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Beltrán Gali-Aleksandra
Technologic University of Durango, Associate Professor,
Department of Geophysics, Mexico
ORCID ID: 0000-0001-7186-332X
gali.beltranzh@gmail.com

Zhizhko Elena Anatolievna
Autonomous University of Zacatecas, Humanities Department, México
ORCID ID: 0000-0001-9680-8247
eanatoli@yahoo.com

THE USE OF CONCEPT MAPS MADE WITH CMAPTOOLS IN THE CLASSICAL MECHANICS TEACHING IN MEXICAN PROFESSIONAL EDUCATION

Abstract. This paper presents the results of a scientific pedagogical research, which goal was to reveal, how the using of the concept maps made with CmapTools, helps in the teaching of classical mechanics in Mexican professional education. In particular, the results obtained from the study carried out in National Polytechnic Institute of Mexico, are presented. Authors found, that metallurgical engineering students more successful learn the basic concepts of classical mechanics by creating conceptual maps with CMapTools. The way in which such conceptual maps must be carried out, implies preparation by the teacher of good content quality evaluated with a semantic evaluation rubric. According to the study carried out, this innovative teaching technology improved understanding of classical mechanics, affects positively the significant learning of the basic concepts of classical mechanics and increased students´ motivation to study these aspects of mechanics.

Key words: innovative teaching technology; teaching of classical mechanics; Mexican Professional Education; Mechanical Engineering Degree Programs; conceptual maps made with CmapTools.

1. INTRODUCTION

Physics is one of the most fundamental science, since all scientific disciplines use its ideas and it is the basis of all engineering and technology. Understanding the basic laws of physics is essential in every engineer´s job. Within physics, we find classical mechanics. Its study consists of explaining physical phenomena and predicting the effects of forces and movements. The mechanics are divided into:

–*Kinematics*, which studies the different types of bodies movement without considering the causes that originate, and

–*Dynamics*, which studies the effects of the interaction of a system with its environment in relation to its state of movement.

Another important topic is *statics*, encompassed in the study of dynamics, which analyzes the conditions for the balance of bodies.

How to facilitate the student of Mechanical Engineering Degree Programs to learn the basic concepts of mechanics?

To the problem of classical mechanics´ teaching at a university level dedicated their work Latin American researchers such as Bandiera, Dupre, Ianniello, & Vicentini, 1995; Salinas, Cudmani, & Pesa, 1996; Mora & Herrera, 2009; Pedraza & Sánchez, 2011; Maloney, 1994; Guisasola, Furio, Ceberio, & Zubimendi, 2003; Gil & De Guzmán, 1993, among others. Scientists agree that in most cases, the model of this teaching remains traditional. Therefore, it has not been possible to disappear the formative deficiencies of students, as well as long-term learning problems, erroneous preconceptions or inappropriate study strategies. Hence, modifications are suggested in the strategies used in order to motivate the student and achieve a meaningful learning.

This can be achieved with the use of ICT, digital tools that can be used in classrooms in order to improve the student's learning experience. However, the simple use of technology in the classroom is not enough to achieve meaningful learning in the student. It is necessary to make a change in the entire learning environment, from the teaching methodology, the didactic materials, to the activities and communication in the classroom.

The objective of this research was to reveal, how the using of the concept maps made with CmapTools, helps in the teaching of classical mechanics in Mexican professional education. In particular, we present the results obtained from the study carried out in National Polytechnic Institute of Mexico.

The research was carried out in the Metallurgical Engineering Degree Program of the Interdisciplinary Professional Unit of Engineering, Campus Zacatecas of the National Polytechnic Institute of Mexico following the documentary-bibliographic methodology.

2. RESULTS

The study carried out showed that in the Mexican Professional-Educational System, the topic of classical mechanics is among the topics to be studied in the first higher level physics course. The main objective of a course of this type is that the student must develop the ability to analyze mechanical situations in a logical and simple way, applying well-assimilated basic principles to solve them.

