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# Impact of theoretical teaching, laboratory practice and the use of specialized software in the meaningful learning of university students

# Impacto de la enseñanza teórica, la práctica de laboratorio y el uso de software especializado en el aprendizaje significativo de estudiantes universitarios

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**Abstract**

The teaching-learning process of university students in exact sciences must go beyond the traditional approach and incorporate new styles that have a positive impact on their academic training. This implies both the understanding of concepts, models and theories, as well as practice in the laboratory and the use of specialized software for the validity of the results and interpretation of the theory reflected in practice, in order to achieve meaningful learning considering the constructivist approach. In this sense, the present investigation was developed under a quantitative, experimental and longitudinal approach (Hernández et al., 2014; and Bernal, 2016), whose sampling used was non-probabilistic of the type of intact groups (McMillan & Schumacher, 2005). The main finding, after the application of an instrument to 91 undergraduate students, shows the level of impact on meaningful learning, the theoretical training given on the subject: "Determination of adiabatic compressibility coefficients and volumetric expansion of triblock copolymers, through experimental data of density and speed of sound", complemented with practices in the laboratory and the use of specialized software.

**Constructivist theory, Quantitative analysis, Exact sciences**

**Resumen**

El proceso de enseñanza aprendizaje de los estudiantes universitarios en ciencias exactas, deber ir más allá del enfoque tradicional e incorporar nuevos estilos que impacten de manera positiva en su formación académica. Esto implica tanto la comprensión de conceptos, modelos y teorías, así como la practica en el laboratorio y el uso de software especializado para la validez de los resultados e interpretación de la teoría reflejada en la práctica, a fin de lograr un aprendizaje significativo considerando el enfoque constructivista. En este sentido, la presente investigación se desarrolló bajo un enfoque cuantitativo, de tipo experimental y longitudinal (Hernández et al., 2014; y Bernal, 2016), cuyo muestreo utilizado fue no probabilístico del tipo de grupos intactos (McMillan y Schumacher, 2005). El principal hallazgo, tras la aplicación de un instrumento a 91 estudiantes de pregrado, muestra el nivel de impacto que se tiene en el aprendizaje significativo, la capacitación teórica impartida en el tema: “Determinación de los coeficientes de compresibilidad adiabática y expansión volumétrica de copolímeros tribloque, mediante datos experimentales de densidad y velocidad del sonido”, complementada con las prácticas en el laboratorio y el uso de software especializado.

**Teoría constructivista, Análisis cuantitativo, Ciencias exactas**

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## Introduction

In the current era, the teaching-learning process faces new challenges, in which academics must use innovative methodologies in order to achieve true meaningful learning in university students. Also, students have to join with an active participation so that the learning objectives are achieved, that is, leave aside the passive attitude, where only the teacher is the one who transmits the knowledge.

That is why both the theoretical and practical explanation as well as the use of specialized software have an important role in the meaningful learning of students, since in addition to the teachers having mastery of the courses and the necessary skills for the transfer of theoretical knowledge, such as the traditionalist approach, must incorporate practices in the laboratory and the use of technologies.

The foregoing constitutes a great challenge and an advance in the teaching-learning process for the students, who upon graduating from the careers face various problems that they will have to overcome with what they have learned through their teachers. Although this is achieved as long as learning has been internalized, that is, meaningful learning has actually been achieved.

This research is of great importance due to its innovative approach, since it not only uses the traditional teaching model, but also includes the constructivist model of learning, where it seeks the generation of knowledge, from the student's own learning, considering the knowledge prior to adding new knowledge, which requires a lot of commitment and participation from both the student and the teacher.

The technique used in this research is developed under a quantitative, experimental and longitudinal approach (Hernández et al., 2014; and Bernal, 2016), which includes descriptive statistics both to explain the phenomenon under study and to test the hypothesis. In this same sense, the sampling used was non-probabilistic of the type of intact groups (McMillan & Schumacher, 2005).

This technique has added value with respect to other techniques such as qualitative, since the results yield numerical data that allow describing the population and explaining the research problem, as well as verifying the hypothesis based on the supporting theory and proposing new teaching learning strategies in this area.

Consequently, the problem that is intended to be solved lies in identifying the impact on true meaningful learning in university students with the use of innovative methodologies, not only traditional teacher-centered teaching, but changing to constructivist teaching where the teacher is considered as a facilitator of learning and the student is at the center of the process.

In this sense, the research question is formulated as follows: What is the impact of theoretical training on the subject: “Determination of the coefficients of adiabatic compressibility and volumetric expansion of triblock copolymers, through experimental data of density and speed of sound”, complemented with practices in the laboratory and the use of specialized software, in the meaningful learning of the undergraduate student?

Now, the central hypothesis to be tested is as follows:

- $H_0$: Theoretical training on the topic: "Determination of the coefficients of adiabatic compressibility and volumetric expansion of triblock copolymers, through experimental data of density and speed of sound", complemented with practices in the laboratory and the use of specialized software, not significantly influences the meaningful learning of the undergraduate student.

- $H_a$: Theoretical training on the subject: “Determination of the coefficients of adiabatic compressibility and volumetric expansion of triblock copolymers, through experimental data of density and speed of sound”, complemented with practices in the laboratory and the use of specialized software, influences significantly in the meaningful learning of the undergraduate student.

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This article includes nine sections. In the first, an introduction to the research topic and its importance, the technique to be used, the added value, the description of the problem, and the hypothesis to be tested, as well as generalities of this research, are presented. In the second section, the review of the state of the art is presented, as support for the approach to the problem and the incidence in its explanation, which includes teaching-learning models such as the traditional teaching model and the constructivist learning model that includes problem-based learning, laboratory practices, OriginPro software and finally meaningful learning.

In the third section, the method used, the type and design of the research, the description of the variables, the measurement instrument, the participants, the procedure and the data analysis are described. In the fourth section, the results and discussion are included, with descriptive statistics, as well as the discussion in light of the supporting theory. In the fifth section, the annexes are included, where the instrument used is incorporated. In the sixth section, the acknowledgments are added to the participating informants and to the institution from which they come and in the seventh section the source of financing of the research work is shown.

