






Use of active methodologies and simulators in technical education

Uso de metodologías activas y simuladores en la educación técnica

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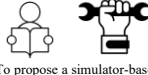
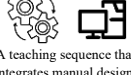
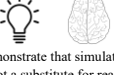
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Abstract




This investigation proposes a methodology based on virtual simulators for teaching CNC lathe and mill programming in technological high schools. Given the lack of physical equipment, a seven-stage process is suggested: paper design, algorithms, ISO coding, virtual machine setup, execution of the programs, digital pieces as result and feedback, all of this, integrating ICTs to minimize the gap between theory and industrial practice. Expected results include increased student creativity and precision, as well as adaptation to real-world work environments. Challenges are identified, such as students' low digital literacy and the need to adjust teaching pace. The whole strategy seeks to develop analytical and multidisciplinary skills.

Use of simulators in the practical part of education at the upper secondary level		
Objective	Methodology	Contribution
 To propose a simulator-based methodology to strengthen practical programming instruction on numerical control (CNC) lathes in technological high schools, addressing physical resource limitations and gaps in students' digital skills.	 A teaching sequence that integrates manual design, algorithms, ISO coding, virtual simulation, and iterative feedback, linked to higher education institutions for real-life practice.	 To demonstrate that simulators, while not a substitute for real-life experience, enhance analytical understanding, creativity, and multidisciplinary, facilitating the transition to the workplace.

CNC simulators, ICT in manufacturing, active methodology

Resumen

Esta investigación propone una metodología basada en simuladores virtuales para la enseñanza de la programación de tornos y fresadoras CNC en escuelas técnicas superiores. Dada la falta de equipo físico, se sugiere un proceso de siete etapas: diseño en papel, algoritmos, codificación ISO, configuración de la máquina virtual, ejecución de los programas, piezas digitales resultantes y retroalimentación. Todo ello, integrando las TIC para minimizar la brecha entre la teoría y la práctica industrial. Los resultados esperados incluyen una mayor creatividad y precisión en los estudiantes, así como su adaptación a entornos laborales reales. Se identifican desafíos, como el bajo conocimiento digital de los estudiantes y la necesidad de ajustar el ritmo de la enseñanza. La estrategia en su conjunto busca desarrollar habilidades analíticas y multidisciplinarias.

Uso de simuladores en la parte práctica de la educación a nivel medio superior		
Objetivo	Metodología	Contribución
 Proponer una metodología basada en simuladores para fortalecer la enseñanza práctica de programación en tornos de control numérico (CNC) en bachilleratos tecnológicos, abordando las limitaciones de recursos físicos y las brechas en habilidades digitales de los estudiantes.	 Secuencia didáctica que integra diseño manual, algoritmos, codificación ISO, simulación virtual y retroalimentación iterativa	 Demostrar que los simuladores, aunque no sustituyen la experiencia real, mejoran la comprensión analítica, la creatividad y la multidisciplinariedad, facilitando la transición al ámbito laboral.

Simuladores CNC, TIC en manufactura, metodología activa

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

Industry 4.0 [i4.0] is currently growing in the country, and educational programs are not as dynamic as they could be because, as Castillo [2023] mentions, there is a conflict of educational relevance in the face of sudden technological changes that are currently impacting industrial processes. These changes have become an all-encompassing phenomenon in which societies and future jobs are inevitably involved in one way or another, without realizing it, as is the case with artificial intelligence and the excessive use of the internet and automation, among other aspects.

Therefore, in upper secondary education in the area of vocational training, it becomes important to help students develop skills that are as compatible as possible with the almost immediate technological future that our industrial scenario increasingly presents.

The proposal will be developed at a DGETI educational institution, with the subjects of module 4 of the fifth semester, corresponding to the subjects entitled: 'Machining mechanical parts on a numerically controlled lathe' and 'Machining mechanical parts on a numerically controlled milling machine'.

Programming the machining sequence on a numerically controlled lathe

Prepare the machining sequence on the numerical control lathe

Machine parts on the numerical control lathe

Check the results obtained, expressing ideas and concepts through the programming sequence.

Relate symbolic expressions using information technologies through the CNC [Computerized Numerical Control] program developed.

Checking the results obtained, expressing ideas and concepts and considering current safety regulations by obtaining the mechanical parts machined on the CNC lathe.

The added value is the combination of various elements or educational models for technical training that allow us to develop the teaching-learning process in an optimal, agile, fluid and meaningful way for upper secondary school students.

The working method to be used will require the implementation of the traditional model of direct instruction together with the active methodology of the Flipped Classroom and the use of simulators [Virtual Learning, VL], which together aim to reduce the time spent on theory or independent work by the student to a minimum in order to focus on direct instruction through the review of material, simulation from preparing the virtual machine to executing a program, and the resulting feedback corrections.

