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Project-based active learning in the design and construction of a didactic robotic arm

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Summary
The results obtained in an active learning environment based on projects and mathematical modeling in the design and construction of a didactic robotic arm with four degrees of freedom (4GL) that is carried out for an institutional interest, report findings, moments where the student takes a active and leading role in their learning process, by developing activities of professional interest that demand challenges. The mathematical model obtained allows to know the dynamics and direct kinematics of the robot arm with four degrees of freedom. The research that is presented focused on the determination of the substantive elements that the mathematical modeling process contributes in the formation of professional skills in future engineers. It was developed at the TecnológicoNacional de México / Tantoyuca campus, with students from the 6th semester of Electronic Engineering with the purpose of investigating the role played by students and their interest in learning
Keywords: *mathematical modeling process, robotic arm, professional competencies, Project Based Learnina. active learnina. collaborative work*

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I. INTRODUCTION

Currently, higher education in Mexico seeks to develop new pedagogical strategies that allow the training of engineering professionals with the competencies required in the increasingly dynamic and globalized work and social environments. They seek to enhance the development of competencies: learning to learn, organize and plan, analyze and synthesize, apply knowledge to practice, express themselves clearly orally and in writing, critical and self-critical capacity, work collaboratively, initiative capacity and leadership and knowing a second language (Schmal, 2012).

In the higher education of the 21st century, learning focuses on skills and attributes of graduation. Faced with this need, CACEI (the Council for Accreditation of Engineering Teaching) proposes that higher education institutions offer quality education and indicates essential attributes in the graduate (solve engineering problems, carry out adequate engineering design processes, carry out experimentation adequate, communicate effectively, recognize their ethical and professional responsibilities, constantly update themselves, work as a team).

Given these demands, the design of a project-based learning model and the mathematical modeling process (ABP-mathematical modeling) is proposed. That demand from the student the inclusion of their learning process and request mental-physical effort to find the optimal solution to the phenomenon under investigation.

Project-Based Learning involves students in projects that solve a problem situated in reality and make them participate in the development of specific solutions. An active-collaborative learning model in which a related problem is addressed in a physical or social environment. In an environment that demands challenges, analysis, reflections and debates. Where strategies are proposed to address the phenomenon, brainstorming, solution tactics, searching for relevant information, proposing solutions and communication of results before a scientific community or society.

The mathematical modeling process involves processes of simplification, idealization and structuring of a phenomenon, mathematization of the phenomenon, formulation of the mathematical model, study, interpretation and validation of data in order to justify the coherence of the mathematical model. Contreras and Martínez-Cruz (2009) consider that mathematization is part of the actions involved in the construction of a representation that accounts for the aspects described in a daily or scientific situation.

Modeling is a very important process in learning mathematics, it allows students to observe, reflect, discuss, explain, predict, revise and in this way construct concepts in a meaningful way; an environment where experimentation and simulation are used for the study of the variables in real time that include the mathematical model of the phenomenon under study. Biembemgut and Hein (2004) suggest some strategies to approach the mathematical modeling process: exposition of the topic, delimitation of the problem, formulation of the problem, development of the programmatic content, presentation of analogous examples, formulation of a model and resolution of the same from the model, interpretation of the solution and validation of the model. This process demands challenges from the student that require physical and intellectual effort, in which the ability to explore, inquire and get to know the world around them is put into play. Actions that place her in a leading role in her own learning process.

It is necessary to underline, the research proposes a learning model focused on the professional interest of the student, in an engineering context where optimal solutions that demand challenges are requested.

A didactic-pedagogical model framed in project-based learning and the mathematical modeling process, an environment where mathematics is used as a tool to awaken the critical and creative sense in the development of tasks located in the study of a phenomenon.

The nature of this type of active learning is built by facing challenges, student-teacher cooperation. Fidalgo, Sein, and García (2017) Challenge-based learning can be applied in the context of the students' academic environment, an environment where students are involved in solving the proposed challenge, this method includes cooperative learning, debate and communication; strategy that encompasses an applied vision of various academic subjects.