In the eighth section, the conclusions and recommendations are shown, where the main findings, limitations and future work are explained. Finally, in the ninth section, the references of the authors who contribute directly to this study according to the review of the state of the art are listed.

## State of the art

### *Teaching-learning*

Teaching is the process by which knowledge about a subject is transmitted. While learning is the process in which a person acquires knowledge, data and information to solve specific situations, it is also learned by trial and error. Learning can be autonomous, it is the appropriation of knowledge in a critical way according to a life experience, intellectual or cultural, through the theoretical analysis of basic concepts, principles and values (Cabrera-Medina et al., 2016).

Learning can also be collaborative, arising from interaction with people, done in groups, or inclusive, which also takes place in groups to achieve successful learning (Cabrera-Medina et al., 2016).

Therefore, education faces various challenges in the face of changes and demands of society, which permeates teachers to change their way of instructing and training students, which leads to a constant search for information and research to be incorporated into the changes, considering technological tools (González-Zambrano et al., 2022); and professionally train students who can enter the labor market at the end of their university education (García et al., 2021).

In this same context, emphasis is placed on the rapid change in both science and technology since the middle of the previous century, which has caused a revolution in society, including educational systems, where new teaching paradigms have been created. and methodologies for planning the teaching-learning process in order to achieve meaningful learning in students. For this, the teacher will have to consider the intellectual capacities of the students to develop and implement new didactic strategies; but it must socialize and review the already existing contents in order to link them with the generated knowledge; and also achieve with these strategies the motivation of the students to continue learning and promote the search, collection and generation of the provided knowledge (Guamán & Venet, 2019) [1].

In this regard, there are two main teaching-learning models, the first focused on the teacher's teaching and the second on student learning. The first is explained as the traditional model centered on the teacher, in which the information is transmitted and is merely expository, the participation of the students is null (Gargallo-López et al., 2011).

[1] Guamán, V. J., & Venet, R. (2019). El aprendizaje significativo desde el contexto de la planificación didáctica. Revista Conrado, 15(69), 218-223.

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The teacher is responsible for stimulating student learning, where knowledge is obtained externally and when acquired, a reward or punishment is received (Guerrero & Flores, 2009), which is reflected in the exam grades, is supported by behaviorism theory, motivation is external, students depend on external stimuli, there is not a rich relationship between the student and the teacher, in addition, the evaluation is associated with a grade in the exam that responds to the reinforcements . While the second model focuses on learning, its starting point is the student as established by constructivist theory, and the role of the teacher in facilitating learning (Gargallo-López et al., 2011). This entails contemplating the previous knowledge of the students to add new knowledge, through a process of analysis and reflection for learning in conjunction with various methodologies.

*Traditional teaching model*

From birth the learning system of the human being is active, therefore, contemplating the experiences and previous knowledge with the new knowledge constitutes a process in which the student gives meaning and understanding to the new concepts, this entails regulation and control of mental processes and general thought, among them are attention, perception and memory, which affects many information processing activities (Machado et al., 2018).

The teaching-centered model conceives knowledge as an external construction from a set of scientific knowledge of a discipline that the teacher is responsible for transmitting to the students, for which the teacher is responsible for organizing the information developed by the scientists. For this model, learning then refers to acquiring or increasing knowledge in a certain area for future applications (Gargallo-López et al., 2011).

In this sense, teaching understood as the transmission of knowledge by the knower, who is the teacher who masters the subject, facilitates the understanding of the topics, is up-to-date and explains. Therefore, the method used by the teacher is basic, the master class and the teacher's presentation, due to this, the interaction between teacher and student is unidirectional, if anything it becomes bidirectional in the space of questions or doubts (Gargallo-López et al 2011).

The traditional teaching model focuses on teaching and the teacher, so knowledge is already defined or constructed, therefore, the teacher's goal is to transmit it; that entails mastering the subject, updating knowledge and knowing how to explain it in a masterful presentation, without considering previous knowledge. The teacher's own notes and a textbook are used as study material. Therefore, the student's knowledge is increased by repeating what is taught by the teacher, for which he is limited to listening and copying (Morales et al., 2015).

In addition, this model uses the exam as an evaluation method so that students repeat what they have learned. Finally, teacher tutoring is voluntary and in certain temporary spaces (Gargallo-López et al., 2011).

*Constructivist learning model*

During the last decades, the traditional form of learning has been questioned, since a professional must graduate from the university with knowledge that can be applied to social reality. Must consider elements such as social, economic and technological changes to be competitive graduates. Therefore, a professional must have the skills to perform in working life based on knowledge. That is why the constructivist model is taken up, which has different ways of teaching and generating knowledge (Ramos & Palacios, 2007). For this type of learning, the techniques used are cooperative active learning as opposed to traditional passive learning. With techniques that facilitate learning such as interactive methods, dialogue or group techniques (Morales et al. 2015).

Therefore, it is possible to affirm that in the university the teaching-learning process has changed, since it seeks to focus the learning strategies on the student, where the student is the authentic axis of university education and the teacher is a mediator or mediator. rather a guide merely (Fernández & Aguado, 2017). Therefore, the teaching-learning process is conceived not only as a transmission of knowledge, but as a reconstruction process, which implies the accumulation of different learning experiences (Piaget, 1950).

Consequently, constructivism influences the teaching-learning process when it highlights the student with their knowledge, skills, abilities, expectations, attitudes, and conditions to acquire new knowledge (González-Zambrano et al., 2022). The constructivism approach conceives the student as responsible for their own learning and their skills, which requires the identification of the problem, as well as the knowledge that they have and that they want to investigate for the solution of the problem with critical thinking and creativity; while the teacher is responsible for facilitating the didactic strategy (Lozano-Ramírez, 2020).

This constructivist model focuses on the student while the teacher facilitates learning. For this, knowledge is understood as a social and negotiated construction, that is, both the student and the teacher create it, so knowledge is not fixed and immutable, it is not outside to eliminate ignorance. While learning is understood as a process of personal construction which is shared and negotiated with other people, which gives a significant new understanding for the evolution of conceptual and also personal changes (Gargallo-López et al., 2011).

The constructivist theory of Harré, (1986) and Osborne (1996) has five main objectives (Insausti & Merino, 2000):

- Understand and disseminate scientific messages with the use of both oral and written language properly, including various notation and representation systems as needed.

