Hybrid method in engineering education: a case study applied to electrical engineering

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***Abstract*—This study presents a new engineering education approach based on combined classical and modern theories. This approach is valid based on an experiment with students of the subject Introduction to Electrical Engineering in the regular undergraduate course for three consecutive periods at the University of Amazon State, Brazil. This study reflects the view of a teacher towards students in a disciplinary context of workload and content, associating evaluation methods for the development of innovation and creation skills. The proposed methodology consists of the systematization of applied steps: Problem-Based-Learning (PBL), Bloom's process, Conceptual map, and motivations. The practical study involved 146 students, and the results were satisfactory regarding their scope of construction of knowledge and skills achieved. A high rate of 74,66% was obtained in developing practical skills based on theoretical models of electrical engineering, aspects of relational technology about communications techniques, and devices electronics with sensors.**

Keywords—education, learning and teaching, hybrid method.

I. INTRODUCTION

Currently, the social reality is radically changing with new technologies, which are also rapidly spread by the media, such as social networks. Therefore, it is necessary to adapt the teaching of professionals directly involved in creating or maintaining these new technologies. Considering the current problems related to an academic education that implies the disinterest or loss of motivation of the students, in general, it will be due to the limitations of traditional teaching methodologies, which include the complete exposition of the contents. The inappropriate use of teaching methodologies in the academy harms the teaching and learning of students, even more so when the matrix of higher education is directly related to the development, maintenance, and improvement of technologies, as is the case of engineering. In this sense, the application in practice of a new methodological approach for teaching engineering includes, from the student's admission to the academy to his professional training, the use of didactic pedagogical techniques related to the construction of maps conceptual. The stability of this methodological approach will be presented from the result of its application in practice in the form of case reports. In the following topics, a theoretical foundation and its aspects are presented, aimed at teaching whose goal is problem-solving. In the first topic, we will delve into the following items: the technique focused on entrepreneurship, the construction of concept maps, and the elaboration of concept maps in the electrical engineering career; in the second, an explanation of the methodology used in this research is made; in the third, it presents the results and their respective discussion.

I. METHODS AND MATERIALS

A. Problem-based learning

The methodology of Learning Based on Problems (PBL) in the teaching of Engineering presents an observation of the problem of reality and technological mechanisms, resulting in innovation and materialization of knowledge in a product for the benefit of society, another methodology [1][2], highlights that learning to reflect, reason, use problem-solving strategies to adapt to new generations to know better and differently and flexibly is a fundamental need for education.

For the student to enhance the innovative process [1] reinforces, in the sense that knowledge based on internalized and mediated social interactions involves an intentional dialogue between experienced and inexperienced subjects, specifically in the view of [2], that the innovative teaching-learning process uses the position of socio-cognitive conflicts, accepting the existence of various approaches and various points of view on the same topic (problem), suggesting the emergence of doubts, discussions, and debates without tension, enhancers of cognitive

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development of more coexistence and cooperation. It should be noted that the students presented autonomy after the interactions in the laboratory, and those interactions in the exchange of experiences build a type of environment that allows creation.

The method known as "Problem-Based Learning" (PBL) was the fundamental basis for designing the methodological approach presented in this study first because of its centrality in the construction of knowledge from the resolution of problems faced by students in their social reality [3].

It is highlighted that the method can be used to develop skills that students will require when they are trained and perform professionally [4]. Research on engineering profiles indicates some desirable professional skills acquired through PBL. For example, an engineering graduate's ideal requirements are group work, oral and written communication, problem-solving, professional and social responsibility, adaptability, and continuous learning.

B. Conceptual maps applied to Electrical Engineering.

The growing complexity imposed on us by the environment in which society is inserted to multiple questions and reflections in the search for continuous improvement to reduce the impact.

The teaching process is no different. The professional profile of engineering graduates requires that they respond to the speed of change, given the high content of information available through new technologies, social networks, and the labor market challenges, considering that professional practice requires flexibility, creativity, autonomy, and continuous training. According to "The visions to contemplate the need to compose an education with a broad and holistic vision and with a critical and reflective scope" [5].

