

**REAL PROBLEM SOLVING AS A TEACHING STRATEGY
FOR PHYSICS EDUCATION: CASE STUDY****P. A. López-Jiménez¹, G. M. Gil-Duque², Y. A. Garces-Gomez^{*3}**^{1,2,3}Universidad Católica de Manizales, Manizales Colombia

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Accepted: August 13th 2020. Approved: March 25th 2021. Published: March 31st 2021**ABSTRACT**

The project presents the application of the stages proposed by Poyla for solving problems in mathematics, which have been adapted in mechanical physics. Critical reading strategies have also been applied resulting in reading physical problems comprehensively. Objectives: To incorporate real problem solving as a teaching strategy in two mechanical physics courses (one experimental and another traditional), in order to characterize the group that applies the problem-solving strategy. To validate the problem-solving strategy in mechanical physics. Methods: Mixed research including analysis and contrast of results obtained from two control groups: one experimental (24 university students of Mechanical Physics) and another traditional (16 university students of Mechanical Physics). The control group approaches the study of the subjects in a traditional way where the problems proposed are solved intuitively and somehow mechanically. The experimental group solves the proposed problems by applying each of the stages of the proposed sequence. The experimental group solves the proposed problems by applying each of the stages of the proposed sequence. This study differs from previous studies in that most are related to problem-solving in mathematics and in this case, we focus on physics with the value of involving elements related to critical reading, which gives a more realistic look of the Physical phenomenon studied from the interpretation of its occurrence and how it impacts the environment, which favors its theoretical understanding and gives meaning to its mathematical modeling.

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Keywords: problem-solving; physics teaching; teaching process; learning process; critical reading

INTRODUCTION

The Ministry of National Education requires higher education institutions to strengthen students' capacities to think critically. To this end, they ask that undergraduate curricula include components that develop reading and writing skills, but at the same time ask interdisciplinary networks to be established. Institutions of higher education are increasingly aware of the need to assess core competencies so that graduating students are able to think and read critically, research and use information, analyze quantita-

tive data, and write effectively and fluently (Rao et al., 2009; Shepherd et al., 2012; Callejas, 2015 Bowers, 2017).

Professors of the Physics department ask how students carry out problem-solving, there is a significant failure of the subject, which has led to questioning the teaching processes and in turn create improvement mechanisms for students (Bhang et al., 2013; Alonso Silva, 2016; Zuluaga et al., 2020; Yanti, et al., 2021). There are studies that investigate critical reading and its relationship with mathematics. For this reason, it is important to look for approaches that have been adopted and which individuals have applied them from higher education. The idea is to of-

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fer students from both institutions the means to recognize their reading levels, improve them and thus solve problems in mathematics, in this case, mechanical physics. It also will help university professors to incorporate real problem solving as a teaching strategy. Steps to guide, monitor, and help students on how to solve problems developing their critical skills.

To solve problems, training in critical reading is necessary, applying different techniques and theories that allow the student to develop and strengthen critical thinking. The reading of the text, therefore, is not only complementary but also bases, models, and makes critical our capacity for judgment to observe the world”.

The research presents the integration of critical reading with physics, answering the following question: How to strengthen the learning process of the phenomena of mechanical physics through problem-solving incorporating elements of critical reading, in physics students at the Universidad Católica of Manizales and Universidad Nacional? It is important to initiate an integration that shows a balance between what is read and what is written, and that makes the solution of a problem in physics not a difficult process. Integration should allow students to relate their theoretical and practical knowledge to critically solve problematic situations. Important studies support the need of understanding Critical reading as Cassany (2012); López et al. (2013); Rendón (2013); Rendón et al. (2014); and Carlino (2017).