On the other hand, it was found that in the contemporary Mexican education, mechanical or memorized learning of outdated content in physics matters has been promoted. This occurs despite the fact that for years the importance of student-centered teaching, learning to learn and meaningful learning has been emphasized. Therefore, until now, the physics teaching and learning process in the Mexican Professional-Educational System, in most cases, has the following characteristics (Moreira, 2014):

- It´s focuses on the teacher, not on the student.
- Follows a narrative model and it is monological, not dialogical.
- Obeys the laws of conductism/behaviorism.
- Try to deposit knowledge in the student´s head without worrying if it was understood.
- Teaches unfocused and unclear concepts.
- Does not promote critical meaningful learning.
- Does not incorporate information and communication technologies (ICT).
- Does not use situations that make sense to the student.
- Teaches correct answers without reasoning or questioning, only to pass a test.

Given this unflattering situation, since the beginning of the 21st century, many studies on "preconceptions" of physics students and on the "common sense" views of teachers about science and its teaching, by Mexican educational researchers have been carried out. These researches have led to a deep questioning of the usual teaching of science, including physics (Ferreyra & Gonzalez, 2000).

Modern Mexican educational scientists believe that the main objective of the educational process is to achieve significant learning in the student, so it is necessary to plan schoolwork to achieve this goal, considering the efficient use of available teaching resources and addressing the deficiencies that hinder the formative advance.

Founding on constructivism and Ausubel´s learning theory, Mexican researchers consider; that learning theories have a descriptive character and, therefore, accentuate the aspects of learning where the protagonist is the student. The theory of meaningful learning aims to know and explain the conditions and properties of learning, related to effective ways of deliberately causing stable cognitive changes, capable of endowing it with individual and social meaning (Ausubel, 1976).

According to the notion of meaning construction refers to Ausubel´s Theory of Meaningful Learning, which is the theoretical basis of many Mexican professional education researches, to achieve true learning, it is necessary to relate the teaching strategies of the teacher with the student´s previous knowledge and present the new information in a coherent and consistent way. In this way, significant learning will occur, that is, long-term learning (Ausubel, 2000).

The Theory of Meaningful Learning, created by Ausubel, explains how cognition is produced. This theory centers the attention on the learner, on what happens in the classroom when someone is learning, in the nature of this learning, in the conditions needed to produce the learning, on its results and its evaluation. "Meaningful learning" is a fundamental notion in educational psychology and is the central concept of Ausubel's theory. It refers to the process by which the learner relates a new knowledge in a non-arbitrary and substantive way with his previous knowledge.

The non-arbitrariness of meaningful learning represents the relationship between the materials to be learned with the pre-existing knowledge in the student's mind. From this, it can be said that the important thing is that the student has relevant information and concepts that are clear and available, which will allow the incorporation and understanding of new knowledge.

The substantively characteristic means that what matters is the content and the background of the new knowledge that is acquired, not the precise words used to express those new ideas.

Ausubel's theory is a classroom learning theory; it explicitly presents principles and strategies that can be put into practice. In this research, an analysis of the content of the subject was carried out to identify the basic concepts that the student needs to understand, and through concept maps an attempt was made to relate these ideas with the relevant previous ideas of the student's cognitive structure.

However, there is a problem when the student relates new knowledge with previous ideas derived from their common sense, especially in physics. The student creates through his daily experience certain beliefs about the world around him/her, which are not always compatible with the established concepts of this science. In the present work, this problem was also observed from some of the students and an attempt was made to correct it. The use of strategies that promote meaningful learning is an alternative method to memorization that is more effective.

The study carried out showed that in the works of Mexican theorists of professional pedagogy (Buenfil-Burgos, Campos-Arenas, Catalán, Concari, De-Alba, Díaz-Barriga, Escamilla, Hernández, Serrano, among others), teaching is defined as a process of construction joint between the learner and the teacher, who acts as facilitator or originator. This construction is also the product of the students´ exchanges with the instructional context (the institution, the culture), and is unique and unrepeatable.