We have conceptual, or mind maps to complete these visions, which help organize, visualize, and integrate knowledge. A conceptual map "consists of the construction of a diagram that indicates the relationship of concepts in a two-dimensional perspective, trying to show the hierarchical relationships between the concepts appropriate to the structure of the content" [6]. Conceptual maps try to give an overview of a topic or broad area, enabling the planning of routes/actions through the provision of better conditions in the context in which it is inserted due to the large amount of data employed. Disposition [7], thus stimulating problem-solving, allowing perception of new creative paths in a projection of totality.

This perspective applied to the processes of academic construction can provide the articulation of the structure of hybrid knowledge loaded with intertwined meanings, in addition to reconnecting disciplinary expertise with each other, promoting integrated practices and shared pedagogical connections, considering that according to [8], conceptual maps They can also promote: the provision of structured summaries of relevant topics for quick reference; the provision of a structured method of study; facilitate the extraction of the essence of a content; the rapid prestructuring and restructuring of a semantic product; the integration of content from multiple sources; the dynamic integration of ideas produced by a group; the synthetic record of a procedure; the provision of a cognitive resource in the presentations; the development of the search and perception of multiple aspects of a topic or situation; stimulate seeing an idea in a larger context, rather than in isolation, providing a more complete and balanced understanding; the development of objectivity; the facilitation of the application of knowledge due to the similarity of the representation that is used mentally, the development of both synthesis and analysis skills; the development of relational thinking, one of the pillars of systemic thinking; providing a framework for not-knowing; the provision of greater flexibility; more precise and stable decision making, due to the consideration of more aspects and possibilities; facilitate knowledge sharing; and promote better coordination of the members through a better and easier division of tasks, within a global vision, increasing the probability that the group's objectives will be achieved.

Teachers must build their position in the curricular framework, following the synergy of the process to improve the quality of the Electrical Engineering career. In this way, the network of intertwined knowledge allows us to think about the academic universe beyond its immediate pedagogical context, as mentioned by [9].

These relationships directly affect the performance of the people involved since "the different types of influences provide opportunities for the emergence of their customs, often shared, but which are not uniform, common to all" [9].

II. PROPOSED METHODOLOGY

The idea of planning an effective learning process mobilizes teachers to implement effective forms of learning, encouraging greater involvement, symbolic exchanges, and didactic and social constructions through differentiated strategies in the teaching-learning process of the new technologies that have a dynamic, systemic vision in tune with the needs of the current scenario. This study considers the "teaching" process in higher education, locating the importance of rethinking curricular relationships and relying on innovative strategies.

This idea is to fill the gaps in the student's knowledge, see figure 1, from their background in their profession, with motivational teaching elements that they have as a vehicle in small projects in electrical engineering.

Among the possible strategies proposed:

• Development of personalized projects in work teams duly placed in different groups of students. The topics are conveniently oriented by specialist professors in each area, with appointments scheduled in the corresponding periods of the semester. It begins with a presentation by the academic team with a brief dissertation on the problems to be developed by the students. In the end, the evaluation concludes with a representative indication of the results, with the participation of the Faculty of Engineering.

• Introduce elements of emotional intelligence to add to students' self-esteem in complementary psycho-pedagogical courses or simple conferences by specialists with motivational

objectives on the topics of the profession. It is possible to locate subjects such as Elements of Psychology, Interfaces and Simulation of Processes, Geographic Information Systems (GIS), and Introduction of Intelligent Systems.

• Use of conceptual maps as a tool or itinerary to follow to assess the pedagogical practice carried out, favoring and expanding the relationships and connections built by the learning of conceptions and concepts represented by corresponding nodes, which is being implemented in the first courses of Electric engineering, from known until by unknown, figure 1, which help understand aspects for beginning motivation in learning and teaching process.

Fig 1. The essence of learning: achieve fill the knowledge through the unknown.

Fig 2. Algorithm of learning

The study aims to put the necessary tools for students to reach or complete unknown knowledge, using didactic and psycho-pedagogical resources based on a motivational strategy within the active curriculum of students in the shortest possible learning time. This aspect is shown in figure 2. In this methodology, it is essential to follow a logical sequence of students' knowledge to increase their interest in achieving new skills in their profession.

III. RESULTS

The solutions developed by the students were presented as proof of concept, with models of the projects in operation in Technological Exhibitions according to the set of methods and applications proposed by [10]. Of a total of more than 20 projects, 11 were considered suitable for the problem method and are listed below:

Project 1- Problem: Time wasted in the classroom when passing the list. Proof of Concept: Automated system with Arduino UNO, TAG, and biometric reader to validate the student's presence in the classroom. Since the teacher has control to decide the start and end of the validation period.