This active learning model seeks to be the managerial process of the paradigm shift in higher education, an action that will give students the opportunity to build their learning process from their own experiences that request challenges and stimulate curiosity and develop professional skills. . Offering the possibility to explore, manipulate, suggest hypotheses, make mistakes and recognize them, justify, expose and debate.

In an environment where communication is the main vehicle for learning and evaluation is considered as a process of building learning and continuous improvement. On the other hand, the mathematical modeling process is considered a scientific activity in mathematics that is involved in obtaining models typical of the other sciences. This scientific process is a tool for the representation of phenomena, with the purpose of obtaining observations, data, reflections, proposals, conclusions.

The intention of this research is to attend and solve an institutional problem located in the electronic engineering area of the Higher Technological Institute of Tantoyuca. The problem: the electronic engineering laboratory does not have a didactic instrument for modeling, simulation and control; to carry out practices in real time in the subjects (vector calculus, linear algebra, analysis of mechanisms, programming and robotics). For the solution, it is required to design and build a robot arm based on programming and mechanism analysis, based on mathematical models in order to predict and make the movements reproducible using joints with different arm lengths. With this, it is possible to carry out practices in real time with complex movements and simulation of the joints of four degrees of freedom: rotation, position, orientation, center of mass and joint speed.

The importance of granting an active role to students in their learning process is fundamental and unavoidable, the potential that these active-collaborative learning methodologies originate are of considerable benefits to students. Rué Domingo (2016) states that active and collaborative learning is one of the aspects that define an effective educational practice; Students learn more when they are intensively involved in their education and are asked to think about and put what they are learning into practice in different settings. For Rué Domingo (2016) the elements that are combined in active learning are: purpose, meaning, complexity, autonomy, reflection and metacognition. Learning should be active, not passive. In learning-centered classes, students need to be actively involved (McCombs, 2001). They must have active learning opportunities and, to a large extent, act in diverse contexts and build their own knowledge (Stroh and Sink, 2002). They must learn by doing, and not sitting passively listening.

Students learn when they are involved in their learning construction process, understanding that physical and mental energy is required to build their own learning. This can be achieved when the student manages to reflect and ask herself how much I have learned, what I need, questioning her own beliefs and values, what are the things necessary to address the subject. That is why the importance of planning didactic strategies that will be used to develop: critical thinking, decision making, self-directed learning, cooperation among equals, conflict resolution, lifelong learning, social skills, etc. It therefore seems that this learning approach can provide an effective response to the new training needs of students in their process as future engineers.

The use of project-based learning (PBL) as a learning didactic strategy brings tremendous benefits to students. For Cobo Gonzales and Valdivia Canotte (2017), project-based learning is a methodology that is developed in a collaborative way that confronts students with situations that lead them to propose proposals when faced with a certain problem.

This type of project-based learning is built in an active-collaborative learning framework, an environment that encourages the student to investigate in a real engineering context, where it is requested to propose several solutions and choose the optimal one. Rojas (2005) exposes some benefits of the ABP; prepares students for jobs. Students are exposed to a wide variety of skills and competencies such as collaboration, project planning, decision making, and time management. In addition, it ventures into decision-making, where essential issues must be identified, seek the participation of other people with the appropriate profiles and analyze their points of view; with the intention of building solid evidence that justifies decision-making.

Various authors have proposed active pedagogical strategies, as an alternative to traditional teaching, in which the student becomes the axis of the training process. Some of these strategies are: problem-based learning (PBL); project-oriented learning (AOP); competency-based learning (ABC) (Vega, Portillo, Cano &Navarrete, 2014).

Driver and Bell (1986) state, if we want the objective of learning science to be fulfilled, we need to take into account the latest knowledge provided by research on the scientific knowledge of students, about the acquisition and development of concepts especially the data that sustains that learning is an active process in which students construct and reconstruct their own understanding in light of their experiences.

