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Theoretical approximations between Sternberg's Theory of Triarchic Intelligence and Ausubel's Theory of Meaningful Learning: a proposal for evaluating the emergent learning of the Problematized Experimental Activity (PEA)

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Abstract: In the formal teaching of Natural Sciences, it is verified that experimental activities are developed occasionally, either due to the lack of spaces suitable for their realization, or due to the precarious conditions for teaching, or even due to the lack of preparation and/or disapproval of the teacher in doing so. The Science laboratory, however, if used effectively, is fertile ground for the development of cognitive and metacognitive skills, and for the meaningful learning of scientific concepts, principles and theories. In this regard, carrying out an assessment of the skills developed by students is crucial, with a view to qualifying teaching methods and methodologies. As such, as a theoretical research problem, we seek in this article establish approximations between Sternberg's Theory of Triarchic Intelligence and Ausubel's Theory of Meaningful Learning and, based on the emerging arguments, develop and show Cognitive Performance Indicators, under the domain of conditions for practical, analytical and creative intelligence. Finally, in the light of the Problematized Experimental Activity (PEA), it will be argued about space-time for the application of such indicators, with the purpose of learning evaluation, considering sequential studies and interventions.

Keywords*:* Cognitive and Metacognitive Skills. Cognitive Performance Indicators. Experimental Science Teaching.

Aproximaciones teóricas entre la Teoría de la Inteligencia Triárquica de Sternberg y la Teoría del Aprendizaje Significativo de Ausubel: una propuesta para evaluar el aprendizaje emergente de la Actividad Experimental Problematizada (AEP)

Resumen**:** En la enseñanza formal de las Ciencias Naturales, se verifica que las actividades experimentales se desarrollan ocasionalmente, ya sea por la falta de espacios adecuados para su realización, por las precarias condiciones de la enseñanza e incluso, por la falta de preparación y/o desaprobación del profesor al hacerlo. El laboratorio de Ciencias, sin embargo, si se utiliza con eficacia, es un terreno fértil para el desarrollo de habilidades cognitivas y metacognitivas, así como para el aprendizaje significativo de conceptos, principios y teorías científicas. En este sentido, es fundamental realizar una evaluación de las competencias desarrolladas por los

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estudiantes, con miras a cualificar métodos y metodologías de enseñanza. Siguiendo esta línea, en este articulo, como problema de investigación teórica, hemos buscado establecer aproximaciones entre la Teoría de la Inteligencia Triárquica de Sternberg y la Teoría del Aprendizaje Significativo de Ausubel y con base en los argumentos planteados, desarrollar y presentar Indicadores de Desempeño Cognitivo, bajo el dominio de las condiciones para la inteligencia práctica, analítica y creativa. Finalmente, a la luz de la Actividad Experimental Problematizada (AEP), se establecerá el espacio-tiempo para la aplicación de dichos indicadores, con el fin de evaluar los aprendizajes, considerando estudios e intervenciones secuenciales.

Palabras clave: Habilidades Cognitivas y Metacognitivas. Indicadores de Evaluación Cognitiva. Enseñanza de las Ciencias Experimentales.

Aproximações teóricas entre a Teoria da Inteligência Triárquica de Sternberg e a Teoria da Aprendizagem Significativa de Ausubel: uma proposta de avaliação da aprendizagem emergente da Atividade Experimental Problematizada (AEP)

Resumo: No ensino formal das Ciências da Natureza se verifica que as atividades experimentais são desenvolvidas ocasionalmente, seja pela ausência de espaços próprios à sua realização, seja pelas condições precárias ao exercício da docência, seja ainda pelo despreparo e/ou desapreço do docente em fazê-lo. O laboratório de Ciências, contudo, se utilizado de modo eficaz, é terreno fértil ao desenvolvimento de habilidades cognitivas e metacognitivas, e à aprendizagem significativa de conceitos, princípios e teorias científicas. Nesse propósito, realizar a avaliação das capacidades desenvolvidas pelos alunos é fulcral, na intenção da qualificação dos métodos e das metodologias de ensino. À guisa disso, a título de problema teórico de pesquisa, busca-se neste artigo estabelecer aproximações entre a Teoria da Inteligência Triárquica de Sternberg e a Teoria da Aprendizagem Significativa de Ausubel e, a partir dos argumentos emergentes, desenvolver e apresentar Indicadores de Desempenho Cognitivo, sob domínio das condições à inteligência prática, analítica e criativa. Por fim, à luz da Atividade Experimental Problematizada (AEP), argumentar-se-á sobre espaços-tempo para a aplicação de tais indicadores, com propósitos de avaliação da aprendizagem, tendo em vista estudos e intervenções sequenciais.

Palavras-chave: Habilidades Cognitivas e Metacognitivas. Indicadores de Avaliação Cognitiva. Ensino Experimental de Ciências.

1 Introductory Aspects and TTI-TML-PEA Associations

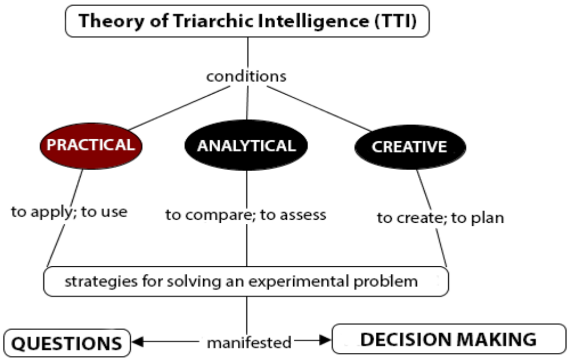
Science teachers commonly acknowledge that experimentation sparks interest and motivation among students, whether to investigate the subjects specific to Science or through the practices inherent to scientific procedures. Experimental activities provide students with opportunities to interpret phenomena, construct meanings, and handle utensils and equipment while conducting certain practical assays. Moreover, experimental classes (i) promote greater teacher-student interaction; (ii) allow for more significant knowledge exchange; (iii) facilitate the assimilation of theoretical subjects and make them more tangible; and (iv) foster the learning of scientific processes. By valuing such assumptions, experimentation can serve as a motivating factor and promoter of the learning process, through reception, discovery, and/or research. It is also important to highlight that the cognitive skills expected in students' education, when dealing with scientific themes, are related to the abilities of understanding, seeking well-founded information, enhancing communication and expression, creating and innovating, and applying the knowledge developed in situations not yet explored in teaching environments (Merço, 2003; Silva; Silva, 2019; Monteiro et al., 2013; Oliveira, 2010).