Project 2- Problem: Waste of resources with students to turn on and off equipment and classroom lighting, given that the university has 500 classrooms. Proof of Concept: Automated system with Arduino UNO microcontroller with a timer to turn on and off air-conditioning systems; the project also included lighting on and off using LEDs. The proof of concept also had a display that had to be placed on the door of the classroom to inform which teacher was in the room and what subject was being taught, as well as notify the teacher when he was exceeding his time in the classroom, harming another discipline and another teacher.

Project 3- Problem: It consists of the exact definition of the problem of project 2. Proof of Concept: Automated system with temporary activation component With the BWT40R and Arduino UNO to activate and deactivate the refrigeration systems (air conditioning), the students presented a proof of concept with a device with a cooler.

Project 4- Problem: When there is no electricity, and the teacher writes the subject's content on the blackboard, this content is lost since the students cannot complete the copy of it. Proof of Concept: Automated system with a micro-controller that, upon detecting the absence of electricity, activates the LED lights placed in the upper part of the frame so that the teacher can complete the content.

Project 5 - Problem: a university with a constructed area of 1,000,000 m2, a student body of 16,000 students, a faculty of 630 professors, and ten car parks. Therefore, despite the sizeable functional space, there are still traffic jams between 5:30 p.m. and 7:00 p.m. and the night shift starts. Change starts between 9:30 p.m. and 10:30 p.m. Proof of Concept: Automated system with Arduino UNO microcontroller, ultrasonic sensors positioned in each garage, and computer interface (applications) that gives access to university teachers and students indicating the number of spaces in each parking lot, thus avoiding traffic in the internal area of the university.

Project 6 - Problem: The university in question has an enormous infrastructure to support its educational potential in the Amazon, which means that its energy consumption is also high. The University has a built area in a relatively flat relief region and has a buildable area of 1,000,000 m^2. Therefore, it is an excellent helpful place for installing solar panels. Proof of Concept: Automated system with Arduino UNO micro-controller and a system with an angular rotation mechanical arm coupled to a solar panel to take better advantage of the insolation since the panel rotates automatically with the incidence of radiation on the device proposed. The students used a car battery and a light bulb to demonstrate how the solar panel works for educational purposes.

Project 7 - Problem: A university has a graduate program in aquaculture, and at the request of the program, there is a need to modernize the laboratories with temperature control of the fish used in the program's research. On some occasions, fish die in the laboratory due to excessive decrease or increase in temperature. Proof of Concept: Automated system with Arduino UNO microcontroller and temperature sensor for control of aquatic environments, the implemented system shows the temperature via wireless network to the researcher's

cell phone and generates an alert in critical cases of temperature. They are providing the researcher of the graduated program with an alternative to correct this temperature with appropriate procedures and techniques.

Project 8 - Problem: Specifically, a student in the group related an event from his family experience, in which one of his relatives was diagnosed with autism. This student observed that his relative (boy) repeatedly managed to leave his room at night without the supervision of his parents, exposing herself to dangerous situations. Going deeper into the topic, the students observed that this is a common practice among autistic people. Proof of Concept: Automated system with Arduino UNO, presence sensors (SP), and capacitive sensors (SC), positioned on the internal doors of the house; the system was developed for preventive residential monitoring purposes.

Project 9 - Problem: Students noted that neonatal incubators do not have a mechanism to monitor newborns' temperature continuously. This fact can lead to seizures or hypothermia if the health professional does not perform temperature control. Proof of concept: Automated system with Arduino UNO, containing a high-precision thermocouple strip, in which the newborn's temperature can be monitored in real-time and continuously interconnected with the health professional's or doctor's mobile phone. Students were instructed that this application is not limited to neonatal intensive units but can be used in all medical-hospital cases, where continuous body temperature monitoring is necessary.

Project 10 - Problem: After observing the students, the allocation of beds in serious situations such as traffic accidents is done by radio between the rescuer and the hospital. In which the rescuer identifies the severity of the patient for subsequent referral to the emergency room or intensive care units, the rescuer needs to search nearby hospitals for available beds according to the identified severity. Proof of Concept: Automated system with Arduino UNO microcontroller, in which presence sensors are placed in the beds to indicate their occupation or vacancy. So that there is no false start when were occupied, the system is only activated after the absence of the sensor signal after forty minutes, so that the system is not triggered by mistake when the patient leaves his bed for personal reasons or doctors - hospital.