Therefore, it will be necessary to use checklists to assess improved procedural understanding.

The existing problem is the perception of difficulty of the topics presented as subjects, due to both low technological literacy, mathematical deficiencies in workshop calculations and programming topics, under the premise that everything technological is complex and extremely difficult. In addition, the campus has a limited number of computer labs, but they are ultimately available for use, which allows students to work directly on developing ICT skills.

Therefore, the hypothesis to be tested is whether using a work methodology that balances the aspects identified as areas of opportunity and, based on them, builds small, sequential, meaningful processes for knowledge accumulation will allow students to perform acceptably in their graduate profile competencies in CNC equipment programming.

To begin with, we can affirm that simulators allow for risk-free experimentation, enabling students to understand the dynamics of complex processes [Rojas, 2003], and that ICT in technical education must be aligned with active approaches that promote student autonomy.

Based on classroom experiences, students show a high percentage of disinterest in ICT due to stigmas about industrial mechanics that identify it as 'dirty work' without the interference of technology.

Additionally, students have deficiencies in office automation and algorithmic thinking [e.g., flowchart design] and have very limited access to real CNC machines.

Castañeda [2003] proposes that for this research, we understand Information and Communication Technologies [ICT] to be those tools that, based on the use of computers, allow for the storage, processing, presentation, and transmission of digitized information.

Rodríguez et al. [2016] consider that the use of ICT by students is linked to the teacher's educational approach and, according to the educational uses to which they are put, classify ICT into three categories: a) ICT that support the transmission of messages from the sender to the recipient, b) ICT that supports active learning through experimentation with the objects of study, and c) ICT that facilitates interaction for learning.

Rojas [2003], for example, investigated the development of simulators based on cases and dynamic modelling for the maintenance of quality systems. Based on the analysis of the results of the exams administered to both the control group and the experimental group, it was concluded that there were significant differences in learning between the students who used the simulator and the students who were only taught using the traditional case method. The group using the simulator showed a greater understanding of the dynamics that gave rise to the problem in the case, which resulted in more complete and accurate answers in the assessment questionnaire.

In order to develop the activities relevant to the aforementioned module, which addresses the programming of numerically controlled lathes and milling machines, a sequence is required that allows us to identify the steps to follow to successfully complete a manufacturing programming process. Rather than simply assigning tasks to be performed, in the industrial mechanics module, we aim to convey the best practices that govern the manufacturing industry itself, in order to facilitate the student's short-term entry into the labor market, if necessary.

Part of the difficulty in addressing programming in the areas of industrial mechanics is the generic idea that it involves 'iron' and 'getting dirty with grease,' which has become stigmatized.

However, our job as teachers is to give a professional touch to secondary schools, referring to the glory days of past years, it therefore starts from an environment with low capacity for interaction with ICTs, as "they do not see any application for them if they are going to be industrial mechanics". This type of thinking has an impact on analytical performance when drawing up a flowchart or algorithm to outline the manufacturing idea required to solve a programming problem in numerical control, whether on a milling machine or a lathe.

The general context of the students is one of a certain deficiency in office automation, for which a work methodology is followed that allows them to be the designer and their own developer throughout the creative cycle, enabling them to 'materialize' their creation through links with higher education institutions that allow us to use CNC machinery and enable students to put what they have learned into practice in the laboratory, simulating a professional throughout the process.

It should be noted that the use of simulators is sometimes an alternative route to achieving the objectives of the subjects in the absence of equipment, which means that, despite the errors shown in simulated situations, it will never replace the real conditions of work performance. To reinforce this point, I would like to mention an experience I had during a visit to a higher education institution that allowed us to use its numerical control machinery.

When the students expected to simply arrive with their USB sticks, read the file and run it to receive the physical piece in their hands, they were faced with the everyday situation in which the numerical control machine must be adjusted for the process to be carried out, which took up two hours of their eagerly awaited visit to a numerically controlled machining area.

The methodology used and adapted, for example, to Module IV of CNC Mechanical Parts Machining, involves the following:

1. Design of the part with specific dimensions by drawing on graph paper. See Figure 4.
2. Design of an algorithm of activities to be carried out in order to have a guide when developing the programming.

3. Coding of the design into ISO CNC language, lathe or milling machine, as applicable.
4. Preparation of the CNC machinery [raw material, cutting tools, parameters, accessories] using the simulator.
5. Configuration of the zero point in the simulator.
6. Execution of the designed program [error detection and correction].
7. Virtual obtaining of the expected part.

This methodology can be rethought and is not limited to use in professional subjects only, but also in disciplinary subjects. In some subjects, such as physics, simulators are perfectly suited for conducting laboratory experiments in a virtual environment; experiments that in most cases are difficult to carry out in the real environment due to the scarcity of materials and additional resources.