From this affirmation, they conclude that it cannot be considered a single valid way of teaching or a successful method for all teaching and learning situations. Even knowing the recommendations on how to carry out pedagogical proposals in the classroom, the way in which they are applied, will always be different, since it will depend on the unique conditions of each case (Díaz-Barriga & Hernández, 2002).

The context, in which students operate, is also very important in the development of their learning. Today, young people act in a technological context, so this is a determining motivational aspect for them. The motivation felt by students for the use of ICT, and the determining way in which this type of didactic instruments can achieve increased creativity and emotional intelligence of students has been confirmed (Escamilla, 2010). With the integration of technology in the classrooms, new pedagogical spaces were opened that enrich the practices of science teachers.

Based on several authors (Mayer, Shuell, West, Farmer, Wolff, among others), the Mexican theorists of professional pedagogy point out that teaching strategies are procedures that the teacher

uses in a reflective and flexible way to promote the achievement of significant learning in the students. In addition, they are resources to provide pedagogical help.

The teacher must be clear about what type of strategy to use. It´s important to know, why to choose this strategy and how to use it, at each moment of teaching. For this, it is necessary to take into account five essential aspects:

1. Consider the general characteristics of the students (their level of cognitive development, their previous knowledge or the presence/absence of subsumers, motivational factors.
2. The type of mastery of knowledge in general and of the curricular content in particular, which is intended to be taught.
3. The goals to be achieved, and the cognitive and pedagogical activities that the student must carry out to achieve them.
4. Constant vigilance of the teaching process: the strategies previously used, the progress and learning of the students.
5. Determination of the intersubjective context created with the students, if applicable (Díaz-Barriga & Hernández, 2002, p. 141).

Subsequently, they distinguish the following didactic teaching strategies: learning objectives, summary, previous organizer, illustrations, analogies, interleaved questions, concept maps and semantic networks, use of textual structures, etc. These teaching strategies are defined as follows (Díaz-Barriga & Hernández, 2002).

The *objectives* refer to the propositions that establish conditions, type of activity and form of evaluation of the student´s learning, as well as generate appropriate expectations. The *summaries* are a synthesis of the information of an oral or written speech. They emphasize key concepts, principles, and central argument. *Pre-organizers* have to do with introductory and contextual information. They serve as a cognitive bridge between new and previous knowledge.

In addition, *illustrations* are related to visual representations of objects or situations on a specific topic. The *graphic organizers* are visual representations of concepts, explanations, or patterns of information. The *analogies* refer to propositions that indicate that a known concept or event is similar to an unknown one.

The *interleaved questions* are inserted in the teaching situation or in a text. They maintain attention and encourage the practice, retention, and gathering of important information. The *signs* are the marks that are made in a text or in the teaching situation to emphasize or organize relevant elements of the content.

Concerning the *conceptual maps* and networks, they represent the graphs of knowledge schemes. They indicate the relationships between concepts or propositions of the study topic. Finally, the *textual organizers* are rhetorical organizations of a speech that influence the understanding and retention of information.

These strategies can be included before (pre-instructional), during (co-instructional), or after (post-instructional) specific curricular content. The *pre-instructional strategies* prepare the student for what he/she is going to learn; and mainly with them, it is about activating or generating pertinent previous ideas. Some of these more common strategies are goals and pre-organizers.

Furthermore, the *co-instructional strategies* support the teacher´s work during the teaching and learning process itself. Essentially, they are intended to improve student attention and find out the main information, achieve a better conceptualization of the learning content, and organize, structure and interrelate important ideas. Illustrations, networks and concept maps, analogies and synoptic tables are included here.

Finally, *post-instructional strategies* are presented at the end of the teaching event and allow the student to form an integrative and critical vision of the material learned. The most recognized are the final summaries, graphic organizers, networks and concept maps.

