies for information collection

and analysis. The results were then analyzed regarding the diagnosis of environmental education dimensions, gathering perceptions from students, faculty, administrators, employers, and representatives from unions, as well as communities. As a result, an innovative strategy was consolidated for the integration of environmental education into the training of Petroleum Engineers in Colombia.

Methodological Approach

Research design

This study follows a qualitative approach based on the phases proposed by Sampieri (2012) and adapted by Huete [8]. The research is supported by didactic references [9] and is grounded in the Systematic Inquiry Pedagogical Approach (EPIS), allowing for continuous interaction and redefinition as the analysis progressed. The components developed include the nature of the research, the selection of target audiences, the sources of information, and the development, validation, and application of instruments.

Document review and participant observation

The process began with an exhaustive document review, complemented by participant observation and field notes. Based on this, data collection instruments were developed and validated, which were then applied through surveys and interviews. Once data collection was complete, theoretical constructs emerged from the analysis, the instruments were adjusted, and a detailed analysis of the results was conducted to build and validate an alternative educational strategy proposal

Selection of target audiences

The target audiences included universities offering Petroleum Engineering programs in Colombia, such as the Universidad Surcolombiana, Fundación Universidad de América, Universidad Industrial de Santander, Universidad Nacional de Colombia – Medellín campus, and the Escuela Superior de Empresa, Ingeniería y Tecnología. These audiences comprised social actors involved in the training and professional practice of Petroleum Engineers, including faculty, students, alumni, administrative staff, employers, union representatives, and communities. The selection was made considering the diversity of roles and contexts to obtain a comprehensive perspective (Figure 1).

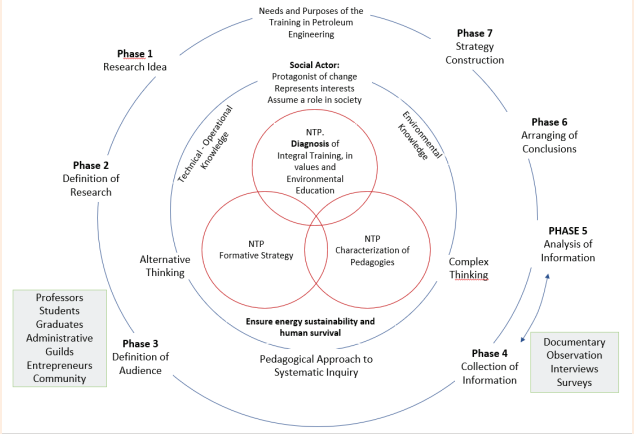

Figure 1: Research Methodology from the EPIS Perspective. Note: It details the dimensions of investigative analysis.

Information sources and data collection strategies

The information sources were carefully selected to address the research objectives, focusing on key variables such as social actors, study categories, and data collection methods. An informal approach strategy was used, combining interviews and observation to refine the study's categories and subcategories [10]. Participant observation, conducted in a natural context, facilitated the development of an interpretative model through partial observations and field notes, with questions derived from both the theoretical framework and direct observation. A strategy of diagramming with an informal approach (interviews and observation) was used as a first step to refine the study's categories and subcategories [10]. Participant observation, a non-evaluative strategy in a natural context, allowed for the development of an interpretive model through partial observations and field notes. The questions for the observation were derived from both the theoretical framework and the observation itself.

The study variables includeincludeed: Soci"l Ac'ors (faculty, students, alumni, administrative staff, union members, employers, and community members), categories (integral education, values education, and environmental education), and data collection methods (non-personal document analysis, personal document analysis – resumes, participant observation, in-depth personal and group interviews, and surveys).

In-depth interviews and document analysis

In-depth interviews were conducted flexibly and dynamically, using an unstructured and open format, following Taylor and Bogdan (1992). Life history interviews and experience narratives were employed. The questions, formulated descriptively, included hypothetical situations to stimulate complex responses. A document review of both formal and informal documents was also conducted (Table 1). The three established categories and subcategories allowed for an organized handling and analysis of the information (Table 2).

Table 1: Document information collection. Note: Summary of document sources.