Project 11 - Problem: The lack of information leads people to store their medicines in inappropriate places, generating risk situations, such as changing the property of the treatment and even its validity. Proof of Concept: Automated system with Arduino UNO, thermocouple sensors placed in thermal boxes in which it warns through an application on the mobile phone that the medicine is at an inappropriate temperature.

A. Statistical the results

Regarding statistical validation, the universe of samples was 146 students enrolled in the subject Introduction to Electrical Engineering arranged in three (3) groups for statistical purposes, 50 students from semester 01/2016, 32 students from 02/ 2016, and 64 students on 01/2017 (series not symmetrical with each other). To investigate the hypotheses of this research, these groups were analyzed in terms of their academic performance.

The Q-Q Plot method was used to evaluate the normality of the series; the result indicated a non-normalized distribution for all the series, which suggests that for this study, the most appropriate statistical methods are the tests for non-parametric series distributions.

The test for equality of variances - ANOVA was used to test whether there are significant differences between the variances or standard deviations of the three selected groups. The variable p-value is extracted from this analysis, whose value is compared with its level of significance to evaluate the null hypothesis.

The first hypothesis corresponds to the fact that there are no significant differences between the completion status of the subject (final average) of the groups of students in Class 01/2016 (μ_{C1}); Class 02/2016 (μ_{C2}), and Class 01/2017 (μ_{C3}). In the second hypothesis, the alternative idea, in which there is a difference between the adopted metrics, for this the following assumptions were considered:

$$\mu_{C1} = \mu_{C2} = \mu_{C3} = \mu_{C4}$$
$$\mu_{C1} > \mu_{C2} > \mu_{C3} > \mu_{C4} \quad (1)$$

In this analysis, a level of significance (α) of 0.01 was considered, indicating that the risk of concluding that there is a difference when there is no real difference is 1%. The p-value analysis is performed according to the following criteria:

If the p-value is $> \alpha$, the standard deviations' differences are not statistically significant.

If the p-value is $\leq \alpha$: the differences between some standard deviations are not statistically significant.

In a complementary context, the evaluation of the efficiency of the new methodological proposal was carried out according to the student's competencies, the academic desertion rate, and the learning rate.

The Minitab Statistical Software program [11], version 18 (Windows), was used in all statistical analyses and data processing.

The analysis of the results is divided into two stages. The first shows the impact of the comparison between the variability of academic performance for the three classes. In contrast, the second shows the development of the evaluation of the efficiency of the new methodology proposed.

First step - Comparison of the variability of academic performance. For example, the Class 1 population is within the confidence interval. According to the results obtained in the first step, we can say that the equality of variations test showed no statistically significant difference between the three groups and the student's academic performance in the discipline. In this way, the student's behavioral skills, the theoretical dropout rate, and the learning rate for the total number of students were analyzed. Considering the universe of the samples, figure 3 shows the graph of the final state in the discipline. The chart shows a total of 109 students who passed (AP), six (6) students who failed by grade (RN), and 31 students who dropped the course (TC).

The motivation for the study and building of models allowed in figure 4, improvement increasing scope in the construction of knowledge and skills achieved.

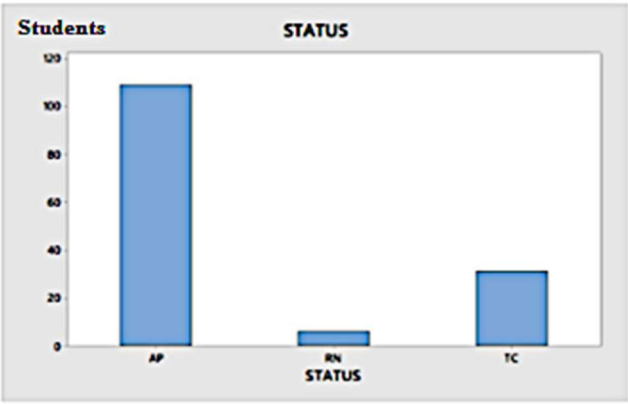

Fig 3. The final situation of the students.