The most recent studies by Mexican educational investigators related to the subject of didactic strategies mediated by ICT applied to basic science courses, such as physics, chemistry or mathematics, generally show that this type of strategies have a positive impact in academic

improvement for students, increasing their motivation and interest in those subjects (Catalán, Serrano, & Concari, 2010; Gómez-Mercado & Oyola-Mayoral, 2012; Rodríguez, Cegarra & Díaz-Caceres, 2014).

Mexican scientist found also, that in the teaching of physics, still in many cases, behavioral learning theories, which favor mechanical learning, are very common. This is a type of learning that is not recommended, since students only memorize formulas, definitions and correct answers to later reproduce them in tests, and do not acquire long-term learning.

On the contrary, according to the cognitive and constructivist theories, the learning should be significant and it requires the understanding and construction of meaning. The student builds his/her knowledge from his/her own thinking and interpretation of the information, so he/she must be someone who actively participates in the learning process.

To learn a content, means that the student attributes a meaning to it, builds a mental representation with the help of images or words, or makes a certain mental model to explain the said knowledge (Díaz-Barriga & Hernández, 2002). Concept maps help students in this process. Therefore, the *concept maps* are tools that can help the learner to structure the knowledge or concepts that already exist in their cognitive structure, so that the new information to learn is easier to "anchor" to the previous knowledge.

The studies carried out regarding the use of concept maps in teaching, in general conclude that the application of this didactic tool allows students to be more motivated to do the activities, to be more responsible in the construction of their own knowledge. They are also supportive for being able to visualize the relationships between concepts, to organize and to express their ideas, to prioritize information and to organize models based on it. Concept maps can help students "learn to learn", facilitate collaborative work and gain a deeper knowledge.

The concept mapping strategy, developed by Novak (1991), is a technique that emphasizes concepts and their relationships. Concept maps can be used as a didactic, assessment, analysis of the curriculum and as a metacognition tool. In this research, it was decided to use this technique as a didactic resource for students, which helped them to understand basic concepts of mechanics and the relationships between them.

It should be noted that concept maps could be used at any time during instruction: at the beginning, they serve as preliminary organizers; during instruction, its function is to organize and improve internal relationships between relevant concepts; in the end, they help the student to integrate all the knowledge learned. In this study, concept maps were used during instruction to organize relationships between concepts.

It is important to specify that the *concept map* as one of the teaching strategies. It is a visual representation that allows establishing relationships between concepts in an explicit way. Likewise, concepts based on new information can be related to the knowledge previously acquired by the student.

The main characteristics of concept maps are hierarchy, synthesis and visual impact. The ranking refers to the order of importance or inclusiveness of the concepts, the most inclusive are at the top and the examples in the last places. Maps are a summary that contains the most significant of a topic or text. Regarding visual impact, a good concept map is concise and shows the relationships between main ideas in a simple and colorful way (Campos-Arenas, 2005).

Concept mapping is a method that facilitates meaningful learning. It requires the student to make decisions about: the importance of ideas and concepts, how these concepts relate to each other, and how new ideas relate to prior knowledge.

To make a concept map, the student can be based on a text, his/her class notes, his/her laboratory notes, and so on. It can be done on a specific topic or on the entire content of the subject. Thus, the Argentine researcher Chrobak (2004) mentions three steps required to create a concept map:

1. Identify the relevant concepts: a concept describes the relationship of a group of facts and it is designated with symbols. That, what student already knows, plays a preponderant role in the perception of these relationships.

2. Establish a hierarchical order for the concepts: in this step, the student must make decisions regarding the importance of one concept over another. It is necessary to place the ideas in a staggered order from the most general to the most specific, that is, a hierarchical order. The hierarchical order of the concepts depends on the context. For example, in the field of physics, the subject of Kinematics would be the context, and the concepts within it: acceleration, velocity, position vector and reference triple.