The mathematical modeling process is considered as a scientific activity in mathematics that is involved in obtaining models of the other sciences, it does not happen automatically or immediately, it requires a certain period of time in which the researcher puts knowledge into play mathematicians, knowledge of the context and the phenomenon to be investigated and their abilities to describe, establish and represent the relationships between variables in such a way that a model can be built that represents the phenomenon under investigation. Berrío (2011) observes how students by committing themselves to the study of phenomena, not only interpret and (re) construct mathematical models, but also (re) construct their considerations regarding the phenomenon itself, becoming a prominent factor towards dynamization . In engineering, the mathematical modeling process constitutes an indispensable professional competence of practical utility, where mathematics is considered as a tool to investigate, model and solve problems of real cases that arise in everyday life.

For Biembengut and Hein (2004), the modeling process involves a series of procedures, namely, choice of topic; recognition of the situation / problem; delimitation of the problem; familiarization with the topic to be modeled; theoretical referential; problem formulation; hypothesis; formulation of a mathematical model, development; resolution of the problem from the model, application; interpretation of the solution and validation of the model. The modeling process is considered a tool in engineering to study real world phenomena; with the purpose of obtaining conclusions about the phenomenon under study.

It is important to highlight that the mathematical modeling process aims to search for a mathematical model that allows a better explanation of a real contextual situation in terms of the phenomenon under study. Bearing in mind that it is important to distinguish when talking about mathematical modeling between model and modeling; Modeling refers to the process while model refers to the result or product of that process. Modeling is described as a process that starts from a real situation or problem and ends, through a succession of steps or phases, in a mathematical model that responds to the problem or real situation initially posed. In the process, previous steps are retaken, with which the process adopts a cyclical behavior.

Mathematical modeling is a process involved in obtaining a mathematical model. A mathematical model of a phenomenon or problem situation is a set of mathematical symbols and relationships that represents, in some way, the phenomenon in question. The model allows not only to obtain a particular solution, but also to serve as support for other applications or theories. The model allows not only to obtain a particular solution, but also to serve as support for other applications or theories. In practice, this set of symbols and relationships can be linked to any branch of mathematics, in particular, to the fundamental instruments of mathematical applications (Biembengut, 1999, p.20).

In the present research, an active-collaborative learning model is proposed that contributes to the process in the construction of professional skills in future engineers. The didactic strategy is framed in the processes: Project-based learning and mathematical modeling. This didactic-pedagogical approach involves the student in a project of interest and in connection with the environment. An approach that requires mental-physical effort to find the optimal solution to the phenomenon under investigation.

II. DEVELOPMENT

In project-based learning, students face phenomena that demand challenges, usually throughout an academic period, applying the fundamental concepts and principles learned previously. The ABP provides an active learning experience that involves the student in a challenging and meaningful project. According to Camacho (2014), project-based learning is located within the broad framework of experiential and collaborative university education: it promotes active, critical and creative learning, where students commit to their learning process and that of their classmates. . In addition, it encourages the development of other transversal skills and is a fundamental element in motivating students. Learning process, which approaches a concrete reality in an academic environment, through the completion of a work project. The contradictions that arise and the ways to solve them, contribute to this object of pedagogical influences becoming an active subject. Also, project-based learning offers the opportunity to achieve meaningful knowledge through the resolution of situations in the professional field. According to DíazBarrigaArceo (2015), it is required to work on real projects and tasks, from everyday life or from a field of professional competence, facing practical, concrete and realistic experiences. Project-based learning is a method that gives great importance to the process of researching around a topic to solve complex problems from open solutions, or to the process of addressing difficult issues that allow the generation of new knowledge (De Miguel, 2005).

The mathematical modeling process occupies an increasingly important place in the training of engineers, either in terms of competencies or content. Modeling offers the learning process a role, which is appropriate to the current era in education; in which the results and decision-making assisted by the engineers are in real time. The objective is to provide the student with mathematical tools that support him in modeling real situations situated in the context of engineering. In engineering the mathematical modeling process constitutes an indispensable competence, the models are used extensively in engineering, industry and manufacturing. For example, engineers use computer models of skyscrapers to predict their strength and how they would behave in an earthquake. Aircraft manufacturers use elaborate mathematical models to predict the aerodynamic properties of a new design before actually building the plane, etc.