The instrument used is a checklist to verify only that the student understands the process in its general context and is able to follow a procedure.

This methodology is used throughout the semester, across two sub-module subjects, with the aim of reinforcing the way of working and subsequently generating an appropriate rubric.

As a result of this methodology, the students performed better than they themselves expected, since, once their creativity was awakened, they came up with a flood of ideas for the 'n' ways to make a design. A sample of the work is shown in Figures 1 to 3, in the annexes section.

Strengths [what was done well]

Self-directed learning was developed, as well as decision-making regarding the approach to algorithms or flowcharts proposed to solve the manufacture of the piece, by confronting the student with the solution of problems in the manufacture of various pieces, giving them the leading role as programmer of the way in which it will be carried out.

The sense of analysis is reinforced by reviewing all the information relevant to the production of the parts, in addition to the considerations to be added in the real situation, through the verification of the relevant flowchart, algorithm or checklist, as applicable.

The advantage of using ICTs in situations specific to the speciality was successfully connected and promoted by solving manufacturing situations through virtual environments.

The multidisciplinary skills required in the workplace are demonstrated by interacting with the part manufacturing simulation process with software management activities. With resources being reduced, the development of decision-making skills is strengthened, which is something that characterizes graduates from public educational institutions.

Weaknesses [areas for improvement]

Students require greater preparation in the use of computer equipment and the general management of ICTs, given that it is a step backwards to return to teaching basic points such as turning a computer on and off, saving files, among other points, and this in parallel with the recovery of prior knowledge.

It was discovered that the student does not have a work methodology, despite the fact that, upon entering this module, he already had experience with conventional lathes and milling machines, which makes it difficult for him to adapt to linear thinking that would facilitate his understanding of the virtual environment of the numerically controlled milling machine and lathe. At the student's request, teaching will be slower and more detailed, due to the above-mentioned reasons.

Methodology

In order to begin the work plan, we will start by defining the active methodologies referred to, such as the flipped classroom and project-based learning. In reviewing the literature, we find that Espinosa [2022] argues that the elements of the flipped classroom model can be consolidated into three, according to their use [see Figure 2]: 1. Simple model: through lessons at home via videos. Tasks are carried out during class by resolving doubts and questions. 2. Observation model: The home lesson adds questionnaires with information and forums for questions. 3. Innovative model: Adds micro-activities to the home lesson based on the proposed video, uses the results of class activities, allowing for the restructuring of the proposed questionnaires and forums for questions.

Classroom assignments are programmed into the development of evidence as a teaching resource and continuation of the class.

Box 1

Elements of the Flipped Classroom Model

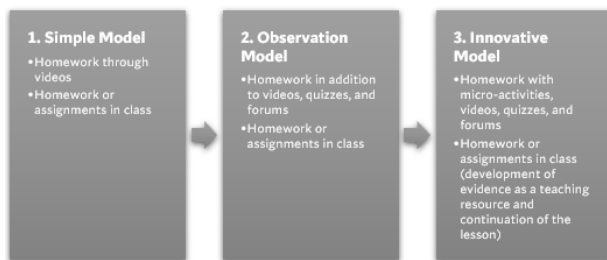


Figure 1

Reverse Classroom Models Source: [Espinosa 2022]

On the other hand, Rodríguez et al. [2016] define Project-Based Learning [PBL] as a method based on the creation, development, and evaluation of a real project, in a work team, with the aim of providing a solution or responding to a loosely structured, interdisciplinary situation or challenge, based on constructivism, focused on the work to be carried out and on the student's learning in the medium or long term.

To do this, we must start with a question to be solved, decided upon by the team, exercising decision-making about the necessary resources and critical thinking skills. The role of the teacher is reduced to that of a mere facilitator of the reflective processes that enable cordial interpersonal relationships within the team.

Similarly, Rodríguez et al. [2016] emphasize that the use of technologies [ICT] in teaching is closely linked to the PBL method, and additionally, Soparat et al. [2015] argue that the use of ICT with PBL helps to develop five key competencies, namely: skills for communicating ideas, problem solving, life skills, skills for using technology, and learning the content of the subject area.

For direct instruction issues, the following adaptive sequence is used for both subjects: a) manual design: This is done by drawing the figure of interest on graph paper. The requirement is that a symmetrical figure is needed for the lathe, while for the milling machine, the figure or model can generally be irregular [Figure 4]. b) Algorithm: In order to establish a logical diagram of ideas that represents the flow of the process, a flow chart must be established, or failing that, a process diagram that considers both the steps and the tool requirements and operating parameters. c) Coding: translate the colloquial language used in the flowchart or process diagram into ISO language for CNC programming. d) Simulation: Configure the parameters calculated in the process diagram in the simulation software [e.g., the location of the part zero, speeds, tools and their changes, etc.]. e) The developed and simulated program is validated, focusing on error detection and correction, in order to optimize the programming.