Problem-solving as a didactic strategy to achieve in-depth learning in the natural sciences arises from the need for students to relate their declarative and procedural knowledge to solve problematic situations posed from specific contexts, thus “the emergence of the problem-solving approach as a didactic concern arises as a result of considering learning as a social construction that includes conjectures, tests, and refutations based on a creative and generative process” (Pérez et al., 2014). According to Poyla (1965) in May Cen (2015), a problem is solved by consciously seeking actions to achieve an established goal, which cannot be achieved immediately, developing certain skills and abilities in students.

Within the strategies of teaching and learning of disciplines such as physics, the resolution of problems, every day is more used generally associated to situations of a proving character of phenomena of reality, however, it is sought that it is no longer done mechanically and repetitively as it is traditionally done, besides the importance of taking into account that the problems in physics are problems of reality is established, where

there are some criteria of theoretical order and mathematical models that represent the natural phenomenon of study. (Ozuru et al., 2009; Pérez de Pérez, 2009; Rico, 2011)

Problem-solving and critical reading are connected aspects that contribute directly to the cognitive development of students, Pozo et al. (1994), indicates the importance of starting with a problematic situation if the development of critical thinking is intended. Therefore, an enabling environment must be created with appropriate strategies aimed at achieving these goals. Thus, as Laiton Poveda (2011) states, “there is a relationship between the application of pedagogical intervention and the presence of characteristics of a critical thinker in students”. Similarly, Bhang et al. (2013) in a study, asks university professors to develop and exercise the ability to reason reading, critical, creative, and autonomous thinking, and the skills to understand, analyze and interpret what is read, so that they can clearly express and support, orally or by writing, their ideas, opinions, and findings. (Vázquez, 2010; Carrasco Altamirano et al., 2013). This study differs from previous studies in which most are related to problem-solving in mathematics and in this case, we focus on physics with the value of involving elements related to critical reading, which gives a more realistic look at the Physical phenomenon studied from the interpretation of its occurrence and how it impacts the environment, which favors its theoretical understanding and gives meaning to its mathematical modeling.

METHODS

Based on the study of the content of mechanical physics topics, specifically kinematics and dynamics, mixed research was carried out. The results obtained were contrasted with a control group (n = 16 participants) and an experimental group (n = 24 participants), university students of a mechanical physics course. The control group approaches the study of the topics in a traditional way where the proposed problems are solved intuitively and mechanically. The experimental group solves the proposed problems by applying each of the stages of the proposed problem-solving sequence, for which they had a previous explanation and instruction. The real problem-solving strategy results from combining Poyla (1965) in May Cen (2015) tags for solving problems in mathematics and adapted in mechanical physics with elements from Reading levels ICFES (2017). Students read physical problems comprehensible.

After dealing theoretically and mathematically with the topics mentioned, the proposed problems were solved by applying each of the stages in the described sequence, emphasizing on the students' incorporation of each stage of the sequence into the solution of the problem in a written or verbal way. With the control group, the theoretical and mathematical study of the contents of the proposed topics was also carried out, although in this case, the students solved the problems in a free and spontaneous way.

Even though Polya's stages are applied to the solution of problems in mathematics, in this work these stages are adjusted to the solution of problems in physics, which is adapted in a coherent way taking into account that mathematics as the language of physics allows the modeling of

phenomena, starting from a theoretical analysis that allows defining the relationships between the variables that represent the physical magnitudes present in the statement of the problem. Figure 1 shows the sequence and stages of the proposed strategy for solving problems in physics applied by the students in the experimental group. Likewise, the reading levels are coupled to Polya's stages, where the problem is read, that is, first the local contents that make up a text are identified and understood (in this case the situation posed); then it goes to the inferential level, where it is understood how the parts of a text are articulated to give it a global sense; until reaching the critical level to reflect from the text and evaluate its content.