The mathematical modeling process involves a series of actions or phases that make the construction or interpretation of a model not develop instantaneously, the cycle begins with the choice or determination of a phenomenon or problem in the real world until the evaluation, interpretation and validation of the mathematical model. It is essential to identify in this process all the factors involved in the study of the phenomenon and to make the necessary simplifications to build the mathematical model that represents the phenomenon.

Biembengut and Hein (2006) the modeling process involves a well-articulated series of phases: choice of topic; recognition of the problem phenomenon/situation & delimitation of the research phenomenon; familiarization with the topic to be modeled & theoretical reference; formulation of the problem & hypothesis; formulation of a mathematical model & development; resolution of the problem from the model & application; interpretation of the solution and validation of the model & evaluation. The elaboration of a mathematical model requires, on the part of the modeler, knowledge of both mathematics and other sciences, in addition, a good dose of intuition and creativity to interpret the context and discern which variables are involved (Biembengurt and Hein, 1999, pp. 12-13).

The concept of mathematical model has been present in many fields of engineering, some definitions of mathematical model are raised that make reference to a great extent, to the vision that one has of mathematics in relation to reality. A Mathematical Model is defined as a mathematical construction aimed at studying a particular system or phenomenon in the real-world. This model can include graphs, symbols, simulations, and experimental constructions. (Giordano Weir and For, 1997). A mathematical model is a mathematical description of a real-world phenomenon. As defined by Biembengut and Hein (2004), a mathematical model of a phenomenon or problem situation is a set of symbols and mathematical relationships that represent, in some way, the phenomenon in question.

The purpose of this model is to understand the phenomenon, experiment, and make predictions regarding future behavior. The generation of a mathematical model is not done immediately, on the contrary, it requires a certain period of time in which the researcher is challenged to test his knowledge of the subject in question, knowledge of the context, abilities to describe, establish and represent the existing relationships, identify variables with the intention of building a mathematical model that represents the phenomenon under investigation, with the purpose of obtaining conclusions about the phenomenon under study and subjecting it to a procedure of observation and experimentation of its behavior with the intention of identifying the behavior of the variables and predict at a certain moment the present and future behavior of the situation for decision making.

Cruz (2010) considers that the design of didactic experiences in the training of engineering students should be oriented to the content, the development of mathematical thinking, the usual work of an engineering professional and the development of strategic thinking oriented towards the use of design, via mathematical modeling. Engineering design is not a finished product but a methodology that relies on knowledge, inventiveness, creativity and awareness of the concept of urgency, to visualize a real problem, formulate it in technical terms, explore possible solutions, evaluate alternatives, propose one or more forms or ways of solution, evaluate the possible processes that need to be used and their corresponding results, select one of the best solutions based on a set of criteria, execute the necessary actions to carry out a particular proposal and evaluate the process and the results of each and every one of the actions, permanently making adjustments and corrections and issuing judgments and recommendations that are based on facts, preferably quantifiable. For Krick (1996) she considers that engineering design is a five-phase process with inputs and outputs: formulation of the problem; problem analysis; investigation; decision making; specifications (details of the proposed solution).

The methodology used in this research is a strategic articulation of the processes: project-based learning (PBL) and the mathematical modeling process.

Phases of the mathematical modeling process in the development of the Project

Phase I (Formulation of the problem): In this phase, the real problem located in a context of interest is specified (delimitation of the phenomenon or problem). Define a real model by simplifying, structuring and idealizing the phenomenon under investigation, the first task is to formulate the phenomenon using the language of mathematics (we proceed to the representation of reality through the mathematization process). The theoretical and physical considerations of the phenomenon are studied until an interpretation of the associated data (obtaining data involves a mathematization or use of mathematical skills).

Phase II Solve (definition of elements, data collection and analysis): Transform the real phenomenon into a mathematical model; formulate the mathematical model that represents the problem by identifying the variables (independent and dependent). The importance of the analysis of the initial conditions of the phenomenon under investigation is highlighted, in order to obtain the model that relates and articulates the variables. The model is mathematically treated in different representations (graphical, numerical and algebraic) moving between representations with the intention of constructing solid arguments that justify the model.