In this sense, assessing the development of students' cognitive and metacognitive skills is essential for the establishment and refinement of teaching strategies capable of fostering meaningful, transferable, and enduring learning experiences. Cognitive and metacognitive skills, within the context of science education, are associated with *practical, analytical*, and *creative* intelligences - anchored in the Theory of Triarchic Intelligence (TTI), or Full Intelligence, proposed by Robert J. Sternberg. Intelligence, in this framework, is defined as:

> [...] the ability to learn from experience, using metacognitive processes to enhance learning, and the ability to adapt to the environment around us. It may require different adaptations within different social and cultural contexts (STERNBERG, 2012, p. 474).

As Full Intelligence, we have "[...] the integrated set of capabilities necessary for an individual to succeed in life, regardless of how they define it, in their sociocultural context" (Sternberg; Grigorenko, 2003, p. 16), for the purpose of problem-solving and often manifested through questioning and decision-making. In Figure 1, the arguments previously presented have been organized in an intentional articulation to the purposes of this article.

Figure 1: TTI: theoretical relationship between concepts



Source: authors (2023).

Once the teaching methodology is interconnected with *problem-solving* and *experimentation*, Sternberg's implications (1988) come to light, considering that the science laboratory, when used efficiently, is fertile ground for the development of cognitive and metacognitive skills, as well as for meaningful learning (Zoller, 1993; 2001; 2004; 2013).

In the perspective of David Ausubel's Theory of Meaningful Learning (TML), the role of the teacher becomes that of mediating the process of knowledge construction, and their actions are reconfigured to take into account the students' prior knowledge as a starting point for their praxis. In this understanding, the teacher is no longer the central figure in the teaching-learning processes. This position is now occupied by the student, ensuring an active role in their learning (Ausubel, 2003; Ausubel *et al*., 1980; Moreira, 1999; Novak, 1981; Pozo, 2002).

The Problematized Experimental Activity (PEA) is a teaching methodology that uses experimentation aligned with the principles of a psychologically based learning process resulting from an investigative process potentially capable of promoting autonomy and a constant search for solutions to a problem. This assertion is based on theoretical and methodological axes. The theoretical axis refers to the planning of the PEA and is composed of three stages: the proposed problem, experimental objective, and methodological guidelines, as described in Table 1 (Silva; Moura; Del Pino, 2015; 2017).

Table 1: Characterization of the theoretical axis of the PEA.

Proposed problem	The problem that originates the PEA requires the elaboration of a solution, or its derivation into new arguments, distinguishing itself from the singularity of a question that generates the expectation of an answer. Problems privilege processes, refer to the use of heuristic strategies, methods, techniques specific to systemic investigation, in the search for a solution, compared to many others that could be considered..
Experimental objective	It refers to proposals for practical activities that centralize experimentation, operationally. Which technique is essential in generating data that will subsequently be transformed into results and, thereby, potentially provide practical support for solving the proposed problem? At the end of the empirical procedures, what is intended to be obtained/produced? What product/object can be generated?

Methodological guidelines	Not under a prescriptive trend, but reinforcing the idea of procedural guidance, they constitute a protocol of practical actions derived from the experimental objective. They act as guiding propositions for the procedures to be carried out. They should not be admitted as a limiting factor of experimentation; it is argued here that when it comes to experimentation under observational biases or deterministic procedural biases, learning is reduced.

Source: adapted from Silva, Moura, and Del Pino (2022).

The methodological axis, referring to the conduct of the PEA, consists of five stages, namely: *previous discussion, organization and development, return to the workgroup, socialization, and systematization*. Table 2 provides descriptions of each of them.

Table 2: Characterization of the methodological axis of the PEA.

Previous discussion	As a triggering action of the PEA process, an introductory discussion is proposed, in the classroom or in the laboratory, to identify students' prior knowledge about the main themes to be addressed.
Organization and development	It aims at the procedural organization of the experimentation. It begins with the proposition of the theoretical problem (elaborated, identified, or selected) and its derivations in the experimental objective and methodological guidelines. It continues with the collective implementation of an organization of experimental work, involving the arrangement of students in small groups, with subsequent recommendation of initial discussions in each of them, followed by the raising of hypotheses for the solution of the proposed problem, emerging from the students' prior knowledge. It is followed by the development of the experimental activity, in which students carry out the experimentation based on their understanding, under the observation and guidance of the teacher.
Return to the workgroup	At this point, the aim is to promote reflection and internal discussion within the workgroups, followed by the arrangement and systematization of the recorded information. After completing the experimental activity, students are asked to return to their workgroup to organize the records they deem relevant, in order to establish understandings that can lead to a collective argumentation.
Socialization	The aim here is to make visible the methodological paths followed based on the justifications with which each group will defend their results and a possible solution to the problem that triggered the PEA. From the confrontation between different points of view, it is possible to move towards a possible generalization, considering the guidance given by the teacher.

Systematization	It is recommended to materialize a product as an essential action for learning as well as for the generation of psychological knowledge. Printed material can be used as theoretical support, followed by a textual production, report, or conceptual map (among other possible strategies/resources) developed by the student based on the knowledge generated around the manipulated, collected, and/or produced information.

Source: adapted from Silva, Moura, and Del Pino (2022).

In light of the aforementioned, this article aims to establish connections between Sternberg's *Theory of Triarchic Intelligence* (TTI) and Ausubel's *Theory of Meaningful Learning* (TML), with a view to developing indicators for the cognitive assessment of learning scientific knowledge objects, through the lens of experimentation, in the particularities of the Problematized Experimental Activity (PEA), with the intention of enhancing the theoretical-practical approaches circumscribed to Science education.