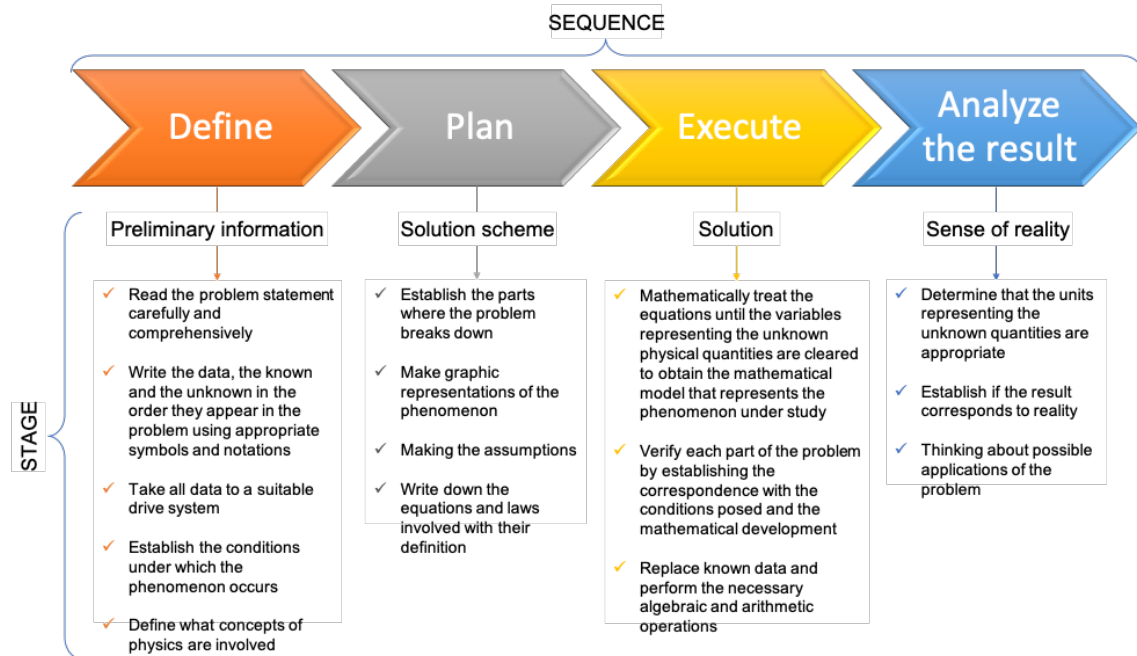


Figure 1. Proposed Problem-solving Strategy in Physics. Source: made by the authors

Complementarily, guiding questions that led the students to go beyond thinking only about the resolution of the problem under the initial conditions that were proposed were asked: What parts of physics are involved? under what other conditions can the problem be posed? can the problem be reformulated differently? is the problem similar to others already solved? were all the data provided by the problem used? is there another way to solve the problem?

The above in terms of critical reading with a view to strengthening critical thinking, according to ICFES guidelines (2017); and researchers such as Javeriana and Cun (2007), Rodríguez (2007), Vázquez (2010), Pérez Abril et al. (2013), Estepa and Rodríguez (2015), Velásquez Almonacid et al. (2017), Higuera-Rodríguez and Medina-García (2020), could be combined as follows (see Figure 2).

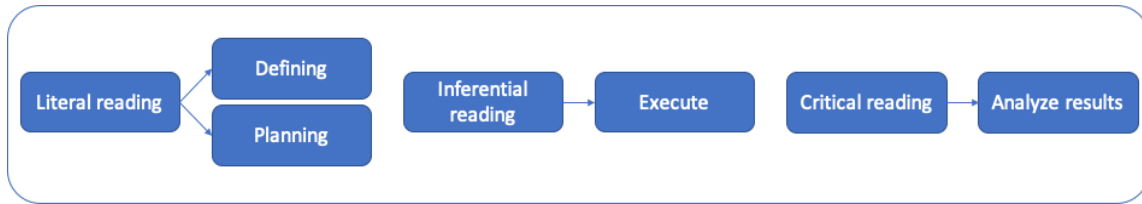


Figure 2. Combining Critical Reading Terms in Strengthening Critical Thinking. Source: made by the authors

Finally, an assessment of the to the two groups where this study was applied topics was made in order to establish the advantages and disadvantages of learning through real problem solving as a strategy to strengthen the teaching process and to determine if the learning was deep, establishing the appropriation of the concepts and the mathematical development, analyzing the students' performance during all the problem-solving.