- Use the basic concepts of science and its scientific interpretation.

- Use personal strategies, consistent with scientific procedures.

- Plan and execute scientific activities in teams.

- Form reasoned individual criteria about basic scientific and technological issues of this time.

In relation to these constructivist objectives, it is stated that the real knowledge of the sciences should not only focus on collecting knowledge out of context and inoperative, but also that concepts should be interrelated with reality. That is why students must learn science and also do science, that is, acquire cognitive and metacognitive content, so the right place to acquire and form new knowledge is precisely in the place where science originates, in the laboratory (Insausti & Merino, 2000).

Now, the knowledge that the student acquires is not only to pass the subject, but must serve to interpret the reality in which he develops. Therefore, teaching is understood as an interactive process to facilitate the construction of knowledge, the teacher must have the didactic-pedagogical training so that the generation of knowledge is achieved. With this, the teacher makes use of various methods in relation to the objectives contemplating the context, there is a bidirectional interaction, various bibliographic resources are used to generate critical thinking, dialogue and discussion, as well as teamwork. The evaluation method goes beyond repetitive exams, problem solving, case studies and self-assessments are used (Gargallo-López et al., 2011).

With this model, the student reaches a significant level of understanding that helps to have a conceptual and personal change. Therefore, the knowledge, in addition to being useful to pass the subject, will serve to face reality (Morales et al. 2015). Likewise, the skills (Insausti & Merino, 2000) that are intended to be achieved through the procedural contents are those of research that include the identification of problems, hypotheses, variables, data analysis, use of models and techniques, as well as the generation of conclusions. As well as the development of manual skills and the generation of both written and audiovisual communication skills.

*Problem-based learning*

Problem-based learning focuses on experimental learning in relation to a real problem, which is solved by students (Hurtado & Salvatierra, 2020), contemplating: the exploration of the problem, the establishment of hypotheses, the identification of knowledge required to address the problem, the search for information, independent study of the topic, critical analysis and discussion about the knowledge acquired for the application to solve the problem and reflection on the process, and feedback. Previous knowledge is considered, since it will influence the resolution of the problem (Llorens-Molina, 2010).

To this end, critical thinking, basic knowledge, self-learning skills, individual and collective responsibility are promoted (Hurtado & Salvatierra, 2020) and the development of negotiation, communication and experience skills that affect their professional training (Lozano-Ramírez, 2020). This learning involves developing the following skills: technical (know/knowledge), methodological (know how to do), skills (know how to be) and personal (know how to be) (Gil-Galván et al., 2021).

Problem-based learning, in addition to being a methodology, is a teaching technique or an alternative strategy for active and autonomous learning that allows the student to learn cooperatively (Espinoza, 2021). This learning shows its effectiveness in reading comprehension, by having an investigative approach, where students seek answers to problems in a given context, creating doubts and uncertainties to change them into significant and challenging ones (Hurtado & Salvatierra, 2020). Students acquire and apply knowledge without the need for the teacher to give a master class (Fernández & Aguado, 2017).

Therefore, it requires students to develop analysis and reflection skills in order to solve the problem objectively, critically, and creatively, making the right decisions to establish expectations and goals for the solution (Lozano-Ramírez, 2020). This learning is related to the behavioral paradigm, which highlights the relevance of the students' attitude to guarantee success in the teaching processes (Bustillo, 2020).

However, this learning allows students to develop critical skills through thinking and problem solving with a high cognitive level, in order for the student to be interested in the subject and also to achieve learning. In this regard, it is highlighted that learning is the responsibility of the student (Ramos & Palacios, 2007).

Based on the foregoing, the construction of a series of increasingly complete and complex concepts is provoked, which entails including new methodological tools such as this one, since it broadens the change, by introducing laboratory work and contributing to the development of cognitive skills (Llorens-Molina, 2010). This learning seeks to introduce the student within a context of a specific problem linked to the social and professional reality in order to encourage him to develop a plan with cooperative work and with the supervision of teachers (Llorens-Molina, 2010).

Problem-based learning is a didactic approach for the construction of knowledge based on the context, which can affect the intrinsic motivation to achieve deep learning, based on a real and interesting problem. Although, it requires a broad methodological commitment and resources to implement it (Ramos, 2018), the following being necessary: establish objectives, identify the problem, ask questions, make decisions on the part of the students, use the appropriate instruments and evaluation tools, to end with the publication of the findings.

With this, undergraduate students establish a commitment to society in the search for problem solutions under a scientific and technological approach (Soltero-Sánchez et al., 2021).

*Laboratory practices*

According to the constructivist model, laboratory practices are understood as a didactic strategy for the generation of scientific knowledge (Espinosa-Ríos et al., 2016) and if before carrying out an evaluation is applied to know what the students know, during the practice will show greater motivation and interest, promoting the development of certain scientific skills.

This model seeks that students build scientific knowledge for the development of scientific skills, promoting greater autonomy and participation, with the aim of propagating and carrying out laboratory practices in the conceptual, procedural and attitudinal dimensions (Espinosa-Ríos et al. al., 2016).

Therefore, practice is fundamental in scientific theory, when checking with verifiable activities, trial and error experimentation and the handling of certain devices. Likewise, carrying out practices in the laboratory is directly related to meaningful learning and allows us to understand the phenomena. The student's work in the laboratory allows them to discuss, reason and compare their results to solve problems (Flores et al., 2009).

It should be noted that the teaching of science is complemented with practices in the laboratory, since this work involves learning the conceptual foundations, where the teacher acts as a support and guide in this regard. This is extremely necessary for learning that goes beyond the verbal training that the student obtains by listening to the teacher's explanations or by seeing the way in which the experimentation is carried out in the laboratory. For this reason, one of the main objectives of the practices in the laboratory is based on the constructivist theory, which highlights their ability to promote conceptual change, that is, exchanging superficial beliefs for scientific approaches about the natural phenomena (Barberá & Valdés, 1996).

The teaching of science, due to its experimental nature, has always been developed through theory and practice in the laboratory, despite this, what is sought is that a true contribution be developed. This depends largely on the objectives sought, which depend on the teaching approach, the type of activity, the type of evaluation instrument, the educational level to which it is directed, the curriculum to be developed, in addition to the correspondence between what is intended to be achieved and how it will be done (Flores et al., 2009).