Information	Document or Data Type
Non-personal Document Analysis	Reports for Qualified Registration Renewal
	Curriculum Plans
	Web Pages with Program Information
	Educational Regulations
	Regulations on Professional Practice
	Management Reports
	Historical Reports
	Theoretical Framework Conceptualization
	Values Education Conceptualization
Personal Document Analysis	Resumes
	Life Narratives

Table 2: Research categories and subcategories. Note: Resulting from the processing and triangulation of information.

Category	Subcategory
Integral Education	Construction of Convictions
	Construction of an Alternative, Complex, and Multidimensional Rationality
	Humanistic Education
	Growth of the Self as a Whole
Values Education [7]	Vital Values
	Social Values
	Cultural Values
	Personal Values
	Religious and/or Spiritual Values
Environmental Education [57]	Resolutive Model
	Naturalistic Model
	Anthropocentric Model
	Systemic Model
	Activist Model

Development, validation, and application of instruments

The research instruments included interview scripts with the audiences and primary and final surveys. The first instrument evaluated the fulfilment of the institutional and program missions in relation to environmental education, the coherence between academic training and ethical and environmental responsibilities, the strengthening of ethics and environmental responsibility, as well as the communities' perceptions of the environmental awareness of Petroleum Engineers. The primary surveys identified respondents' opinions on integral education, values, environmental education, and the educational objectives for Petroleum Engineers (Table 3). The final surveys validated the preliminary conclusions and strategies for integrating environmental education, focusing on integral education and values. A total of 205 academic surveys and 49 community surveys were conducted, including two rural communities from the Santa Clara (municipality of Palermo) and San Francisco (municipality of Aipe) villages, as well as two urban communities from the municipalities of Tesalia and Neiva, in Huila state (Table 4).

Table 3: General thematic content of the primary academic survey. Note: Information for scenario building.

Central Theme	Objectives Related to the Research	Specific Topic
Integral Education	Diagnose integral education in higher education for Petroleum Engineers in Colombia	Philosophical and intellectual perspectives such as: Gerardo Remolina, Enrique Leff, Humberto Maturana, Guillermo Hoyos, Adriana Nova, Arnobio Maya, Rafael Campo, Mariluz Restrepo, Edgar Morin, Luis Orozco, José Rincón, and Miguel Martínez.
Values Education	Diagnose values in higher education for Petroleum Engineers in Colombia	Vital, social, personal, cultural, and religious or spiritual values, with their various expressions
Integral Education in Higher Education	Diagnose integral education in higher education for Petroleum Engineers in Colombia	Characterize pedagogical practices inherent in the integral education of Petroleum Engineers. Philosophical perspectives and thinkers such as The World Conference on Higher Education, Luis Orozco, Jacques Delors, Gabriel Misas, Hernando Gutiérrez, Amparo Ruiz, Martha Nussbaum, José Roig Ibáñez, and Augusto Pérez.
Integral Education in Higher Education in Colombia	Diagnose the values of integral education in higher education for Petroleum Engineers in Colombia	Characterize the pedagogical practices inherent in their integral education in Colombia Propose a coherent educational strategy for the formation of Petroleum Engineers and the environmental dimension. Perspectives: Law 115 of 1994, Law 30 of 1992, CNA (2013-2021), Luis Orozco, Martha Nussbaum, and Adriana Nova
Integral Education from the University	Diagnose the values of integral education in higher education for Petroleum Engineers in Colombia	Characterize the pedagogical practices inherent in their integral education in Colombia Propose a coherent educational strategy for the formation of Petroleum Engineers and the environmental dimension. The institutional and programmatic mission of each university offering the Petroleum Engineering program.

Table 4: Audience consulted. Note: Breakdown of participants in the research

Academic Community	Faculty	Students	Alumni	Unions	Business Leaders
USCO	10	63	37	1	1
UIS	1	8	10	0	1
UNALMED	1	7	11	0	0
FUA	1	18	35	1	2
ESEIT	1	0	0	0	0
Community					
	Elementary	High School	Professional		
Rural	14	15	2		
Urban	2	7	7		

Information processing and strategy development

Based on the collected information, the study categories were defined, which were subsequently coded to design the primary and final surveys. The survey results were organized into matrices and charts using Excel, and this information was restructured according to the research objectives and different audiences to highlight their perspectives. The research results enabled a diagnosis of environmental education in Petroleum Engineering programs in Colombia, identifying relevant pedagogical practices for the inclusion of environmental education (MEN and MAVDT, 2003; 11,12), following the EPIS methodology (Figure 2). Finally, an integrative strategy for environmental education in the training of Petroleum Engineers in Colombia was designed, focused on promoting environmental awareness, social responsibility, and sustainable development, effectively contributing to the preservation and care of the natural environment [13,14].