A methodological aspect that emerged during the process was the posing of a simpler problem, but of the same nature, when the stu-

dent presented problems in solving the proposed problem, intending to develop previous ideas for the resolution of the initial problem. The reading and writing analysis analyzed whether the non-solution of the problem was due to the difficulty in understanding the statement or to the lack of competence in solving the exercise (Olivos, 2011).

To carry out the analysis of the data obtained, they were coded as shown in Table 1 where the parts of the sequence are related to the stages of resolution of the proposed problems, establishing the frequencies of their use.

Table 1. Description of the Stages to be Developed

DEFINE Preliminary information		PLAN Outline of the solution	
D1	Read the problem statement carefully and comprehensively	P1	Establish the parts where the problem breaks down
D2	Write the known and the unknown data, in the order they appear in the problem, using appropriate symbols and notations	P2	Make graphic representations of the phenomena
D3	Take all data to a suitable drive system	P3	To make the hypotheses
D4	Establish the conditions under which the phenomenon occurs	P4	write down the equations and laws involved with their definition
D5	Define what concepts of physics are involved		
EXECUTE Solution		ANALYSIS OF RESULTS	
E1	Treat the equations mathematically if necessary, until the variables that represent the unknown quantities are cleared up, to obtain the mathematical model that represents the phenomenon under study	A1	Determine that the units represent the unknown quantities adequately
E2	Verify each part of the problem by establishing the correspondence with the conditions posed and the mathematical development	A2	Establish if the result corresponds to reality
E3	Replace known data and perform the necessary algebraic and arithmetic operations	A3	Thinking about possible applications of the problem

The variables analyzed were the frequency of use of the stages applied and their contracting with the sequence between the control and experimental groups.

The reorganization for data processing was: a. Establishment of the frequency of use of the steps by a sequence in the educational strategy proposed to solve the problems raised in the pilot group. b. Establishment of the frequency of use of the steps by a sequence in the didactic strategy proposed to solve the problems raised in the control group. c. Relationship between the time of resolution of the problems between the experimental group and the control group. d. Comparison between the frequency of the stages carried out in each sequence in the control group and the experimental one. e. Correlational analysis between the stages used by the two groups of students and their implications within the learning

process f. Reading levels according to the guidelines given by the ICFES associated with those proposed by Poyla in mathematics and adapted to Physics (Calderon et al., 2018).

RESULTS AND DISCUSSION

In accordance with the sections established in the processing of the data, the results obtained were as follows:

The graph in Figure 3 shows the frequency with which students in the experimental group used each stage of the sequence of the didactic strategy proposed to solve the problems.

The graph in Figure 4 shows the frequency with which students in the control group used each stage of the sequence of the didactic strategy proposed to solve the problems.

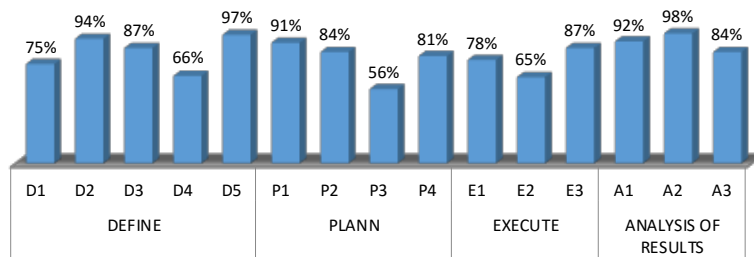


Figure 3. Frequency of Use of the Steps Included in the Problem-solving Sequence by Students in the Experimental Group. Source: made by the authors

A ratio was determined between the number of problems solved by the control group and the experimental group, obtaining a 3 to 1 ratio, i.e. while in a given time the students in the control group solved 3 problems, the experimental group solved one problem by applying all the stages of the sequence, however, it was observed that the students in the experimental group solved the

problems more satisfactorily than the control group, and also reported a rigorous analysis of the control group, while the students in the control group solved the problems by always looking for an answer, mostly numerical, at the expense of the analysis and in-depth understanding of the physical phenomenon posed.