2 Methodological aspects: a proposal for dialogical convergence

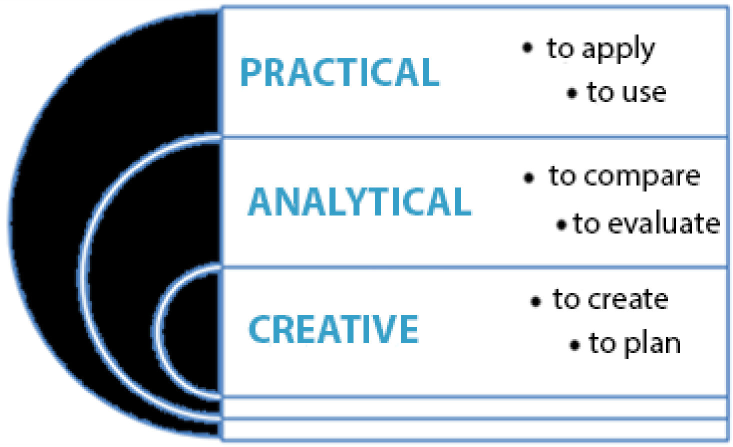
This article presents the results of a theoretical-methodological research, as it is an investigation aimed at inquiring into methods and procedures adopted as evaluative. Therefore, it is associated with the paths, forms, and procedures followed to achieve certain ends, as well as the study of the paradigms, methods, and techniques dominant in scientific production. Regarding the procedures, it consists of a bibliographic research, as it starts from the exploration of the main theoretical bases contained in scientific publications on the proposed topic. From this bibliographic research, specific objectives were aimed at, in order to describe the methodology employed in the process of creating evaluative indicators and to contribute to the learning and usability of Science. The results were constructed based on bibliometric and scientometric techniques, as they are considered adequate by their authors to achieve the proposed objectives and to enable applications in the experimental teaching of Science (Demo, 1994; Gil, 1991; 1997; Araújo, 2006; Callon *et al*., 1995; Bogdan; Biklen, 1994; Denzin; Lincoln, 2006; Flick, 2009; Sampieri *et al*., 2013).

In these terms, the bibliographic survey was systematically conducted using bibliometric technique, on data/information search platforms about Sternberg's Theory of Triarchic Intelligence (TTI) and Ausubel's Theory of Meaningful Learning (TML), taking care to use primary sources from both authors. This survey was followed by the construction of evaluative indicators of learning in Sciences and aspects related to cognitive and metacognitive skills and to triarchic or full intelligence, in its practical, analytical, and creative conditions. Finally, the developed evaluative indicators were associated with the Problematized Experimental Activity (PEA) in its theoretical - *planning* - and methodological - *intervention* - axes.

3 Indicators of Cognitive Performance (ICP)

Accepting the dynamic nature of Science and comparing various contemporary epistemologies, it is observed that its foundations and principles are constantly changing, whether in relation to its objects of knowledge or its practices. One could say: in its foundations, justification, and scope. Therefore, nothing is more pertinent to an educational theory than considering the mediation of different contents that are evolving, precisely to meet the demands of teaching. For this, it becomes necessary to deal with the cognitive processes of learning and it is opportune to evoke Sternberg's Theory of Triarchic Intelligence (TTI), which proposes that human intelligence is tripartite in its *practical, analytical*, and *creative* conditions (Figure 2).

Figure 2: practical, analytical, and creative intelligences.



Source: adapted from Sternberg (1988).

Practical intelligence refers to the ability to translate theory into practice, that is, to transform abstract constructions into material productions. Analytical intelligence is related to the ability to go beyond the data; to analyze, compare, evaluate ideas, solve known problems, and make decisions. Creative intelligence can be characterized as the individual's ability to plan, create, and invent new and original ideas. Although analyzed separately, these intelligences operate simultaneously; they are considered, therefore, interdependent (Sternberg, 1988; 1993; 1994; 1996; 2000; 2002; 2012).

In a learning context, the three different aspects of intelligence can be related to the different stages of the cognitive process in which the student is involved in carrying out the proposed activity. Both the stages of the process and the aspects of intelligence recruited in a particular task do not follow a fixed or predetermined order. In other words, depending on the task or problem to be solved, the order can vary considerably. However, it is possible to associate each aspect of intelligence - practical, analytical, and creative - with very specific stages of the cognitive process. In the context of the Problematized Experimental Activity (PEA), it is considered that each aspect of intelligence will be, to a greater or lesser extent, present in the different stages that compose it.

Deals with thinking focused on using previously acquired or consolidated knowledge to transform or adapt the environment (Sternberg; Grigorenko, 2002). This intelligence differs from intelligence associated with academic success and the set of skills necessary for individuals to achieve their goals. It is understood, therefore, that this aspect of intelligence will be recruited for tasks that involve more practical or procedural actions, such as: (1) researching additional information to complement the knowledge acquired on a particular topic being studied; (2) using the experimental practice environment as a material coping strategy for the problem to be solved; (3) establishing priorities in order to understand the general context in which the problem to be solved is inserted; and (4) applying what has been learned in another context or in situations different from those experienced in the teaching environment (Sternberg, 1988; 1993).

The creative proposition of discussions about Science can be seen as art, especially when some material is created or an innovative process of knowledge production or investigation about little-themed or not yet themed subjects is developed; the definition of a new paradigm, different from the one adopted in the traditional interpretation of the results obtained by the scientist; the formulation of a differentiated interpretation of scientific data and the convincing of others that such interpretation is correct; the consideration of an alternative explanation for a generally accepted scientific phenomenon; or the revision of an approved laboratory procedure for a new experiment to ensure its effectiveness (Sternberg, 1988; 1993; Grigorenko; Sternberg, 1998; Sternberg; Grigorenko, 2003).

Damascena, Silva, Kauark, and Moura (2022) addressed the practical applications of the Problematized Experimental Activity (*PEA1*), aimed at solving students' learning difficulties for the object of knowledge *inorganic functions*. This research focused on the study of compounds extracted from minerals, based on a local productive arrangement that worked on the generative theme of *marble rock*. In this domain, students addressed a proposed problem to determine a procedural and experimental route. They also addressed the mineralogical constitution of rocks, their formation and extraction processes, beneficiation, and socio-environmental impacts..