Even so, university students face some difficulty in applying the conceptual constructs acquired during their university career to their current social reality, which reflects the insecurity of the acquired professional knowledge, which is decontextualized from reality and even conceptual outdated, although teachers and researchers implement new methodological teaching tools, different from rote ones (Rodríguez-Cepeda, 2016).

In addition, on certain occasions the practical work carried out through experiments in the laboratory disturbs the students, as the objectives are not clear and the conceptual theoretical discussion is confused, disassociating the theoretical teaching processes from the experimental one. Therefore, they do not perceive that knowledge is being generated through experimentation. That is why the common thread of conducting experiments will be through the relationships achieved between the works and scientific production (González, 1992).

However, there is a certain disparity in the objectives of practical work in the laboratory, both for teachers and students. In this sense, teachers expect the discovery of laws with experience, training in conducting experimental reports and the development of the daily log, as well as fostering interest in studying science. While the students show a slightly different vision in this type of work, since the main objectives for them are mainly learning experimental techniques, assessing the quality of the results obtained and reinforcing the theoretical classes (Barberá & Valdés, 1996).

It is provided that once the students are clear about the objectives of the laboratory work, it is easier for them to make decisions to carry out the established task. Since the student's attitude improves, giving security, commitment, playful attitude and proactive participation in relation to what they are asked to face. In addition, it allows them to understand the connections between theory and phenomena, associating new concepts and finally developing procedures (Montino et al., 2011).

It is also important to allow a self-assessment of the students before the practice sessions in the laboratory to help their preparation and to generate interest in participating and doing the practice correctly, in addition to taking advantage of all the resources available to them. The foregoing has a direct impact on promoting a positive and active attitude towards practices, improves understanding, capacity and skills. Teachers achieve a change in attitude for better use (Noguera et al., 2011). Another didactic technique consists of the application of directed cards to encourage group work of students, and thus encourage their deductive reasoning and their critical capacity. These cards are applied at the beginning and at the end of the laboratory practices, to see the learning achieved (Grueso, 2018).

It should be noted that learning that leads to an understanding of science will allow students to pass exams by acquiring concepts, models, and reasoning. However, when science is successful, students will be able to practice scientific methods and processes, which will allow them to judge the validity of the results. Therefore, it is possible to create new methods, procedures and judgments, hence the importance of the construction of new knowledge (Séré, 2002).

Consequently, practical work in the laboratory motivates students, encourages teamwork, order, cleanliness, and safety, also helps them to experience the phenomena in an experiential way, allowing variables that influence the study phenomena to be correlated, in addition to approaching the methodologies and procedures of scientific research. These practical works are classified into experiences, illustrative experiments, practical exercises and investigations. They also involve: the ability to internalize knowledge (know-know); general and specific knowledge (knowledge); technical and procedural skills (know-how); the development of attitudes (know-how); and social skills (knowing-living together) (Rodríguez-Cepeda, 2016).

In this same sense, the learning that is obtained through the experimental activity in the laboratory is not compared or replaced with other teaching methods, which is why the practical work in the laboratory helps, among other things, to: understand the theory , such as concepts, models, laws, specific reasoning, which sometimes differ from traditional concepts; learn the theory; experience through a certain number of realities, facts and teams that use theories and procedures; learn the procedures to replicate them in other contexts; learn to use the theoretical knowledge learned so that it is present and used when it comes to carrying out a complete research process (Séré, 2002).

Additionally, teaching in the laboratory can be given with an epistemological approach through the use of Gowin's V (epistemological V, heuristic V or V diagram), this is a heuristic tool which guides the interactive integration of theoretical and methods in the search for the solution of problems. In addition, it allows understanding the interrelationships between what is known and what is desired to know; meaningful relationships between events, processes, or objects. Ordinarily, concept maps as resources or learning tools allow organizing information, but these two tools serve to improve learning and evaluate it (Flores et al., 2009).

It is important to note that students need to develop skills and competencies for abstraction, imagination and the use of computer tools for scientific development. At present, new curricula have been designed for the training of teachers to use new information technologies, a tool is the virtual laboratory, which is a model that includes the necessary equipment to carry out research, experiments and scientific work or technical developed by a computer system (Machado et al., 2018).

In this context, it is worth mentioning four innovative proposals for laboratory work. The first focuses on a-theoretical activities, that is, those that are intended to improve practical skills and technical knowledge, however, they are unrelated to theory and real problems. The second consists of the development of resources, which involves activities that include the preparation of the elements that make up the practice in the laboratory plus their improvement. The third consists of new or problematic applications, this proposal refers to new ways of confronting the practices in the laboratory against the theory. Finally, the fourth proposal consists of carrying out small directed investigations, this implies taking the practical work to a real investigation, that is, linking the laboratory task with the generation of knowledge (González, 1992).

This anticipates that it is no longer enough for the teacher to have experience in the subject, but rather he must have theoretical-practical knowledge about the teaching-learning of scientific subjects, so that educational innovation on the part of teachers and the expectation of the students is successful (González, 1992). Thus, the teaching-learning strategies to be developed must consider competencies such as the ability to interpret and evaluate data derived from observations and measurements in order to be related to theory; the ability to develop and apply analytical techniques; knowledge of scientific progress and the ability to plan, design and execute research projects (Márquez, 2022).

*OriginPro software*

The use of Information and Communication Technologies (ICT) as tools in education, denotes the interest of institutions in providing students with the skills required in today's society (Alejo, 2022) with the condition that they are designed for educational purposes academic and focused on areas of knowledge (Álvarez et al., 2022). In this regard, university teachers, in order to achieve the expected learning according to the study plans, are added with new skills (Esquerre, 2022) and digital skills with the use of networks, digital environments, as well as the development and use of digital resources (Poma, 2022).

Consequently, the OriginPro software is integrated as a computer system, which consists of different functions that are used for different branches such as mathematics, statistics, physics, chemistry, among others. This specialized software is functional for data analysis and graphing, which is chosen by scientists, academics and in various laboratories in the world, since it provides an easy-to-use interface initially for beginners, which has the advanced customization capability as you use it. It also has the ability to modify the different mathematical and statistical functions, as well as graphical data display. With the use of OriginPro software, students can view the graphs generated by entering the data and execute the specific functions of the phenomenon analyzed, allowing greater interpretation, which is a pedagogical tool for motivation and improvement of student expectations (Zavaleta & Moreno, 2019).