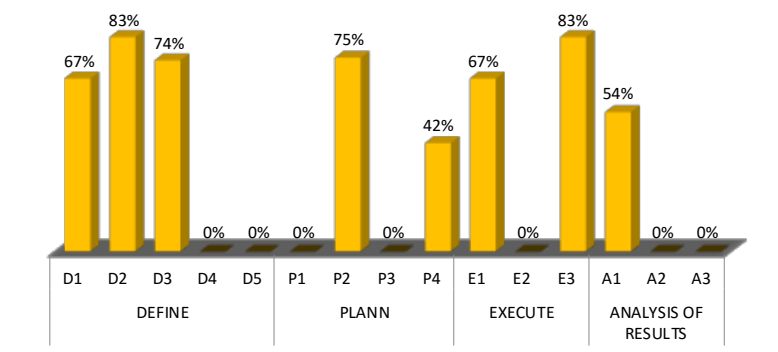


Figure 4. Frequency of Use of the Steps Included in the Problem-solving Sequence by Students in the Control Group. Source: made by the authors

The relationship of the results obtained (see figure 5). with the two groups is shown graphically below

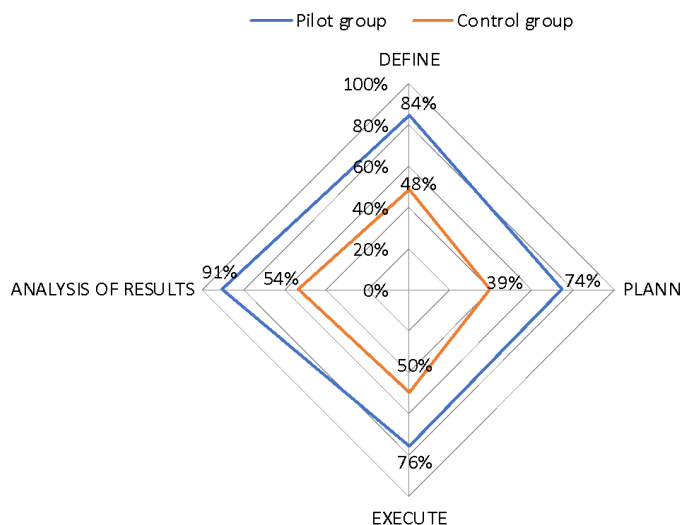


Figure 5. Frequency of Use of the Steps Included in the Problem-solving Sequence by the Students in the Control Group. Source: made by the authors

From the results, it is possible to establish what is summarized in Table 2 below. It is important to mention that for the resolution of the problems, students were asked not to use the calculator in order to encourage mental operations.

Table 2. Results that Can be Highlighted from the Process with Both Groups

		DEFINE
STAGE	PILOT GROUP	CONTROL GROUP
D1	The reading is done quickly by trying to immediately relate the question to a mathematical formula so that the data can simply be replaced	The reading is done comprehensively, highlighting the parts where the most relevant information is found to address the problem. It is at this stage that the student has a first idea of the conditions under which the phenomenon occurs and in which units of the data are presented
D2	Most of students write the data that the problem delivers, however, they present the same weaknesses as the experimental group, they do not know the symbolism and the way to notice the variables	All students follow the instruction to write the data in the order they appear in the problem, however, the professor must advise them on the use of the symbols and appropriate notations according to the characteristics of the variables
D3	A small percentage of students do not recognize the importance of taking the data to a single unit system and start to show difficulty to continue solving the problem correctly. As in the experimental group, they have difficulties in moving from one unit system to another, especially when working with derived physical quantities	It is recognized that there is a need to bring the data into a single system of units, however, the difficulty here is focused on the operational part of moving from one system of units to another, especially the physical quantities derived
D4	They did not work this stage	This is a relatively new issue for students because although they read the statement they tend not to relate and apply these conditions
D5	They did not work this stage	This stage allowed students to establish relationships between the theoretical and the procedural aspects.