In the case of analytical intelligence, thinking is focused on logical operations involving abstraction, in order to compare and contrast concepts, theories, and results obtained (Sternberg; Grigorenko, 2003). Thus, this aspect of intelligence will come into play when the student is involved in activities or tasks that require the following cognitive efforts: (1) correctly identifying a proposed problem in order to understand it in the experimental context and formulating strategies to solve the identified problem; (2) systematizing information before and after the experiment, verified in the organization of information about the tasks to be executed, and comparing the results found with the predicted results; (3) formulating strategies for the different stages of the experiment to be developed effectively and precisely, and monitoring the execution of the planned strategies; (4) being able to identify, systematize, formulate, and evaluate solutions related to the investigated problem, comparing the results found with those initially predicted (Sternberg, 1988; 1993).

The Analytical Condition can be evidenced by confirming that in a science laboratory exercise, safety procedures are being followed, or: by comparing the actual results of an experiment with the predicted and/or obtained results; by monitoring protocols, practical procedures, and analyzing feedback at each stage of work; or by encouraging students to plan solutions reflectively, based on a thoughtful approach and not impulsively, discussing strategies with the group before effectively addressing problem-solving (Sternberg, 1988; 1993; Grigorenko; Sternberg, 1998; Sternberg; Grigorenko, 2003).

Nascimento, Kauark, and Moura (2022) exemplify the requirement of the Analytical Condition, applied in the educational context to investigate thermochemical principles, in order to verify the heat exchanges that occur in the transformations of matter, or in changes in the aggregation state of substances, i.e., in chemical reactions. For this purpose, through the application of the Problematized Experimental Activity (*PEA2*), they addressed the determination of the enthalpy energy of oilseed plants, experimentally verified, using a calorimeter prototype, and with the development of students' cognitive levels, in terms of critical meaningful learning.

Regarding creative intelligence, the focus is on going beyond acquired knowledge and testing the limits of what is consensus in order to enable the emergence of new possibilities (Sternberg; Grigorenko, 2003). Thus, this aspect of intelligence will be present whenever modes or processes manifest themselves from: (1) interpreting the results of an experiment and redefining the procedures to be executed; (2) generating ideas to propose a new experiment or perceiving and testing new guidelines for an ongoing experiment; (3) arguing consistently and justifying the choice of a specific procedure over another, or the procedures adopted in general, and also justifying the results found; (4) developing different approaches to knowledge, including alternative and even novel explanations for phenomena already known and explained by the scientific community (Sternberg, 1988; 1993).

Vivaldi et al. (2020) addressed the evolutionary teaching of chemical concepts (matter and energy) in Elementary School, with 5th-grade students, applying the didactic-pedagogical propositions of the Problematized Experimental Activity (PEA3), through the use of the Science supplementary book *The secret formula: a chemical puzzle adventure* (Green, 2015). Next, in Table 3, nine experiments are presented, sequentially planned (E1 to E9) and experienced by students, in order to articulately and creatively address the chemical concepts of *matter* and *energy.*

Table 3: Chemical puzzle adventure (PEA).

Experiments (E)	Proposed Problems (PP)	Experimental Objectives (EO)
(**E1**) The chocolate from grandma's factory is completely hard!	How can we heat it quickly without burning it in the pan?	Understanding the physical state changes considering the contact surfaces.
(**E2**) The thieves mixed all of grandma's factory salt with the sand from the factory!	How would you separate this mixture?	Understanding what a mixture is; learning the meaning of dissolution; understanding dissolution, filtration, and evaporation as methods of separating mixtures.
(**E3**) To make sure that the table salt was recovered and that it was that white powder, grandma sprinkled some of it	Why did she do that?	Recognizing, through flame testing, that each mineral from the periodic table presents a particular coloration when subjected to fire.

onto the fire!		
(**E4**) The chocolate will melt!	Why did grandma take blankets and layer the chocolates?	Understanding what heat is and how its transfer occurs through materials.
(**E5**) Some balloons from the birthday party fall and others float!	Why are there birthday balloons that float and others that fall to the ground? Why choose helium gas to pass through the electric fence?	Understanding the density of gases; comparing that similar volumes of carbon dioxide and helium have different masses.
(**E6**) Help! I have a stomachache!	Why do we take "fruit salt" or "baking soda" when we have heartburn to improve our stomach?	Identifying if some materials used at home and school are acids or bases; understanding what acids and bases are.
(E7) The underground water!	How does the water get into the water table below the ground?	Understanding the water cycle; analyzing the rock characteristics.
(E8) The key stuck in the block of ice!	How to remove the key from the laboratory that is frozen inside a block of ice?	Understanding the process of cryoscopy; differentiating the temperature change when a solute is added to ice.
(**E9**) The secret formula trapped in the sand castle!	How to destroy a sandcastle as quickly as possible to get the secret formula?	Understanding that materials have forces that bind their structure.

Source: Adapted from Vivaldi et al. (2020).

Based on the described and exemplified assumptions regarding *practical, analytical,* and *creative* conditions, Table 4 presents 12 Cognitive Performance Indicators (CPI), developed considering the guidelines adopted in this article, which follow the principles of the Theory of Meaningful Learning (TML), and fulfill the conditions of triarchic or full intelligence (TTI).

Table 4: 12 CPI, in light of TTI, in its tripartition.

Practical	P_1	Researching additional information on the topics addressed.
	P_2	Using the practice environment as a material strategy to address the problem.
	P_3	Establishing priorities to understand the overall context and the impact of the experiment.
	P_4	Applying learning and developments in other situations and realities.
Analytical	A_1	Identifying the proposed problem.
	A_2	Systematizing previous and subsequent information to the experiment.