*Meaningful learning*

Currently in educational teaching, the concepts of stimulus, response and positive reinforcement have changed to meaningful learning, conceptual change and constructivism, that is, at this time, quality teaching considered as good should contribute to the conceptual change that facilitates meaningful learning (Moreira et al., 1997). The meaningful learning theory postulated by Ausubel et al. (1976) affirms that the acquisition of new knowledge in students is based on previous knowledge, which allows them to interrelate what they have learned with what is new to learn, different from rote learning.

In the same order of ideas, this theory considers learning as a process that occurs when new knowledge or information is related to the previous knowledge (cognitive structure) of the person who learns in a non-arbitrary and substantive way, which starts from anchoring ideas or relevant aspects (Guamán & Venet, 2019) [2].

[2] Loc. cit.

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Likewise, this theory goes beyond the traditional learning of a change in the behavior of the individual, to a change in the meaning of their experience. In this sense, there are several elements that affect student learning; firstly, they are the teachers and their teaching method; second, the structure of the knowledge of the study plan and the way of producing it; and third, the social context in which learning takes place during the educational process (Ausubel, 1983).

The use of the knowledge that the student has so that new learning is generated and becomes meaningful, not rote or mechanical, is of great importance. Therefore, the teacher must establish congruent relationships so that meaningful learning develops (González, 2019).

The meaningful learning theory was born during the rise of constructivism, as a response to behaviorism, where activism and discovery learning were strong (Ordóñez & Mohedano, 2019). However, this learning is likely to occur both by reception and by discovery. Now, this learning is classified according to Ausubel (2000) in: representational learning, in which meaning is attributed to certain symbols without defining attributes; the learning of concepts, defined as common objects, events, situations or properties that characterize a sign or symbol; and propositional learning, where there are combinations of words in sentences that represent concepts.

Meaningful learning (Ausubel et al., 1976) is defined as a process with which new information is directly integrated in a non-arbitrary and substantive way into the cognitive structure of the learner. This theory has two important elements: non-arbitrariness and substantivity. In the first instance, non-arbitrariness refers to the fact that the new knowledge is not related to any knowledge, but rather, it is related to the most relevant cognitive structure, to what is called sub-consumers. This leads to relevant prior knowledge becoming an anchor for new knowledge and facilitating its retention.

Therefore, the important variable for significant learning to occur is based on the previous cognitive structure. On the other hand, regarding the second element, substantivity, it refers to the fact that what is incorporated from the new knowledge is only the substance, that is, new ideas are included, not the exact words used in the transmission of the new knowledge. With this transmission, new knowledge is built with new meanings (Moreira et al., 1997).

For this, it is important to understand that the student will learn from the cognitive structure that he has, that is, the concepts and ideas that are possessed in a certain area of knowledge and the way in which it is organized. Meanwhile, these experiences and previous knowledge of the students will affect learning in a beneficial way. In this regard, learning is significant when it is possible to teach a subject in a non-arbitrary way to what the student already knows, but from what the student knows, a relevant aspect of the cognitive structure is identified and the teaching is carried out to achieve learning of this type (Ausubel, 1983).

That is why significant learning is based on understanding, considering that the student knows the teaching process, in addition to knowing the student's ideas in order to relate the theoretical content with the conceptual bases related to the social environment of the student (González-Zambrano et al., 2022). In this sense, the student is required to reflect a positive attitude in the educational process, therefore, when teaching methods are chosen, it is preferable to select those in which the student participates more in order to achieve interest and conceptual learning without being repetitive (Zavaleta & Moreno, 2019). They can be considered learning resources such as mental and conceptual maps, as well as technological tools to design strategies and methodologies that generate interest and motivation in students (González-Zambrano et al. 2022). Or, choose or create new pedagogical, didactic and methodological strategies on the part of teachers with a focus on achieving true significant learning in professional life (Intriago-Cedeño et al., 2022).

Then, meaningful learning will occur when new information is able to connect or relate to a relevant concept already existing in the student's knowledge, achieving an anchoring of previous knowledge with the new one provided. This does not mean that knowledge is only associated, but that when the interaction between them occurs, new knowledge is generated in the cognitive structure of the students, which allows them to see the difference, growth and development of knowledge. For this, students must be willing to relate the new knowledge not in an arbitrary way but in a substantial way, identifying that learning is significant for them (Ausubel, 1983). With meaningful learning, the individual himself with a predisposition to learn is the one who generates and creates his own learning, therefore, this theory aims to know and explain the conditions that generate learning, so that a balanced cognitive change is achieved in a balanced way have individual and social meaning. Consequently, the learning built in the classroom is evolutionary (Rodríguez, 2004).

On the other hand, with the application of meaningful learning, students are more responsible for their learning through the construction of knowledge with participation in various interaction activities in which they share their experiences and opinions in a group (Intriago-Cedeño et al., 2022). It is important to highlight that this learning contemplates different aspects, which promote interest and the use of strategies so that students advance in the construction and appropriation of new knowledge, as well as affecting academic performance (Intriago-Cedeño et al., 2022).

Ordinarily, two types stand out within meaningful learning: representational learning and propositional learning. The first refers to individual symbols as knowledge of concepts, which leads to generic or categorical representations. The second refers to learning the meaning of ideas expressed by groups of words (Moreira et al., 1997). It should be noted that this theory is still valid, since it has been a benchmark for teachers and researchers in their study plans for more than forty years, but there are still elements that have not been learned significantly in the teaching process. This learning has a great explanatory capacity in pedagogy that justifies its strength (Rodríguez, 2004).

**Method**

*Type and design of research*

This research was developed under a quantitative, experimental and longitudinal approach (Hernández et al., 2014; and Bernal, 2016).

*Variables*

*Theoretical training variable*

Didactic teaching-learning strategy, of a theoretical type understood as an expository master class carried out by the teacher in the classroom on the subject "Determination of the coefficients of adiabatic compressibility and volumetric expansion of triblock copolymers, through experimental data of density and speed of sound”, under the behavioral model.