PLAN		
P1	They did not work this stage	Thanks to the comprehensive reading that was done in advance for the students it was easy to determine the parts that divided the problem
P2	The students made simple graphic representations that superficially represented the phenomenon	Graphical representations were made with some rigor (sometimes to scale) that allowed the student to better visualize the problem situation and sometimes to compare the numerical response with the graph.
P3	They did not work this stage	The hypotheses proposed allowed the student to be guided on what would happen regarding the occurrence of the phenomenon, allowing for more clarity on the strategies used to solve it
P4	Since students tended to solve the problem mechanically, they simply worried about writing an algebraic formula to replace the data. Therefore, they had difficulties when they had to clear up variables or even showed no ability to pose equations when the problem required them	Students related this stage to stage D5 because having a clear understanding of the concepts made it easier for them to shape the mathematical model.
EXECUTE		
E1	At this stage, the students showed many weaknesses in relating the mathematical part, in addition, as the problem was being solved in a not so comprehensive way, there were many difficulties in relating the variables with the physical magnitudes present	From this point on, the student demanded more accompaniment from the professor since they had to develop the problem mathematically. At this stage, students showed more insecurity, but by relating their previous mathematical learning they were able to model the phenomenon under the requested characteristics
E2	They did not work this stage	In retrospect, the students related through a detailed analysis the correspondence between what was requested in the problem with the process they had been developing to solve the problem, which allowed them to be more aware of their learning
E3	Analyzing the work of students at this stage shows that from the beginning they tend to replace the data sometimes including the units, without reaching the mathematical model, which creates confusion and difficulties to work mathematically	Due to the orientation given to the students, they replace the numerical values when they have obtained the mathematical model that represents the phenomenon of the problem, guaranteeing greater success in obtaining the numerical response if required
ANALYSIS OF RESULTS		
A1	Most students did not pay attention to this stage, because they were satisfied with getting an answer or finishing the problem quickly	As most of students had developed the problem by following the stages carefully, the response obtained was satisfactory and consistent. However, those who did not obtain the units that correctly represented the physical magnitude found, was because they had no difficulty operating with the units
A2	They did not work this stage	By establishing that the answer to the problem posed corresponds to reality, the student can determine that the answer is correct and that they have satisfactorily completed the procedure
A3	They did not work this stage	After obtaining the answer, the professor and the students analyzed the possible applications of the problem and how its resolution can contribute to the solution of others of a similar nature. It is at this stage that the student consciously demonstrates the application of physics to the natural phenomena to which they are exposed on a daily basis

The discussion above pointed how researchers incorporated real problems as a teaching strategy, where the combination of reading critical levels with physics associated with Poyla's (1965) stages, models ways of guiding students to think critically through content based in this case physics.

It was easy to characterize the group that applies the problem-solving where the experimental group solved the problems more satisfactorily than the control group. At the same time, the result validates the problem teaching strategy in mechanical physics.