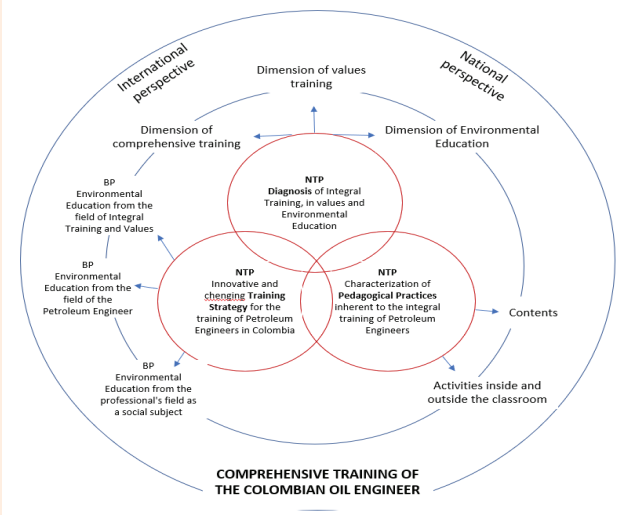

Figure 2: EPIS Methodology for Research. Note: Dimensions and interactions of investigative evolution.

Results

The triangulation of information revealed a clear link between environmental education and integral education, emphasizing the importance of ethics, honesty, responsibility, truth, and respect for others. Additionally, it highlighted the development of soft skills, particularly interpersonal and cognitive skills. The review of the curricula and micro-curricular designs showed that environmental education is largely limited to courses with an environmental or ecological focus, which provide basic concepts and tools without promoting a true environmental culture or fostering significant connections between professional activities and their socio-environmental implications. Therefore, institutional changes and greater interdisciplinarity are required.

In conclusion, the integration of environmental education into Petroleum Engineering should be approached from a systemic perspective supported by the anthropocentric model, a highly beneficial combination. The systemic approach aligns with the concepts of systems and their relationships, while the anthropocentric model allows for the management of ethics and socio-environmental responsibility, with the Engineer as the manager and executor. The fundamental basis for situating the student in the reality of their environment is to go beyond academic concepts, relying on educational tools adapted to concrete facts and situations [15].

Environmental education articulation activities are carried out through interdisciplinary and transversal projects, as well as the analysis of problematic situations that seek to address specific content and problems. These projects are accompanied by community, government, and business activities that promote the dialogue of knowledge and reflections, as well as the application of technical environmental approaches in professional practice. Thus, environmental education is conceived as an intrinsically critical exercise that explores the epistemological foundations of different disciplines, questioning the effects of traditional perspectives [16].

Innovative and challenging articulation strategy

The educational strategy designed follows the guidelines of the Systematic Inquiry Pedagogical Approach (EPIS), for which three Programmatic Blocks (PB) were identified to address the research objectives: Environmental Education from the Field of Integral Education and Values, Environmental Education from Doctrinal Training, and Environmental Education from the Field of the Professional as a Social Subject. This problematizing context fosters more deeper and meaningful learning, where the curricular proposal surpasses the subject-centered approach to transform into a new scheme of knowledge, supported by interactive research. It proposes the development of projects with an integrative vision of the program's knowledge, economic, political, and socio-environmental interaction, considering conflicts, tensions, questions, uncertainties, challenges, and imprecisions susceptible to transformation [17]. The project structure is detailed in Figures 3-5.