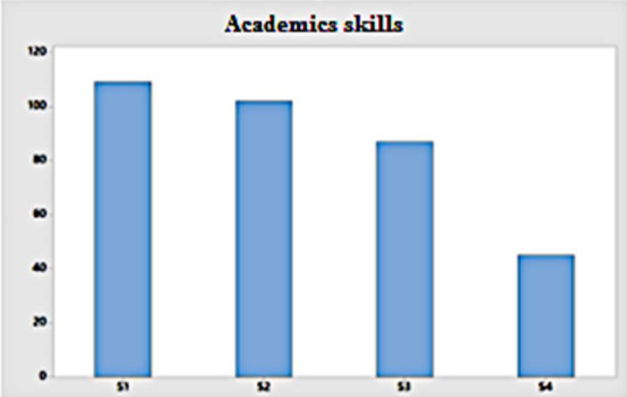

Fig 4. The number of competitions achieved.

Regarding the students' abilities, in figure 4, the students were evaluated in terms of the scope of the specificities:

H1 - Practical and theoretical competencies, in which students were evaluated from the development of practical projects based on academic definitions applied in the classroom.

H2 - Teamwork skills, in which students were assessed on the merits of functional outcomes in the laboratory, considering their interpersonal relationships.

H3 - Communication skills, in which students were evaluated in terms of oral presentation in a technological show and mastery of knowledge of the projects developed.

H4 - Management and leadership skills, in which the students were evaluated in terms of the project led by one of the students and managed in terms of the practical and theoretical experience of the teams. Figure 5 shows the graph of the number of competencies achieved.

The graph shows 109 students (74,66%) obtained the skill S1, in the same way S2 with 102 students (69,86%), S3 with 87 students (59,59%) and S4with 45 students (30,82%). All students, in summary, obtained at least skill S1, which shows that practical skill is the minimum determining factor for passing the subject. At the same time, 30,8% (45 students) added the practical skill to obtain the management and direction skills that form their finals evaluations.

B. Discussion.

In this way, the results presented were satisfactory for using the method. However, [4] cites as a disadvantage of PBL the difficulty of deepening and exploring the syllabus, given that in this study, there are reports that some students question the workload and extra-class time to study the problem. The hypotheses of the new methodological approach were divided according to the research objectives.

Objective 1: Investigation of the influence of the hybrid methodology on the population variance. The metric used as a variable was the final mean of the evaluation. Here is the related hypothesis:

Hypothesis 1.1: there is no influence of the use of the method on the variance in the tested groups.

Based on the statistical results, it seems that hypothesis 1.1 is accepted since there is no difference between the variations of the final averages between the groups tested (class 1, class 2, class 3). This result suggests the method's stability since the tested groups did not differ in population variance in the three consecutive periods. In these terms, the methodological approach proved effective and suitable for supporting engineering education.

Objective 2: Investigation of the influence of the hybrid methodology on the population variance. The metric used as a variable was the final mean of the evaluation. Here is the related hypothesis:

Hypothesis 1.2: there is no influence of the use of the method on desertion in the groups tested.

In the three groups evaluated by the method, there was a high rate (74.66%) of project completion, reflected in the H1 skill. The applied methodological approach resulted in educational training with the commitment of most of the enrolled students, of which 146 students presented and evaluated by the method were thus distributed based on technological innovation with the level of skills and competence.

According to [12], the problem of failure and desertion of academics in the areas of Engineering with the intervention of practices that aim to stimulate the use of resources and methodologies focused on models of individual tutoring and group work [13].

Its results proved that using communication skills [14], in which students were evaluated in terms of oral presentation in a technological show and mastery of knowledge of the projects developed, was possible improvement learning and teaching.

Mind maps helped orientation of the students to tasks about profession future in Electrical Engineering, using aspects of psychological education. [1], [8].

The study and building of models improved knowledge and skills at a high rate [15].

IV. CONCLUSIONS

The study, using the hybrid or combined method of aspects and resources of participation and inclusion of students with projects of the specialty in the teaching of Electrical Engineering, showed an encouraging improvement in the

teaching-learning performance index in three consecutive course periods.

The applied methodological approach resulted in educational training with the commitment of most of the enrolled students, which had been presented and evaluated by the method, were thus distributed based on technological innovation with the level of skills and competence.

This result suggests the stability of the process since many courses using a methodological approach proved effective and suitable for supporting engineering education.