CONCLUSION

The arrangement of the two groups towards the resolution of the proposed problems, despite the instructions given to the control group, was to use stages D2, P1, P3 in the search of an immediate numerical answer to the proposed problem, avoiding essential stages for the interpretation and analysis of the result of the problem, which would lead the student to significant learning of the subject from its application to reality. Although the control group was not advised of the sequences and stages of the strategy, intuitively or due to previous knowledge, they applied some stages of the problem-solving sequence. Likewise, the stages applied by the control group do not necessarily correspond to the logic of the sequence. By having a previous explanation of each of the stages that compose the sequence of resolution of the problems, the experimental group carries out the process in a more structured way. Comparing the two groups experimentally, an increase in the capacity to solve the problems in the experimental group can be seen, because they are more reflective and careful in the resolution process. However, at a certain point in the experience, they saw the method as a straitjacket that prevented them from being more agile in the process, but after evidencing the benefits in the learning process they understood the importance of using the strategy. Among the advantages in the learning process: (a) the process of problem solving, and habituation is systematized; (b) students self-evaluated their process by identifying the errors made in the stages of problem-solving. In the teaching process; (c) identification of the most common mistakes made by students. A significant disadvantage is the time required for problem-solving, however, this issue is compensated by the enhancement of the teaching and learning processes.

REFERENCES

- Alonso Silva, S. V. (2016). *Construcción de una estrategia pedagógica para el fortalecimiento de competencias básicas en la Educación Media Fortalecida desde el Pensamiento de Diseño* (Doctoral dissertation, Universidad Nacional de Colombia-Sede Bogotá).
- Bhang, S. Y., Cho, S. C., Kim, J. W., Hong, Y. C., Shin, M. S., Yoo, H. J., ... & Kim, B. N. (2013). Relationship between blood manganese levels and children's attention, cognition, behavior, and academic performance—a nationwide cross-sectional study. *Environmental Research*, 126, 9-16.
- Bowers, A. J. (2017). Quantitative research methods training in education leadership and administration preparation programs as disciplined inquiry for building school improvement capacity. *Journal of Research on Leadership Education*, 12(1), 72-96.
- Calderón, A., Parra, C. A., & Piñeros, M. A. (2018). Guía de orientación Saber Pro: Módulos de competencias genéricas. Bogotá, Colombia: Instituto Colombiano para la Evaluación de la Educación.
- Callejas, J. S. Z. (2015). El modelo y enfoque de formación por competencias en la Educación Superior: apuntes sobre sus fortalezas y debilidades. *Revista Academia y virtualidad*, 8(2), 5.
- Carlino, P. (2017). Escrever, ler e aprender na Universidade. Uma introdução à alfabetização acadêmica. Buenos Aires: Fondo de Cultura Económica.
- Carrasco Altamirano, A., Encinas Prudencio, M. T. F., Castro Azuara, M. C., & López Bonilla, G. (2013). Lectura y escritura académica en la educación media superior y superior. *Revista mexicana de investigación educativa*, 18(57), 349-354.
- Cassany, D. (2012). En línea. Leer y escribir en la red. España: Anagrama.
- Estepa, R. P., & Rodríguez, R. B. (2015). Una mirada a las pruebas saber pro en la calidad de la educación superior en Colombia. *Pensamiento Republicano*, (3).
- Higuera-Rodriguez, L., & Medina-Garcia, M. (2020). Active methodologies as a key element in teacher training for educational inclusion. *New Trends and Issues Proceedings on Humanities and Social Sciences*, 7(3), 13-19.
- ICFES. (2017). Guía de orientación Saber Pro. Módulo de Competencias Genéricas. Retrieved from: http://www.fce.unal.edu.co/media/files/Guia_de_orientacion_modulos_de_competencias_genericas_saber-
- Javeriana, P. U., & Cun, C. (2007). Pontificia Universidad Javeriana. *Recuperado el*, 13.
- Laiton Poveda, I. (2011). ¿ Es posible desarrollar el pensamiento crítico a través de la resolución de problemas en física mecánica?.