	A_3	Formulating strategies for the development of the experiment's stages.
	A_4	Evaluating the solutions and comparing the results obtained with the predicted ones.
Creative	C_1	Redefining procedures when interpreting the results of the experiment.
	C_2	Generating ideas to propose a new experiment or paths for an ongoing experiment.
	C_3	Arguing about justifications given to procedures and results.
	C_4	Developing different approaches to knowledge, capable of considering an alternative explanation for already accepted scientific phenomena.

Source: Adapted from Sternberg (2012).

The application of Problematic Experimental Activity (PEA1; PEA2; PEA3) demonstrates that the principles of the Theory of Meaningful Learning (TML) were met, as well as the development of the practical, analytical, and creative conditions inherent in the Theory of Triarchic Intelligence (TTI). Therefore, the evolutionary process of cognitive and metacognitive skills and the acquisition of knowledge in Science can be evaluated by the Cognitive Performance Indicators (CPI).

In the context of the synthesized integration of the mentioned theories, framed by the PEA and considering the practical aspect of the conditions for assessing meaningful learning and full intelligence, the importance of seeking complementary information for addressing the themes becomes evident. This condition is favored by the strategic aspect of addressing a problem and by the need to establish priorities in order to understand the contexts and impacts that result from the experiences and the learnings that unfold from them.

Regarding the analytical aspect, there is a need for cognitive mobilization, whether for identifying the proposed problems or for systematizing the previously articulated information and subsequently, the knowledge derived from the experiments. It is also necessary for the comparative evaluation between the expected results and those achieved from the solutions found for the proposed problems.

The creative aspect of triarchic intelligence, on the other hand, is observed in the emergence of different strategies and innovative directions for redefining procedures and interpreting the results achieved experimentally. This occurs through the proactive generation of alternative paths, along with reasoned argumentation of the processes, solutions, and outcomes found in new or ongoing experiments. The creative condition likely favors the development of different approaches to knowledge and the consideration of alternative explanations for established scientific events. In this context, the Cognitive Performance Indicators (CPI) could serve to "verify" knowledge acquisitions, learning, and the development of cognitive and metacognitive skills.

E In summary, the association between TTI, TML, and PEA establishes the basis for understanding the 12 cognitive indicators developed to be observed in specific classroom activity contexts. The 12 indicators are grouped into three different axes, characterized by addressing aspects of full intelligence, namely: practical (marked with the letter P), analytical (marked with the letter A), and creative (marked with the letter C). Each axis encompasses four (4) indicators (marked with the numerals 1 to 4) that, in turn, help to describe more precisely the student's cognitive process during the practices carried out according to the Problematic Experimental Activity methodology. As highlighted earlier, it is important to note that the numerical marking does not suggest a sequential order of appearance of the different mental operations performed by students; it simply aims to facilitate the identification of each cognitive indicator. The predominance of indicators from a particular axis in a specific stage of the activity proposed in the classroom suggests that, in that stage, one of the three aspects of intelligence was most demanded. However, indicators from all three axes can be present in the same stage of the activity, depending on the topic developed in that specific lesson, as well as throughout all stages of the activity.

4 CPI and TML: theoretical approaches exemplified by the Problem-Based Experimental Activity (PEA)

The cognitive evaluation, from the perspective of TTI, brings an aspect that was previously nonexistent or little addressed during the evaluation process: creative thinking. The individual's creative intelligence corresponds to how they communicate through speech and writing, as well as demonstrating their abilities to create ideas for problem-solving. In general, the evaluative methods conventionally used in the field of Natural Sciences emphasize the analytical and practical aspects of learning. However, the creative aspect, in our view, allows for the breaking of limitations and obstacles of practical and analytical thinking, that is, the evaluation of creative thinking can foster, in individuals, the development of innovative potential in the development of other aspects, since intelligences are interdependent (Sternberg; Grigorenko, 2002;

Grigorenko; Sternberg, 1998).

Under these postulates, the purpose of this section is to establish approaches, highlighting those of a theoretical nature, between the assumptions of the primary sources of the Theory of Meaningful Learning (TML), and the Cognitive Performance Indicators (CPI), previously described. Therefore, in defense of this idea and beyond argumentative semantics, a structure of meaning of these two fields of knowledge is proposed, potentially valid for the evaluation of the subject's learning, in this case, exemplified by the didactic strategy of Problematic Experimental Activity (PEA).

4.1 Practical Condition

Regarding the Practical Condition, the indicator encoded as P_1 proposes: "Research complementary information related to the topics addressed." In this case, it is up to the student, under the vigilant guidance of the teacher, to identify in specific sources clarifications capable of leading to deeper understandings or new cognitive articulations. Regarding learning, under the understanding of the TML, it is up to the student to construct their own meanings from the topics raised by the teacher, and in this perspective, the particular movements they are capable of making are essential for the development of naturally psychological knowledge. In the research procedures, even under pre-established frameworks, as defended, possibilities are conferred for identifying new correlations between prior and new knowledge, with perspectives for the development of idiosyncrasies. This principle, in theory, is valuable both in discovery-based learning and in receptive models, as it offers avenues for students to develop their own understanding and perspectives:

> [...] the problems generated by traditional teaching are not so much due to its expository focus as to the inadequate handling of the students' learning process. To foster meaningful learning, it is not necessary to resort so much to discovery, but rather to improve the effectiveness of presentations. For this, it is necessary to consider not only the logic of the disciplines but also the logic of the students. In fact, learning science consists of transforming logical meaning into psychological meaning that is, getting students to take on scientific meanings as their own (Ausubel, 1973, p. 214).

When, in the space-time of the PEA, during *systematization*, students are asked to inquire into appropriate theoretical bases to enable them to contrast what was perceived experimentally (and conceived cognitively) with specific theoretical frameworks, aiming at semantic recording and textual production, research procedures are fostered. As a result, new correlations between knowledge are favored, via principles of subordinated and combinatory meaningful learning, and renewed links between already consolidated knowledge are also favored, in light of postulates linked to superordinate meaningful learning (Ausubel, 1978).