*Laboratory practice variable*

Didactic teaching-learning strategy of a practical type for the development of scientific research skills that entails the applicability and discovery of new theories, as well as the explanation of real phenomena, on the subject: "Determination of the coefficients of adiabatic compressibility and volumetric expansion of triblock copolymers, through experimental data of density and speed of sound”, under the constructivist model.

*OriginPro software variable*

Didactic teaching-learning strategy of a practical type and theoretical applicability, data management and graphics resulting from experimentation in laboratory practices, under the constructivist model.

*Meaningful learning variable*

Teaching-learning strategy that mainly contemplates the student as the center of learning and the teacher grants the requirement of new didactic methodologies to achieve significant learning in students with the theme "Determination of the coefficients of adiabatic compressibility and volumetric expansion of triblock copolymers, using experimental data on density and speed of sound”, under the constructivist model.

*Measuring instrument*

The measurement instrument consists of three questions on demographic variables and twenty reagents, the first nineteen contemplate knowledge questions about the subject "Determination of the coefficients of adiabatic compressibility and volumetric expansion of triblock copolymers, through experimental data of density and speed of sound" and the last question in the pre-test refers to the need to apply theoretical and practical teaching-learning methodologies to improve learning, while in the post-test it refers to the impact achieved after the applied methodologies.

*Participants*

91 undergraduate students from the third to sixth semester of the degrees in Chemistry, Chemical Engineering and Biological Pharmaceutical Chemist participated, who were selected through the type of non-probabilistic sampling of the type of intact groups (McMillan & Schumacher, 2005). The characteristics of the selected sample are detailed below (see table 1).

| Sociodemographic variables | Sample profile |
|---|---|
| Age | 17-20 years = 60%<br>21-24 years = 34%<br>25 years and more = 6% |
| Sex | Male = 29%;<br>Feminine = 71 % |
| Bachelor's degree | Chemistry = 2%<br>Pharmaceutical chemist biologist = 94%<br>Chemical engineering = 4% |

**Table 1** Sample characteristics
*Source: Own elaboration (2022).*

*Procedure*

The method used to collect information was longitudinal, that is, a pre-test and a post-test were applied twice in person in the classroom, a space where the participating undergraduate students met as intact groups. At that time, the link to the questionnaire was sent electronically and they were given advice on how to fill it out. It is worth mentioning that all the items were mandatory questions with the necessary locks to avoid omissions in the answers.

The students answered three questions of the categorical variables referring to demographic data and 19 reagents with response options, of which they selected one for each question. In addition, a final item was added to the pre-test regarding the need to implement the didactic strategy, on a Likert scale from 1 to 5. Also in the post-test questionnaire, the last question served to assess the impact of the implementation of the didactics strategy teaching-learning, on a Likert scale from 1 to 5, from very negative to very positive.

*Data analysis*

Descriptive statistics were used for data analysis, counting, tables and graphs, comparing the findings of the pre-test and the post-test, for the test of the central hypothesis.

## Results and discussion

The university students surveyed, in the pre-test, were asked how necessary it is to receive training that contributes to their academic training with both theoretical and practical support on the subject of "Determination of the coefficients of adiabatic compressibility and volumetric expansion of polymeric systems, through experimental data of density and speed of sound", complementing with practices in the laboratory and the use of specialized software?, on a Likert scale from 1 to 5, being 1 totally disagree and 5 totally agree, 56.04 % selected option 5 as they totally agreed, 31.87% selected option 4 as they agreed, 9.89% selected option 3 as they were impartial, 0% selected option 2 as they did not agree, and 2.20% selected option 1 by totally disagreeing. Therefore, the need to implement the theoretical and practical didactic strategy in high percentages was manifested (see graphic 1).

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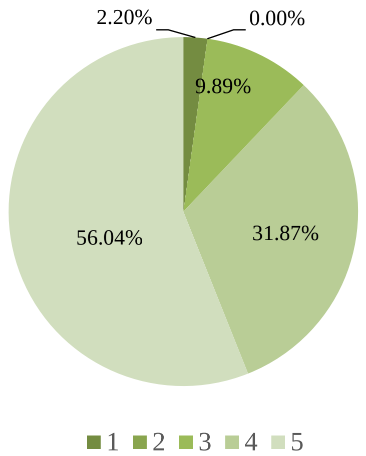
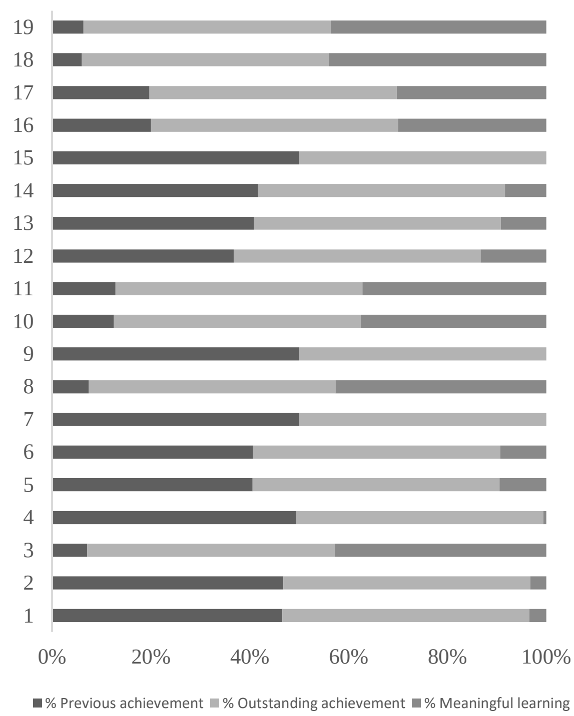



**Graphic 1** Identification of the need to implement the theoretical and practical didactic strategy
*Source: Own elaboration based on the data obtained from the pre-test (2022)*

Now, considering the need to implement the theoretical-practical didactic strategy and considering the results obtained from the pre-test, a contrast of the results obtained in the post-test was carried out, from which favorable results were obtained regarding the significant learning of the students (see graphic 2 and table 2).