Phase III Interpret (formulation and simulation of the mathematical model): Experiment with the mathematical model in order to deduce mathematical conclusions and interpret the data obtained in light of the phenomenon under study. The intention is to reflect and offer accurate explanations and / or build the necessary predictions. Once the mathematical model has been built, the appropriate mathematical techniques will be used to carry out the pertinent experiments or simulations to observe and analyze the behavior of the variables with the intention of constructing predictions and justifications for the phenomenon under study.

Phase IV evaluate (validation and documentation of the mathematical model): Validate the model built in light of the solutions obtained, analyzing the veracity of the data obtained (experiment, verify and test the predictions). Comparing them against new data related to the phenomenon studied. In this phase you need to check the accuracy of the model, see how well it describes the original real situation and how well it predicts past and / or future behavior. If the predictions (established hypotheses) do not relate appropriately to reality, then the model needs to be refined or a new one must be formulated and the cycle started (back to phase 1).

It is important to highlight that the mathematical modeling process in a flexible improvement process continues with approximations to the ideal model requested by the phenomenon under study. In the design of experiments, observations are made, data are adjusted and the improvement of the model that represents the phenomenon in real time continues.

The objective of the methodology was to find the mathematical model to obtain the rotation, position and orientation of the joints of the robot arm through direct kinematics using homogeneous transformation matrices, using the Denavit-Hartenberg algorithm. Also, the use of the Matlab numerical programming software for verification and simulation of the mathematical model.

Phase 1

The type of robot will be built is defined, in this project we opted for the construction of a vertical angular robot, revolution or anthropomorphic, which simulates the parts of the body, using rotary joints and electric stepper motors are used to drive their movements.

Phase 2

To carry out its analysis it was necessary to know the measurements of the four links of the robot, these are made from the axis of joint N-1 to the axis of joint N. where N-1 is the initial position of the measurement and N is the final position of each link.

Phase 3.

The "homogeneous translational transformation matrix T" was designed to obtain the equation of the position and orientation of the joints. Vector and matrix algebra were used to represent and describe the location of an object in three-dimensional space with respect to a fixed frame of reference. Since a robot can be considered as a kinematic chain formed by rigid objects or links joined together by joints. In this way, the direct kinematic problem is reduced to finding a translation homogeneous transformation matrix T that relates the position and orientation of the end of the robot with respect to the fixed reference system located at its base. This matrix T is the function of the joint coordinates.

The resolution of the direct kinematic problem consists of finding the relationships that allow knowing the spatial location of the end of the robot from the values of its joint coordinates.

For the case of analysis, the four-degree-of-freedom robot is made up of four links joined by four joints, so that each joint-link pair constitutes one degree of freedom. Each link can be associated with a joint reference system and, using the homogeneous transformations, it is possible to represent the relative rotations and translations between the different links that make up the robot. Normally, the homogeneous transformation matrix represents the position and relative orientation between the systems associated with these four consecutive links of the robot. Thus, given the robot of four degrees of freedom, the position and orientation of the final link must be obtained.

Although any reference system linked to each element can be used to describe the relationship that exists between two contiguous elements, the usual form that is usually used in robotics is the Denavit-Hartenberg (D-H) representation. Denavit and Hartenberg proposed in 1955 a matrix method that allows to establish in a systematic way a coordinate system linked to each link of an articulated chain, being able to determine the kinematic equations of the complete chain.

According to the D-H representation, by properly choosing the coordinate systems associated with each link, it will be possible to go from one to the next through four basic transformations that depend exclusively on the geometric characteristics of the link.

These basic transformations consist of a succession of rotations and translations that make it possible to relate the reference system of the element with the system of the element.

Since the product of matrices is not commutative, the transformations have to be performed in the order indicated. Carrying out the product between matrices, the representative matrix of each of the links is obtained.

Phase 4.