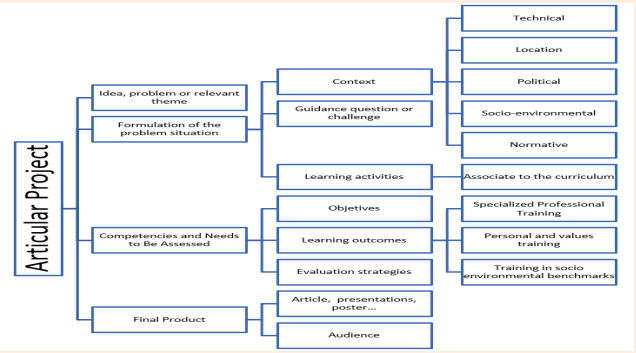

Figure 3: Characteristics of the articulation project for the integration of environmental education
Note: Applicable to any area of higher education.

ARTICULAR PROJECT FORMAT			
RELEVANT IDEA OR TOPIC (Title):			
Formulation of the problem situation:			
Context:			
Technical			
Location			
Political			
Socio-environmental			
Normative			
EVALUATION CRITERIA:			
Competence And Capabilities	**Objetives**	**Learning Outcomes**	**Evaluation Strategy**
Skills and knowledge that the student has to achieve to respond to the requirements of the productive sector, education and environmental culture, training in values and promote social cohesion	Expected results of the students as a result of the training process	They are expressed in terms of contextualized competence and represent the set of skills and knowledge acquired in a learning context, which, mobilized, allow the objectives of the professional module to be achieved.	Student action against learning outcomes based on the fulfillment of objectives
Professionals			
Personal – values			
Socials			
Environmental			
GUIDANCE QUESTION OR CHALLENGE: (Object of the project)			
LEARNING ACTIVITIES: (Associated to the curriculum)			
Theme 1.			
Theme 2.			
Theme 3.			
Theme 4.			
FINAL PRODUCT:			
Design	**Article**	**Presentation**	**Others**
AUDITORIUM:			
Students	**Professors**	**Community (University, Sector, General)**	**Others**

Figure 4: General Format of the Articulation Project. Note: Its applicability will be adjusted according to the area or level of education.

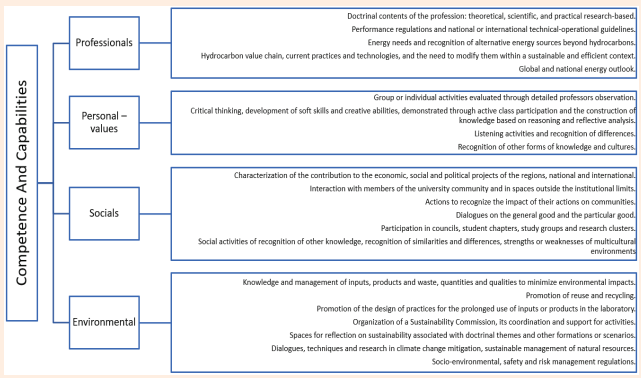

Figure 5: Consolidated Evaluation Criteria for the Development of Articulation Projects. Note: Associated with the professional profile of the Petroleum Engineer.

The evaluation criteria established for the development of articulation projects serve as a guide and must be updated according to the dynamics of training and professional practice [18-20]. As a result of the research, a grading criteria matrix was generated, aligned with the project's guidelines, which are organized into the levels of basic sciences, basic engineering sciences, and applied engineering [21-25]. The general evaluation criteria, adjusted to the professional profile, are detailed in Figure. This proposal does not constitute a rigid line of action; on the contrary, it is designed to be dynamic and flexible, allowing for its continuous enrichment through its application and the changes that occur in the educational environment and the professional practice of Petroleum Engineers in Colombia.

Evaluation of Findings

Linkage of environmental education with integral education

The results obtained from the research indicate that environmental education is deeply interconnected with the integral education of Petroleum Engineers. This finding stems from the surveys and interviews conducted, which reflect an alignment with the philosophical thoughts guiding the educational needs of these professionals, both in the current context and in relation to the future scenarios of the profession [26-32]. The inquiry process led to the identification of values such as ethics, honesty, and responsibility as essential elements for a comprehensive and effective education. This education should also incorporate soft skills, such as interpersonal and cognitive skills, which are vital for effective communication in work environments. Furthermore, the importance of deepening doctrinal knowledge, which interacts with socio-environmental elements and components, is emphasized, thereby fostering complex and highly critical learning. The inclusion of these elements not only prepares students to face technical challenges but also equips them to act ethically and responsibly in professional and community contexts.