The proposed methodology consists of the systematization of applied steps: Problem-Based-Learning (PBL), Bloom's method, Conceptual map, and motivations.

The practical study involved 146 students, and the results were satisfactory regarding their scope of construction of knowledge and skills achieved at a high rate.

For future works, we want to consider the factors that do not contribute to student learning and the favorable evolution of the discipline.

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REFERENCES

[1] L. S. Vygotsky, "El desarrollo de los procesos psicológicos superiores," *Revista Escola Comunidades de aprendizagem*, vol. 1, p. 13, 1979.

[2] V. da Fonseca, *Cognição, neuropsicologia e aprendizagem: Abordagem neuropsicológica e psicopedagógica*, 7ª edição. Petrópolis, RJ: Editora Vozes, 2015.

[3] A. Kolmos. E De Graaf . &, "Características del aprendizaje basado en problemas," *Revista Internacional de Educación en Ingeniería*, vol. 19, no. 5, 2003.

[4] W. J. de Araújo, R. P. Lopes, D. O. Filho, P. M. M. de Barros, and R. A. de Olveira, "Aprendizagem por problemas no ensino de Engenharia," *Rev. Docência Ens. Sup.*, vol. 6, no. 1, pp. 57–90, May 2016, doi: 10.35699/2237-5864.2016.2077.

[5] M. A. Behrens and A. L. T. Oliari, "A EVOLUÇÃO DOS PARADIGMAS NA EDUCAÇÃO: DO PENSAMENTO CIENTÍFICO TRADICIONAL À COMPLEXIDADE," *Revista Diálogo Educacional*, vol. 7, no. 22, pp. 53–66, Jul. 2007, doi: 10.7213/rde.v7i22.4156.

[6] E. de Graaff and A. Kolmos, *Características del aprendizaje basado en problemas*. Joinville: University of Aalborg, 2017.

[7] T. Buzan, *Mapas Mentais e sua Elaboração: Um Sistema Definitivo de Pensamento Que Transformará a Sua Vida*, 1ª edição. São Paulo, SP: Editora Cultrix, 2005.

[8] V. V. Vilela, "Para que usar mapas mentais?" 2022. [Online]. Available: http://www.mapasmentais.idph.com.br/textos/para_que_usar_mapas_mentais.php

[9] D. Santos, "O significado de escola," *Instituto Sedes Sapientiae*, vol. 16, no. 13, pp. 22–61, Dec. 2008.

[10] A. C. O. Lima, P. V. P. Freitas, E. Leal, J. Braga, R. da S. Ferreira, and M. R. F. Machado, "The Impact of Entrepreneurship Engineering Education in Amazonia," *IJIRSET*, vol. 5, no. 9, pp. 16457–16465, Sep. 2016, doi: 10.15680/IJIRSET.2016.0509131.

[11] Minitab, "Understanding test for equal variances." Accessed: Aug. 18, 2022. [Online]. Available: https://support.minitab.com/en-us/minitab/21/help-and-how-to/statistical-modeling/anova/supporting-topics/basics/understanding-test-for-equal-variances/

[12] R. Vasconcelos, L. S. Almeida, and S. C. Monteiro, "O insucesso e abandono académico na universidade: uma análise sobre os cursos de engenharia," 2009. Accessed: Aug. 18, 2022. [Online]. Available: http://repositorium.sdum.uminho.pt/

[13] M. A. Behrens, *Paradigma da complexidade: metodologia de projetos, contratos didáticos e portfólios*, 2ª edição. Petrópolis, RJ: Vozes, 2006. Available: https://www.traca.com.br/livro/435164/paradigma-da-complexidade-metodologia-de-projeto-contratos-didaticos-e-portfolios

[14] E. Morin, *La cabeza bien hecha: repensar la reforma, reformar el pensar. Traducción de Eloá Jacobina*, 10a ed. Buenos Aires, Argentina: Nueva Visión, 2004. [Online]. Available: https://www.academia.edu/28138685/LA_CABEZA_BIEN_PUESTA_Repensar_la_reforma_Reformar_el_pensamiento

[15] A. Do and P. D. Debates, "Das perspectivas á concreture de ações." 2017. [Online]. Available: https://www.gov.br/suframa/pt-br/publicacoes/seminarios-apresentacoes