**Graphic 2** Percentage contrast of previous achievement, outstanding achievement and meaningful learning
*Source: Own elaboration based on the data obtained from the pre-test and the post-test (2022)*

In item 1 regarding the knowledge of polymers, a meaningful learning of 6.59% was achieved; while in item 2 referring to the applicability of the topic in the industry, a meaningful learning of 2.20% was achieved; in item 3 regarding knowledge in triblock copolymers, a meaningful learning of 59.34% was achieved; in item 4 regarding knowledge of density, a meaningful learning of 1.10% was achieved; in item 5 referring to the knowledge of Newtonian fluids, a meaningful learning of 10.99% was obtained; and in item 6 referring to the knowledge of the speed of sound, a meaningful learning of 15.38% was obtained.

However, in items 7, 9 and 15, referring to the knowledge of the speed of sound of Newtonian fluids, the determination of the density and the speed of sound, and the equation of the coefficient of isothermal compressibility, respectively, no results were obtained meaningful learning.

On the other hand, items 8 and 10, referring to knowledge of the effect of density and speed of sound as a function of temperature and knowledge of the density meter model used, a meaningful learning of 57.14% and 56.04%, respectively, was obtained. In item 11 referring to the measurement of the density and speed of sound, a meaningful learning of 31.87% was obtained. Items 12 and 13 referring to the definition of the coefficients of volumetric expansion and isothermal compressibility, 19.78% and 14.29% of meaningful learning were obtained, respectively; while item 14 referring to the equation of the volumetric expansion coefficient, a significant learning of 13.19% was obtained.

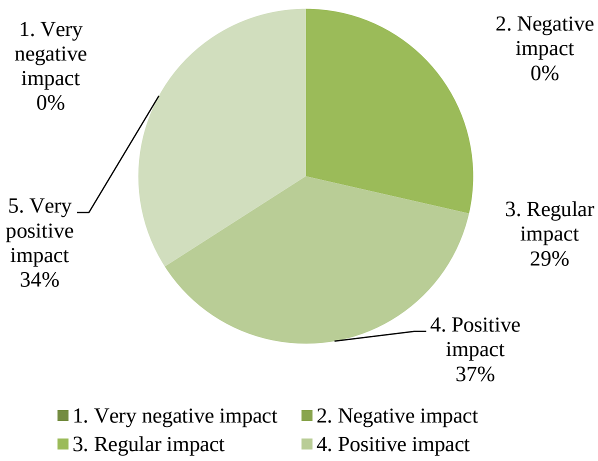
Likewise, items 16 and 17 referring to the calculation of the coefficient of volumetric expansion and isothermal compressibility, a meaningful learning of 46.15% and 47.25%, respectively, was obtained. Regarding the knowledge of the OriginPro software and its use (items 18 and 19), a meaningful learning of 56.04% and 52.75%, respectively, was obtained (see graph 2 and table 2).

| Items | Previous achievement (%) | Outstanding achievement (%) | Meaningful learning (%) |
|---|---|---|---|
| 1 | 90.11 | 96.70 | 6.59 |
| 2 | 31.87 | 34.07 | 2.20 |
| 3 | 9.89 | 69.23 | 59.34 |
| 4 | 92.31 | 93.41 | 1.10 |
| 5 | 47.25 | 58.24 | 10.99 |
| 6 | 67.03 | 82.42 | 15.38 |
| 7 | 45.05 | 45.05 | 0.00 |
| 8 | 9.89 | 67.03 | 57.14 |
| 9 | 92.31 | 92.31 | 0.00 |
| 10 | 18.68 | 74.73 | 56.04 |
| 11 | 10.99 | 42.86 | 31.87 |
| 12 | 54.95 | 74.73 | 19.78 |
| 13 | 63.74 | 78.02 | 14.29 |
| 14 | 65.93 | 79.12 | 13.19 |
| 15 | 85.71 | 85.71 | 0.00 |
| 16 | 30.77 | 76.92 | 46.15 |
| 17 | 30.77 | 78.02 | 47.25 |
| 18 | 7.69 | 63.74 | 56.04 |
| 19 | 7.69 | 60.44 | 52.75 |

**Table 2** Percentage contrast of previous achievement, outstanding achievement and meaningful learning
*Source: Own elaboration based on the data obtained from the pre-test and the post-test (2022)*

It should be noted that the items where more meaningful learning was achieved refer to laboratory practice and the use of specialized software.

On the other hand, in relation to the impact generated on student learning, 34.07% answered that it had a very positive impact, while 37.36% answered that it had only a positive impact; however, 28.57% responded that it had a regular impact. In this sense, no negative or very negative impact responses were obtained (see graph 3).




**Graphic 3** Identification of the implementation of the theoretical and practical didactic strategy in the meaningful learning of the students
*Source: Own elaboration based on the data obtained from the post-test (2022)*

Based on the results obtained, it is possible to confirm the meaningful learning theory of Ausubel et al., (1976), given that from the pre-test applied to university students, in which prior knowledge was detected, it was possible to interrelate the new knowledge identified in the post test, derived from the didactic strategy implemented for the construction of new knowledge, which included theoretical training, laboratory practice and the use of specialized software. Therefore, it is confirmed that the traditional teacher-based teaching approach with the exclusive transmission of knowledge (Gargallo-López et al., 2011; Machado et al., 2018), complemented with the constructivist learning approach, based on student learning and knowledge construction (Piaget, 1950; Harré, 1986; Osborne, 1996; Ramos & Palacios, 2007; Lozano-Ramírez, 2020; Morales et al., 2015; Fernández & Aguado, 2017; González-Zambrano et al., 2022) has a significant impact on the meaningful learning of university students who participated in this research.

## Annexes

The instruments applied in the pre-test and in the post-test are shown below.

*Pre-test questionnaire*

The present survey has the purpose of detecting the level of knowledge that the students of the Bachelor of Chemistry, Bachelor of Chemical Engineering and Bachelor of Chemical Pharmaceutical Biologist enrolled in the University Center of Exact Sciences and Engineering of the University of Guadalajara, have regarding the subject "Determination of the coefficients of adiabatic compressibility and volumetric expansion of polymeric systems through experimental data of density and speed of sound", in order to generate a theoretical-practical didactic strategy that contributes to the meaningful learning of the student.