3. Relate one concept to another by means of linking phrases: in a concept map, the relationships between concepts are represented with lines and words that identify the existing association between individual ideas. The pairs of concepts thus related by a link are called propositional relations. The creation of these links will depend on the level of prior knowledge of the learner, so the variation in quantity and quality of the links distinguishes experts and novices in the development of concept maps (Chrobak, 2004).

Then, it can be affirmed that concept maps are not fixed representations of a person´s knowledge, but only represent the conceptual structure at a given moment and can be modified as new knowledge is acquired. Thus, an example of some relevant concepts in Kinematics and their relationships can be the Kinematics concept map proposed by Chrobak (2004). The steps to create this map consist of:

–Search for cross-links. The cross-links are the connections that can be made between concepts, apart from those determined by their hierarchy. Recognizing these relationships is a creative search where new meanings emerge and increases student understanding. This process may require the incorporation of additional concepts, which will enrich the conceptual map and help the student to form an increasingly global and integrating vision of the subject.

–Examine the structure of the map. In this step, the general arrangement of the conceptual map is analyzed and it is verified if all the concepts have been well integrated with the rest with links. The lack of integration of some concepts may be due to the fact that they are less relevant to the particular context or because they are not associated with the student´s prior knowledge, indicating a need to increase knowledge in that area.

Hence it can be argued, that the creation of concept maps, as is learning in general, is an active process, since the student consciously uses his/her previous knowledge to build the new one. For this reason, Chrobak (2004) states that concept maps facilitate meaningful learning, being based on the relationships between ideas and allowing the student to use what he/she already knows while learning new concepts.

Therefore, a concept map is a graphic way of organizing ideas and that helps to have a better understanding of them, that is, it is a technique to synthesize information. A concept map can be done in the traditional way, using a sheet of paper and a pencil, or you can also make a concept map online, with the help of specialized software. It is worth underlining that creating concept map using software, has some advantages, such as:

–Unlimited size, as it is not limited to the size of the sheet of paper.

–Flexibility, as ideas can be easily rearranged by clicking and dragging.

–Co-creation, for the reason that you can often have multiple users collaborating on the same online concept map.

–Visual presentation, because formatting tools can be used to create eye-catching diagrams that are easy to share and present.

Henceforth, the use of concept maps in the professional education is also related to another important aspect of meaningful learning. It´s about student's motivation, which includes his/her interests and willingness to learn the content. As young people immersed in the knowledge society, surrounded by technologies, the use of ICT in education can help motivate students. This is why the use of a computer program for the creation of concept maps was applied so that the students could rely on it.

There exists various computer programs for creating concept maps, open-ended or proprietary. The open type are free and the private ones are paid. Some of these programs are listed below and

their main elements are described: SmartDraw, MindMeister, GoConqr and CmapTools.

SmartDraw is a program designed for the creation of concept maps and process diagrams, the work can be saved and shared in applications such as Google Drive, Dropbox and OneDrive, and exported in PDF, Microsoft Word, Excel or PowerPoint formats. There is a free version of the software, but the features are limited. To activate all the functions, it is necessary to make a payment (Mejores programas para hacer mapas conceptuales, 2021 Best programs to make concept maps).

MindMeister is a cloud-based tool that allows you to visually capture, develop, and share ideas. It has an easy-to-use interface where you can quickly add concepts, images, videos, documents, links and others. The free version of the software allows you to create three concept maps; then you will have to hire the paid version (Mejores programas para hacer mapas conceptuales, 2021 Best programs for making concept maps).

GoConqr is a free and easy-to-use program that allows you to create concept maps online. The generated maps can be shared with other tools, which facilitates access to them and their integration with other information. It has computer versions for Windows, Mac and Linux.