The indicator P_2 is more closely related to procedures, that is, to approach strategies that prioritize the execution of actions capable of fostering understandings based on what they provoke. By considering "Using the practice environment as a material strategy to confront the problem," the intention is to boost the perception of different means of addressing a certain didactic-pedagogical (or social, we could say) problem, overlapping those of a practical-experimental nature. David Ausubel's TML, regarding problem-solving strategy, attributes to it the status of "[...] any activity in which the cognitive representation of previous experience and the components of a presented problematic situation are reorganized in order to achieve a specific goal" (Ausubel, 1968, p. 533). In this aspect, under a specific conceptual framework, the development of an acceptable solution for a given problem situation is sought, potentially capable of leading the subjects investigating it to form new connections. Rigorously in this aspect, Novak and Gowin (1999, p. 108) treat problem-solving as "[...] a special case of meaningful learning," as it fosters psychological understandings from the perception of coherence and logic that a situation is capable of generating.

Given the guidelines of the PEA, it could be considered that, systemically, this strategy privileges the practice environment in its multiple dimensions and developments. This idea is justified because the PEA is characterized as an experimental proposal for science teaching and learning, which is structured from the originating problem. Thus, the practice environment is approached under the scope of this problem for which a solution is sought. However, specifying the theoretical axis of the PEA, understanding and confronting the *proposed problem* requires cognitive reorganizations on which meaningful learning depends.

The indicator P3, "Establishing priorities to understand the overall context and the impact of the experiment," while still maintaining the Practical Condition of the triarchic or full intelligence proposed by Sternberg (2001), presents, in its backdrop, relations with systemic perspectives of the pedagogical proposal. In this aspect, the concepts of progressive differentiation and integrative (or integrating) reconciliation, constitutive of the TML, deserve emphasis. These concepts, when articulated with each other and aligned with mechanisms inherent to the teaching and learning processes, produce principles of broad meanings that permeate the structural theoretical bases of the theory itself and extend to instructional planning. According to Ausubel (1968, p. 79), in his own terms:

> [...] according to the principle of progressive differentiation, the most general and inclusive ideas of the subject are presented first, and then are progressively differentiated in terms of detail and specificity. This order of presentation presumably corresponds to the natural sequence of awareness acquisition and cognitive sophistication when humans are exposed to an entirely unfamiliar field of knowledge [...] also to the postulated way in which this knowledge is represented, organized, and stored in the nervous system.

According to this claim, learning is facilitated when the teaching dynamics start from the *genera*l and move towards *specificities*. In the didactic scope, the pedagogical strategy of problem-solving starting from concrete and familiar situations to the students is notably close to this conception. In the case of integrative reconciliation, it involves the "[...] part of the meaningful learning process that results in the explicit delineation of similarities and differences between related ideas" (Ausubel; Novak; Hanesian, 1980, p. 526). Therefore, for the context situation to gain in understanding and meaning, the specificities (or teaching units) add value because they contribute to the sophistication and depth of the original situation.

The methodological guidelines, components of the theoretical axis of the PEA, which are characterized as general directions for actions emerging from the proposal, share a close understanding with the CPI identified as P_3 regarding the establishment of priorities. It is also worth mentioning that the understanding of the overall context and the impact of the experiment depends on this intention. By proposing guidelines capable of directing the initial actions in the practical environment, the aim is to keep students focused on the instructional interests established by the teacher and, gradually, to provide them with the abilities and competencies for their own actions and decisions in science, according to the psychological assumptions of learning..

The temporary closing indicator of the Practical Condition (P_4): "Apply learning and developments in other situations and realities," addresses the transference of knowledge across different contexts, an important indicator of meaningful learning. Regarding the transformations from logical meanings (teacher's attribution) to psychological meanings (student's attribution), based on the learning objects of interest, the evidence of these transformations deserves notoriety, both in the scope of the language used. The student's capacity to transcend the arguments, examples, and modes of representation adopted by the teacher during the instruction period contains strong evidence of meaningful learning, as the conversion of meanings referred requires its own correlations between the new and specific elements—subsumers—of the learner's cognitive structure, and depends on them. In this argument, Ausubel, Novak, and Hanesian (1980, p. 34) infer that "[...] meaningful learning involves the acquisition of new meanings, and the new meanings, in turn, are the product of meaningful learning.”.

Seeking repeatedly and recursively associations between the CPI and the stages (theoretical, planning; methodological, and intervention) inherent to the PEA, the previously discussed indicator establishes as a factor evidencing learning, the transpositions of knowledge between different environments. In the case of the PEA's experimental objective – theoretical axis – an action, or a set of actions, is recommended, whose methodological guidelines, subsequently, will provide details. However, strictly adhering to such recommendations will potentially lead to an answer for the objective but not to a solution for the problem originally proposed in the activity. For this, cognitive recombinations capable of leading individuals to establish transpositions of knowledge between scenarios, in this case, those of the experimental objective and those of the proposed problem, will be necessary..

4.2 Analytical Condition

Regarding the Analytical Condition, the indicator encoded as A1: "Identify the proposed problem," specifically deals with the problem that originates the pedagogical investigation, more restrictively, with its recognition. In this aspect, it can be considered that this inspection depends on a full understanding of the situation acting as a context, in terms of logic and coherence, to the point that the investigating subjects themselves, the students, are able to appropriate the situation and mobilize knowledge and resources to address the problem to be solved. Thus, the mobilization of new information and its articulation with previous knowledge, from this recognition - in its full understanding - and from a provocative center of cognitive reconnections and procedural purposes, leads to the production of new knowledge. The TML deals with this aspect by understanding that:

> [...] knowledge is meaningful by definition. It is the significant product of a cognitive psychological process ("knowing") that involves the interaction between "logically" (culturally) significant ideas, relevant previous ideas ("anchored") from the learner's particular cognitive structure (or the structure of their knowledge), and the learner's mental "mechanism" to learn meaningfully or to acquire and retain knowledge (Ausubel, 2003, p. 6).