Limitations in current environmental education

The exhaustive review of curricula revealed the need to implement actions that go beyond the atomization of courses and establish significant connections between professional activities and their socio-environmental implications. This limited approach indicates a lack of integration of environmental education in professional training. Therefore, it is necessary to review and update curricula to adopt a more integrated and applied approach that reflects the current realities and needs of the socio-environmental context, promoting cross-disciplinary and interdisciplinary environmental education [33-40].

Recommendations for methodological approaches

To overcome the identified limitations, it is recommended to adopt a systemic approach in combination with the anthropocentric model. The systemic approach facilitates the understanding of the interconnections and dynamics inherent to the systems managed by the engineer, while the anthropocentric model ensures the proper management of ethics and socio-environmental responsibility. This combination not only enhances the theoretical understanding of concepts but also boosts their practical application in real situations, allowing for a clearer temporal and spatial vision of the consequences of actions [41-43].

Proposal for an innovative articulation strategy

The proposed strategy is based on the Systematic Inquiry Pedagogical Approach (EPIS) and is organized into three programmatic blocks: (1) Environmental Education in Integral Education and Values, (2) Environmental Education in Doctrinal Training, and (3) Environmental Education from the Professional Field. This framework seeks to surpass the traditional subject-centered model by promoting more meaningful and integrative learning. The proposal aims to transform Petroleum Engineering education by focusing on an education that not only addresses academic content but also holistically integrates socio-environmental and ethical dimensions.

Development of interdisciplinary projects

The creation of interdisciplinary and cross-disciplinary projects is proposed, integrating the analysis of real problems and promoting the dialogue of knowledge across different disciplines. These projects should address complex problematic situations, considering a wide range of interdependent factors and relationships. The implementation of these projects will allow students to develop a critical and practical vision of the environment, which will contribute to improving both academic training and the professional performance of Petroleum Engineers.

The integration of community, governmental, and business activities into these projects will also be fundamental in strengthening the connection between academic training and the socio-environmental reality in which future engineers will operate. This not only enriches the educational process but also prepares students to face the real challenges of their professional field with a more holistic understanding. The evaluation criteria for these projects must be dynamic and flexible, adapting to the changing needs of training and professional practice. The proposal must be in constant evolution and continuous improvement, based on accumulated experience and the changes that arise in the educational and professional context. This adaptability will ensure that the articulated strategy remains relevant and effective over time, enabling petroleum engineers to contribute significantly to sustainable development.

Conclusion

a. An integral educational strategy is proposed that incorporates environmental and humanistic education into Petroleum Engineering programs in Colombia, transforming professionals into individuals with improved practices and greater environmental awareness.
b. The strategy is based on an innovative project that prioritizes the development of soft skills and the training of professionals as social subjects. A matrix of actions and commitments has been completed for all levels of Petroleum Engineering education [44-50].
c. Despite the recognition of the importance of integral education, current implementation is insufficient. It is necessary to create an educational environment that allows future engineers to adapt and evolve in response to social and environmental transformations.
d. Values education, such as ethics and responsibility, and the development of skills like empathy, are crucial. Environmental education, currently based on isolated courses, requires a systemic and anthropocentric approach for effective training.
e. The educational strategy is organized into three programmatic blocks: integral education and values, technical training, and social responsibility. These blocks integrate sustainability and environmental education into all subjects.
f. A paradigm shift is necessary in curricula, incorporating values education and environmental education in an integrated manner. The curricular proposal must be flexible and adaptable to changes in the petroleum sector and social and environmental transformations [51-59].

Recommendations

It is recommended to offer continuing education on ethics, social responsibility, and the environment after graduation, and to conduct collaborative workshops with universities and industry associations to keep the proposal relevant. Additionally, the applicability of this proposal to other engineering disciplines and higher education programs should be analyzed. A dissemination plan should be developed to share the research findings at the national and international levels. This research provides a foundation for curricular and pedagogical transformation, aiming to train Petroleum Engineers who are committed to sustainability and integral development, and who are capable of facing the challenges of the energy and environmental sectors.

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