- López, Y., Muñoz Urueta, L. J., Cajiao, F., Reyes, Y., Burgos Cantor, R., & Urbina Rangel, F. (2013). Leer para comprender, escribir para transformar. *Mineducación. Bogotá*.
- May Cen, I. D. J. (2015). George Polya (1965). Cómo plantear y resolver problemas [título original: How To Solve It?]. México: Trillas. 215 pp. *Entreciencias: diálogos en la Sociedad del Conocimiento*, 3(8).
- Olivos, T. M. (2011). Didáctica de la Educación Superior: nuevos desafíos en el siglo XXI. *Perspectiva educacional*, 50(2), 26-54.
- Ozuru, Y., Dempsey, K., & McNamara, D. S. (2009). Prior knowledge, reading skill, and text cohesion in the comprehension of science texts. *Learning and instruction*, 19(3), 228-242.
- Pérez de Pérez, A. (2009). El desarrollo de la lectura crítica: una vía hacia la alfabetización mediática en educación superior. *Letras*, 51(78), 309-356.
- Pérez Abril, M., Rincón Bonilla, G., Vargas, A. P., Zuluaga Ocampo, Z. P., Barrios Martínez, D. M., Vera, R., & Pomares Quimbaya, A. (2013). ¿Para qué se lee y se escribe en la universidad Colombiana? Un aporte a la consolidación académica del país. *Agroecología*, 792, 149.
- Pérez, E. E., Nivelá, M. L. H., & Expósito, R. E. (2014). La resolución de problemas como estrategia de enseñanza para el aprendizaje de la táctica ofensiva en la categoría prebenjamín de fútbol 8. *Revista de psicología del deporte*, 23(1), 209-217.
- Pozo, J. I., Pérez Echeverría, M. P., Domínguez, J., Gómez Crespo, M. A., & Postigo, Y. (1994). Solución de problemas, Madrid: Santillana. *Aula XXI*.
- Rao, S., Cameron, A., & Gaskin-Noel, S. (2009). Embedding general education competencies into an online information literacy course. *Journal of Library Administration*, 49(1-2), 59-73.
- Rendón, J. C. M., Patiño, C. E., Vera, D. C. A., Gómez, J. A. G., & Aristizábal, C. S. (2014). La lectura crítica en la educación superior: un estado de la cuestión. *Revista Virtual Universidad Católica del Norte*, (41), 4-18.
- Rendón, J. C. M. (2013). La interpretación de la caricatura política: un asunto de cultura política. *Zona próxima*, (18), 46-59.
- Rico, L. M. M. (2011). Una práctica de lectura crítica con los estudiantes de la Universidad de Medellín. *Revista Virtual Universidad Católica del Norte*, 1(34), 162-193.
- Rodríguez, A. N. (2007). Lectura crítica y escritura significativa: Acercamiento didáctico desde la lingüística. *Laurus*, 13(25), 241-262.
- Shepherd, M. D., Selden, A., & Selden, J. (2012). University students' reading of their first-year mathematics textbooks. *Mathematical Thinking and Learning*, 14(3), 226-256.
- Vázquez, J. A. (2010). Lectura en pantallas, hábitos de lectura, ebooks, literatura digital. *Dosdoce. com*.
- Velásquez Almonacid, J. N., & Ríos Avella, C. R. (2017). Análisis sobre competencias específicas en Pruebas Saber Pro 2014 en programas de formación en Licenciatura en Biología, Licenciatura en Química, Licenciatura en Física y Licenciatura en Ciencias Naturales y Educación Ambiental de cuatro (4) universidades del país.
- Yanti, V. K., Suliyannah, S., Safitri, N. S., & Deta, U. A. (2021). Evaluation of the Implementation of Cross Interest Physics Subject for Non-Mathematics and Natural Sciences Students at Senior High School. *Journal of Innovation in Educational and Cultural Research*, 2(1), 17-24.
- Zuluaga, Y. E. L., Duque, G. M. G., & Narváez, (2020) A study of critical thinking in higher education students. *Revista Latinoamericana de Estudios Educativos*, 16(2), 256-279