In reference to the PEA, the central didactic nucleus of the discussions in this article, the first moment of its methodological axis, the *introductory discussion*, provides conditions for the teacher to identify their students' perceptions, which result from their appropriation and understanding of the *proposed problem* at the origin of the practical activity. And, if necessary, work more broadly or reiteratively with the knowledge objects necessary for theoretical appropriation that, potentially, will allow for the appropriate decision-making for the purposes established at the moment of practice. The discussions, the exchanges of knowledge among peers and the teacher, the constant returns to the theoretical frameworks of interest, the attention paid to the indispensable procedures in developing solutions to the problem, among others, become important guidelines to be observed at this moment preceding the experimental activity.

The second analytical indicator (A_2) suggests that one should "Systematize information before and after the experiment." The effort to mobilize references related to what is addressed in the knowledge objects, before and after instruction (in this case, supported by the methodology of experimentation) leads, potentially, to the establishment of new ways of perceiving such objects, favoring the construction of a psychological meaning by the subject who learns. Ausubel (1968, p. 34), referring to learning characterized as meaningful, argues that "[...] the attainment of meaning is a purely idiosyncratic psychological phenomenon in a particular person," which underpins the teaching strategy of creating conditions for various interfaces between the desired knowledge for learning and those prior to and emerging from the instruction processes themselves..

In the specifics of the PEA, the *proposed problem*, when intelligibly linked to the students' own contexts, leads them to perceive that for its solution, the manipulation of strategies and knowledge is pertinent. Furthermore, in this case, within the realm of the methodological axis, the moment of *socialization* fosters the emergence of new perceptions and understandings, from the students' speeches, and from the arguments used in defense of their methods, results, and conclusions.

The third indicator of the Analytical Condition (A_3) establishes that one should seek to "Formulate strategies for the development of the experiment stages." In this endeavor, it is expected that the student is able to use their own means to arrive at an acceptable solution for the original problem of the practical activity. By doing so, they exercise their autonomy, their decision-making, striving to relate the situations that arise to the subsumers existing in their cognitive structure, that is, to

> [...] the total content and organization of ideas of a given individual; or, in the context of learning subjects, the content and organization of their ideas in that particular area of knowledge (Ausubel; Novak; Hanesian, 1980, p. 524).

In this sense, the student is allowed to deliberate on how to develop the activity, as well as to understand the consequences of their decisions, assuming an active, participative, and collaborative stance throughout the process. From the discussions generated among their peers and the teacher, it becomes feasible to consolidate already developed knowledge, as well as to generate cognitive routes previously nonexistent.

The PEA presents, as the second stage of its methodological axis, *the organization and development of the activity*, a stage in which conditions are offered for the student to assume an active posture in carrying out the actions (even in the case of those previously suggested). By developing strategies aimed at proposing a solution to a given problem situation raised, with the competence to defend it in the light of satisfactory theoretical frameworks, the experimentation finds the desirable didactic-pedagogical validity.

A_4, the closing indicator of the Analytical Condition, imposes "Evaluate the solutions and compare the results obtained with the predicted ones." This refers to the expected ability in the learner to take into account the feasibility and scope of the means he adopted to propose a solution, scientifically grounded and individually arguable, to the problem established in the practical activity. Therefore, this solution and its developments should make sense and be coherent to him, in order to be able to articulate other knowledge, such as theoretical knowledge, in the appropriation and construction of new meanings and understandings.

The influence of other factors in the learning process is extensively addressed by Ausubel, considering the author's recognition of its complexity and multiple dependencies. According to him (and collaborators):

> [...] Intrapersonal and situational factors interact in their effects on learning, cognitive and affective-social variables also influence the learning process concurrently, and undoubtedly interact in various ways. School learning does not occur in a social vacuum but only in relation to other individuals that generate personal emotional reactions, or serve as impersonal representations of culture (Ausubel; Novak; Hanesian, 1980, p. 26).

In this respect, any capacity for reflection on an achieved result, as well as its contrast with expectations, given the subject's ability to establish new cognitive combinations, demands the use of their previous knowledge, both formal and popular, based on the recognition of the practical-objective sense that the situation offers. Regarding the PEA, *the return to the workgroup*, the third stage of its methodological axis, implies the establishment of a collective conviction (internal to the workgroup), in light of the subjects' ability to transpose their observations, records, and understandings to general contexts, leading them to a broad mastery of the arguments to be constructed and externalized.

4.3 Creative Condition

Regarding the Creative Condition, the indicator coded as C1 states: "Redefine procedures when interpreting the experiment's results." In this context, it is expected that the student can establish new practical guidelines based on what they achieve as a momentary result and their perception of it. This requires that their understanding of the developed procedures is suitable to the point of creating new situations when they perceive that their products/productions do not meet viabilities at the level of understanding and contrast with the adjacent theory(ies). The learning capable of facilitating this process must be meaningful, as "[...] meaningful learning involves the acquisition of new meanings, and these new meanings, in turn, are the product of meaningful learning" (Ausubel, Novak; Hanesian, 1980, p. 34).

In the uniqueness of the PEA, both in its planning and in its intervention, respectively, the stages of *methodological guidelines* and organization/development offer conditions for evaluation that meet the didactic-pedagogical expectation that the teacher has of the students: that they guide themselves supported by the articulation between their prior knowledge, the emerging results, and the understandings constructed.

Regarding the planning of the PEA, the methodological guidelines impose orientations for practical activities, with openness to procedural redirections as materialities and understandings consolidate. The organization/development of the PEA, in its implementation, gives concreteness to this purpose, based on the perceptions of the students, the main agents of the activities, and the teacher, paying attention to empirical and/or subjective evidence.

Continuing with the Creative Condition, the indicator coded as C_2 mentions: "Generate ideas to propose a new experiment or paths for an ongoing experiment." In this perspective, it is expected that the student, when undertaking the PEA, is able to consider the transposition of knowledge between the context of the proposed activities, considering the problem addressed and faced, and other interests, using the framework provided by the teacher throughout the instructional process. Here, therefore, the understanding of the term experiment (*new* or *ongoing*) refers to another process, at a didactic-pedagogical level and integral to formal instruction.