Finally, CmapTools is very powerful software, with which complex concept maps can be created, shared and explored quickly and easily. It was developed by the IHMC (Institute for Human and Machine Cognition) in the United States, as a tool to simplify and teach complex ideas. It is used above all in the educational field. The main advantages of this computer program are (CmapTools, “Features and Advantages of CmapTools”, 2021):

1. It offers a very simple, communicative and intuitive interface, with a clear and easy-to-use menu, so no advanced computer knowledge is required.
2. It allows including images, documents, files or even other concept maps within the final document.
3. Allows maps to be saved on internet servers to promote collaborative work and offers a virtual community of users with whom you can exchange ideas and concept maps.
4. Concept maps can be saved and exported as different types of files: images, PDF documents, web pages, among others.
5. It is completely free.

In this research work, the CmapTools software was used so that students could create concept maps with it, since it is open (free), easy and intuitive to use and favors collaborative work.

3. CONCLUSION

Consequently, based on the study carried out in the Metallurgical Engineering Degree Program of the Interdisciplinary Professional Unit of Engineering, Campus Zacatecas of the National Polytechnic Institute of Mexico, to reveal, how the using of the concept maps made with CmapTools, helps in the teaching of classical mechanics, we can conclude the following.

In this research work, the CmapTools software was used so that students could create concept maps with it, since it is open (free), easy and intuitive to use and favors collaborative work. In the process of creating of concept maps, generated with CmapTools, the students obtained a significant learning of the concepts of classical mechanics. Moreover, the study implemented shows, that the application of this didactic resource was accompanied by a change of attitude in the teacher, as well as the adaptation of the entire learning environment. The students, by creating concept maps on the basic concepts of mechanics with CmapTools with a good quality of content evaluated with a semantic evaluation rubric, improved their understanding of these concepts and increased their motivation when studying these aspects of mechanics.

As the results show, most of the students reported feeling more motivated with this tool, although there were some who mentioned the opposite, feeling unmotivated since they could not fully understand the operation of the program. For this reason, it is considered that it is necessary in the first instance to explain the operation of the software to be used as a digital tool, and then move on to the generation of learning (in this case, with the creation of concept maps).

Therefore, taking into account the results obtained from the study carried out, we can argue that the creation of concept maps with CmapTools has a positive impact on the meaningful learning of the basic concepts of classical mechanics.

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ВИКОРИСТАННЯ КОНЦЕПТУАЛЬНИХ КАРТ, СТВОРЕНИХ ЗА ДОПОМОГОЮ CMAPTOOLS, ДЛЯ ВИКЛАДАННЯ КЛАСИЧНОЇ МЕХАНІКИ В МЕКСИКАНСЬКІЙ ПРОФЕСІЙНІЙ ОСВІТІ

Бельтран Галі-Олександра
кандидат педагогічних наук, викладач кафедри геофізики
Технологічний університет штату Дуранго, Мексика
ORCID ID: 0000-0001-7186-332X
gali.beltranzh@gmail.com

Жижко Олена Анатоліївна
доктор педагогічних наук,
професор факультету гуманітарних наук
Автономного університету Сакатекаса, Мексика
ORCID ID: 0000-0001-9680-8247
eanatoli@yahoo.com

Анотація. У цій роботі представлені результати наукового педагогічного дослідження, метою якого було виявити, як використання концептуальних карт, створених за допомогою CmapTools, допомагає у викладанні класичної механіки в мексиканській професійній освіті. Зокрема, представлені результати дослідження, проведеного в Національному політехнічному інституті Мексики. Автори виявили, що студенти-металургії успішніше освоюють основні поняття класичної механіки, створюючи концептуальні карти за допомогою CMapTools. Спосіб виконання таких концептуальних карт передбачає підготовку вчителем хорошої якості змісту, оціненого за допомогою семантичної оцінки. Згідно з проведеним дослідженням, ця інноваційна технологія навчання покращила розуміння класичної механіки, позитивно впливає на значне засвоєння основних понять класичної механіки та підвищила мотивацію студентів до вивчення цих аспектів механіки.

Ключові слова: інноваційна технологія навчання; викладання класичної механіки; мексиканська професійна освіта; Програми інженера-механіка; концептуальні карти, створені за допомогою CmapTools.