It is important to mention that the information you provide will be handled confidentially, so it will not affect the current course grade. Initially, answer your general data according to the options provided for it and then answer the questions and/or statements numbered from 1 to 20, selecting the option that best reflects your knowledge.

1.- Which of the following statements define a polymer?

a) Macromolecules made up of the repetition of a simple unit known as a monomer, arranged sequentially: linear, branched, grafted, star-like or in blocks

b) Amphiphilic chemical substances that manage to reduce the surface tension of a liquid

c) Chemical substances that have the same composition or molecular formula, but with different physical and structural properties

2.- Select from the following industries, the one that you consider uses polymers the most in the manufacture of its products:

a) Pharmaceutical

b) Automotive

c) Textile

d) Cosmetics

e) Oil company

f) Food

3.- Do you know the commercial triblock copolymers (Pluronics)?

a) Yes

b) No

4.- Which of the following answers define density?

a) Physicochemical property that relates the amount of mass in a given volume of a substance

b) Physical vector magnitude that relates the change of position with respect to time

c) It is the resistance that some substances have during the process of fluidity and deformation

5.- What effect is manifested in the density of Newtonian fluids when the temperature increases?

a) Density increases

b) Density decreases

c) Density remains constant

6.- Which of the following answers define the speed of sound?

a) Physical vector magnitude that relates the change of position with respect to time

b) It is the speed of propagation of sound waves through a given medium as a function of temperature

c) It is the resistance that some substances have during the process of fluidity and deformation

7.- What effect is manifested in the speed of sound of Newtonian fluids when the temperature is increased?

a) The speed of sound increases

b) The speed of sound decreases

c) The speed of sound remains constant

8.- Do you know the effect of the density and the speed of sound in Pluronic/Water solutions when the temperature is increased?

a) Yes

b) No

9.- By means of which instrument it is possible to determine the density and speed of sound of solutions?

a) Electronic hydrometer

b) Viscometer

c) Tensiometer

10.- Do you know any model of electronic density meter?

a) Yes

b) No

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11.- Have you made any measurement of the density and speed of sound in an electronic densimeter?

a) Yes

b) No

12.- What does the coefficient of volumetric expansion physically indicate (α)?

a) Isothermal compression of matter as a function of pressure

b) Isobaric expansion of matter as a function of temperature

c) The effect between expansion and compression

13.- What does the isothermal compressibility coefficient physically indicate (κ)?

a) Isothermal compression of matter as a function of pressure

b) Isobaric expansion of matter as a function of temperature

c) The effect between expansion and compression

14.- What is the equation that defines the coefficient of volumetric expansion (α)?

a) $\alpha = \left[-\left(\frac{1}{V}\right)\left(\frac{dV}{dP}\right)_T\right]$

b) $\alpha = \left[\left(\frac{1}{V}\right)\left(\frac{dV}{dT}\right)_P\right]$

c) $\alpha = \left(\frac{dP}{dT}\right)_V$

15.- What is the equation that defines the coefficient isothermal compressibility (κ)?

a) $\kappa = \left[-\left(\frac{1}{V}\right)\left(\frac{dV}{dP}\right)_T\right]$

b) $\kappa = \left[\left(\frac{1}{V}\right)\left(\frac{dV}{dT}\right)_P\right]$

c) $\kappa = \left(\frac{dP}{dT}\right)_V$

16.- Have you calculated the value of the coefficient of volumetric expansion using experimental data on the density and speed of sound?

a) Yes

b) No

17.- Have you calculated the value of the isothermal compressibility coefficient using experimental data on the density and speed of sound?

a) Yes

b) No

18.- Do you know the software used to process data, OriginPro?

a) Yes

b) No

19.- Have you ever used the OriginPro software to process data and make graphs?

a) Yes

b) No

20.- At what level, from 1 to 5, do you consider it necessary to receive training that contributes to your academic training, both with theoretical and practical support in the subject "Determination of adiabatic compressibility coefficients and volumetric expansion of polymeric systems using data experiments of density and speed of sound", complementing it with practices in the laboratory and the use of specialized software?

1) Strongly disagree

2) Disagree

3) Neither agree nor disagree

4) Agree

5) Totally agree

*Post-test questionnaire*

It includes questions from 1 to 19 of the pre-test, only question 20 is replaced by the impact measurement, on a Likert scale, as follows:

20. At what level from 1 to 5 does the theoretical and practical training received on the subject of "Determination of the coefficients of adiabatic compressibility and volumetric expansion of triblock copolymers, through experimental data of density and speed of sound", complemented with practices in the laboratory and the use of specialized software, impact your academic training?

1) Very negative impact

2) Negative impact

3) Regular Impact

4) Positive impact

5) Very positive impact

**Acknowledgments**

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**Conclusions and recommendations**

The analysis of the state of the art and the results obtained, consequently allow us to conclude that the teaching-learning process is constantly changing, from the traditional teacher-based teaching approach to the student-based learning approach, the latter supported in constructivist theory.

The foregoing is due to the new demands in the training of the next professionals, who after graduating from a professional career must have significant learning, that is, learning added to previous knowledge and with applicability in the real world. Hence, the new teaching-learning strategies that include the classic master class, problem-based learning such as experimental learning, laboratory practices and the implementation of information technologies such as specialized software. With this research, a direct contribution to the theory of meaningful learning of the constructivist approach was achieved, given that with the analysis of the state of the art and the results obtained, two evaluation instruments previously validated by experts were generated, in which qualitative and quantitative variables were incorporated, which allowed describing the population under study and confirming the theory, in addition to identifying the significant percentage of learning achieved. Likewise, the central hypothesis was verified, given that the null hypothesis was rejected and the alternative was accepted, where: Theoretical training on the subject: "Determination of the coefficients of adiabatic compressibility and volumetric expansion of triblock copolymers, through experimental data from density and speed of sound", complemented with practices in the laboratory and the use of specialized software, significantly influences the meaningful learning of the undergraduate student.

Among the main limitations of this research is the selection of the sample, because although it was non-probabilistic of intact groups, it is recommended to generate a larger and statistically representative sample to make generalizations of the population. Likewise, the data analysis was limited to the use of descriptive statistics, for which it is necessary to incorporate more variables to increase the statistical level.

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