In this interim, didactic transposition, that is, the rational and methodological movement between different means, becomes relevant, being supported by a satisfactory learning of the underlying objects of knowledge. It is taken as a reference that the TML deals more specifically with the meaningful acquisition of a body of knowledge organized in a formal situation of teaching and learning. Therefore, the consolidation of prior knowledge in a learning task, when successful, allows "[...] new ideas anchored and stable in the cognitive structure to be available, so that other related learning tasks can be introduced later" (Ausubel, 2003, p. 184). In this way, imperatives will be established so that previous perceptions and their cognitive constructions can be recovered for new actions, systematized by the supporting objects of knowledge.

The PEA, in this regard, can be vital in fostering this transposition capability, regarding a momentary closure understanding of what is addressed in the laboratory (or practice environment). For example, the systematization, the closing stage of its methodological axis, provides that the student records, analytically, elements considered relevant in the sphere of knowledge that they wish to consolidate. It is up to the teacher, when making this request, to provide conditions that lead students to seek points of articulation with other situations and contexts, capable of anchoring new intentions for future learning.

The third indicator within the Creative Condition (C3): "Argue about justifications given to procedures and results," implies the subject's attribute in argumentative defense, in light of consistent theoretical frameworks, of the procedures adopted and the results derived from them. The establishment of new meanings, under specific idiosyncrasies, is imperative for such capacity. In terms of TML, Ausubel (2003, p. 71) states that:

> The essence of meaningful learning, as previously noted, consists of new ideas, expressed symbolically (the learning task), relating to what the learner already knows (their cognitive structure in a particular subject area), in a non-arbitrary and non-literal manner, and the product of this active and integrative interaction is the emergence of a new meaning that reflects the substantive and denotative nature of this interactive product.

This new meaning can become perceptible during the socialization phase, which precedes the systematization of the methodological axis of the PEA. In this space, it is expected that the student will expose the meanings developed, derived from the contrast established between the adopted procedures, the results produced, and their adjacent knowledge, with the teacher fostering arguments considered consistent and contradicting those evaluated as weak and incoherent, based on the scientific foundations of support and their teaching intention.

The closing indicator of the Creative Condition (C_4): "Develop different approaches to knowledge, capable of considering an alternative explanation for already accepted scientific phenomena," implies the subject's ability to create, in light of empirical evidence and their previously consolidated theoretical knowledge, other modes of understanding and argumentation for phenomena that exceed formally addressed topics. Alternative explanations, under theoretical consistency and adhering to scientific concepts, principles, and theories, require a deep interpretation of what is observed, measured, and recorded, given the particularities of the experiment.

The process of meaningful learning tacitly involves the aforementioned interpretation capability, under conditions conducive to desirable transpositions. According to Ausubel, Novak, and Hanesian (1980), the essence of this process lies in relating symbolically expressed ideas to the information previously acquired by the student, through a relationship that is non-arbitrary and substantive. In this regard, *non-arbitrariness* entails:

> [...] the non-arbitrariness is a property of a learning task (e.g., plausibility, non-randomness) that makes it relatable to the human cognitive structure in the abstract sense of the term, on some sensible basis. [...] Substantivity, [in turn], is a [...] property of a learning task that allows for the substitution of synonymous elements without changing the meaning or significantly altering the content of the task itself (Ausubel; Novak; Hanesian, 1980, p. 525-527).

In the specifics of teaching science through experimentation, the non-arbitrariness of the proposal must be ensured already in its planning phase. In this effort, the PEA proposes that the experimental objective suggests the main actions capable of guiding individuals, in light of their understanding, to a scientifically acceptable solution to the original problem. This helps avoid procedural mistakes and the use of actions that are distant from the purposes of meaningful learning of the desirable and central knowledge objects in the instructional process. In conducting the activity, the methodological axis of the PEA, the idea of the coherence of the proposal, that is, its non-arbitrariness, should be intensified in the introductory discussion phase, a moment in which its systemic aspects should be fully understandable, and whose purpose is to produce a solution to the initial problem.

Substantiveness, a characteristic also intrinsic to the instructional strategy, can be evidenced in the methodological stage of the PEA called "return to the working group." In it, conditions are offered for students to dialogue among their peers, using their own terms, aiming at the development of a collective conviction, that is, a solution to the original problem that can be understood by everyone within their working group and, from this, presented, discussed, and defended.

5 Systematization of Results and Considerations

Table 4 systematically summarizes the correlation identified among the 12 Cognitive Performance Indicators (CPI) discussed in their Practical, Analytical, and Creative Conditions, under the framework of the stages of the Problem-Based Experimental Activity (PEA).

Table 4: Strategic Synthesis: TTI and PEA Association.

TTI			**PEA**							
Condition			***Theoretical axis***			***Methodological axis***				
Practical	**Analytical**	**Creative**	**PP**	**EO**	**MG**	**PD**	**OD**	**RW**	**Soc.**	**Syst.**
P1										■
P2			■							
P3					■					
P4				■	■					
	A1		■			■				
	A2		■						■	

A3					■			
A4						■		
C1			■		■			
C2								■
C3							■	
C4		■		■		■		

Source: authors (2023).

It can be observed that at each stage of the PEA, in its theoretical and methodological axes, at least two direct correspondences with the Triarchic Theory of Intelligence (TTI) were demarcated in this essay based on its dimensions and indicators. These, in turn, impose themselves as elements of assessment of learning derived from instruction, under the principles of the Theory of Meaningful Learning (TML). Therefore, it is up to the teacher to propose spaces for student manifestations so that they can perceive the reach generated by the instruction and its potential learning outcome.

Finally, this study is not exhaustive as it is limited to the use of certain goals and methods for evaluating learning emerging from scientific instruction, in its experimental dimension. Therefore, there are still several research intentions, from which other interests and procedures will emerge, in order to shed light on the Cognitive Performance Indicators, constructed, tested, and analyzed throughout the text. Once again, concerning the particularities of the PEA, a theoretical-methodological assertion acting in this article as the background for the validation of evaluative propositions, the expanded conception of experimentation is understood as the experiencing of different experiences provided by the proposal and the resulting knowledge acquisitions, whether through the practical actions of the research to address the proposed empirical problem or through the creative measures employed in carrying out the practical activity.

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