Obtaining the mathematical model of the robot with four degrees of freedom.Direct kinematics with homogeneous matrices. We make the product of the matrices for each link based on the Denavit-Hartenberg (D-H) algorithm process. We calculate the position and orientation of the first and second link of the robot with respect to the coordinate system of the base. We calculate the position and orientation of the first, second and third link of the robot with respect to the coordinate system of the base.

We calculate the position and orientation of the four links of the robot with respect to the base coordinate system, in this way we obtain the transformation matrix T that indicates the location of the final system.

Based on the expression of the Transformation Matrix T we have the final position of the robot.

Phase 5.

Using the MATLAB tool, the mathematical model of the position of the Robot with four degrees of Freedom is verified. For the calculations of direct kinematics with homogeneous matrices in MATLAB a script was made.

The evidences report findings about the role that didactic activities play in a context of professional interest and the sense of reality in the implementation of the mathematical modeling process within the process of building professional competencies in the training of future engineers. An alternative look at the meaning and application of mathematics at the engineering level is also exposed.

The findings found during the development of the mathematical modeling process at different times are set out below.

At first, the problem situated in a context of professional interest was raised, the students accept the challenge demanded by the project "design and construction of a didactic 4GL robot arm". The first task consisted of identifying the initial conditions, previous knowledge and the variables involved. Thus also structuring the first approach to the mathematical model that represents the phenomenon under investigation. To carry out these tasks, the students actively participated in the presentation of ideas-hypotheses, collaborative work and debates. The mathematization process was used to study the theoretical and physical considerations of the phenomenon until interpreting the associated data. Through operations with matrices to obtain the homogeneous transformation matrices that represent the position and orientation of the joints of the robot arm. Activities where mathematical concepts give a meaning and application to mathematics, which allow addressing and studying a phenomenon in research.

In a second moment, the project is defined and directed, they rethink hypotheses, debate and discuss the solution methods; activities that allow the use of cognition and metacognition in students. A second approach is formulated to the mathematical model that represents the problem by identifying and articulating variables. The model is represented mathematically in different representations (graphical, numerical and algebraic) moving between representations with the intention of constructing solid arguments that justify the model. To build the mathematical model of analysis it was necessary to know the requirements: technical and physical specifications of the robot arm. And by means of the mathematization process, the mathematical model that represents the robot arm is obtained by means of a homogeneous transformation matrix of translation T, in order to obtain the equation of the position and orientation of the joints.

In a third moment, the group debate is opened, the validation and refinement process of the proposals made in the previous phases, moments where collaborative group work is observed among the students. The teacher takes a promoter role in the presentation of ideas, stimulating the participation of students and encouraging the establishment of justifications. To justify the arguments presented, we experiment with the mathematical model of the robot with four degrees of freedom, which allows predicting the position and orientation of the four links of the robot with respect to the base coordinate system. Using the homogeneous transformation matrix "T" the location of the final system of the robot arm is indicated. To carry out this task, the mathematical software MATLAB is used, the pertinent experiments or simulations are carried out to observe and analyze the behavior of the variables with the intention of constructing predictions and justifications of the mathematical model with respect to the position of the Robot with four degrees of Freedom. Experimenting with the mathematical model is possible to deduce mathematical conclusions and interpret the data obtained in light of the phenomenon under study. The intention was to reflect and offer accurate explanations and / or build the necessary predictions of the model.

III. CONCLUSIONS

The experimentation captured the attention and motivated the student, also generated a space where the student had the opportunity to interact with variables under study in real time, discover the explanation of the phenomenon under investigation using metacognitive processes. The evidences report findings of a project-based learning environment and the mathematical modeling process, located in the professional interest of the student with an active-collaborative learning dynamic and a leading role of the student. The inclusion and development of competencies in real environments was generated, facing authentic projects in real situations that demand challenges. The mathematical modeling process with a focus on the use of mathematics applied to other sciences, linked to the study of situations and solving problems in the real world, contributes to the development of professional skills.

The nature of this type of project allows the student to focus the training process as a future engineer. It is important to consider the orientation of the contents, the development of mathematical thinking, the usual work of an engineering professional and the development of strategic thinking oriented towards the engineering design process.

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