Additionally, and enriching the framework of active methodologies, Prillwitz [2025] argues that a very current methodology is Collaborative Learning, and that in addition to the many virtues of this modality, it stands out as a great enhancer of creativity and equitable training, which is why it is considered a core part of regulated self-learning. He concludes that this type of work should be encouraged. The way in which it is integrated with the focused methodologies is implicit, as it occurs naturally in the development of the activities. Additionally, links are established with institutions or companies that have CNC equipment with the intention of being able to carry out demonstration practices on real machines, which allow students to connect what they have seen in class, based on their notes, and apply it to a productive machine.

Box 1

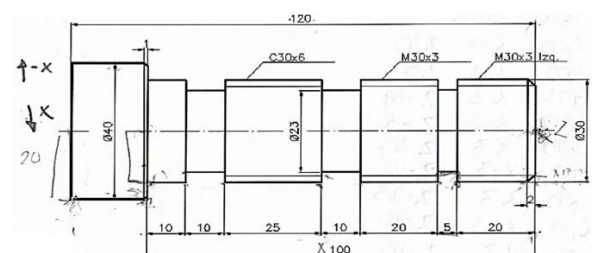
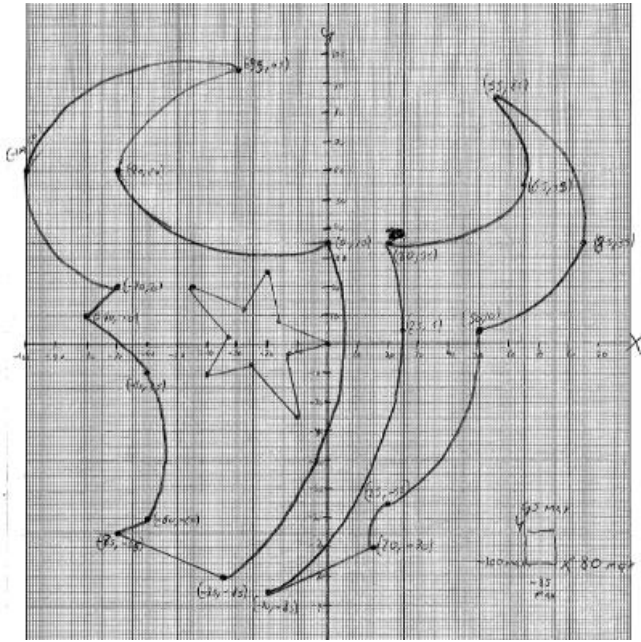


Figure 2

Dimensioned drawing of the part to be made
Source: Own elaboration

Box 3**Figure 5**

Millimetre sheet for the start of programming

Source: Own elaboration

Results

By applying the active Flipped Classroom methodology, students reduced the stress of having to take notes throughout an entire class and focused more on following the operation and programming, details of interaction with the basic menu, which significantly reduces the learning curve by being oriented towards more practice. See Figure 4, which represents a programmed and correctly compiled piece.

Through the PBL methodology, combined with direct instruction, the students worked in teams to solve the problem of programming the piece and, by following the sequence, were able to collectively complete the proposed challenge [programming the piece]. See Figures 2 for the CNC lathe and Figure 5 for the milling machine.

Conclusions

Simulators are effective complements between theory and practice in contexts with limited resources, but they require pedagogical and instructional support to bridge digital divides.

Links with higher education and/or business institutions enrich the experience by exposing students to real challenges [e.g., non-simulated machine adjustments].

As an area of opportunity, we suggest implementing introductory workshops on digital literacy and project methodologies from the first semesters onwards.

Declarations**Conflict of interest**

The authors declare that they have no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the reported article.

Contribution of the authors

*Estrada-Castillo, Francisco Javier*_ Research and main idea

Castillo-Flores, Esther Saraí: Research and format

Fernández-García, Luis Guillermo: Research and methodology

Esteve-Hollinger, Blanca Rosa: Research and format.

Availability of data and materials

The simulator used by the students is SWANSOFT software, which can be found at <https://swansoft-cnc-simulator.software.informer.com/download/>. Within this software, the GSK 980Td CNC lathe emulator is used.

In addition, FAGOR software is used, which has a CNC lathe and milling machine, and can be downloaded from its website <https://www.fagorautomation.com/es/documentacion/>

Teaching materials:

Theoretical support materials include ISO coding manuals and equipment manuals for demonstration purposes, available online in various formats.

Collaborations:

The faculty has agreements with workshops and universities to attend demonstration practices.

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Abbreviations

ABP	Project Based Learning
TIC	Information and Communication Technologies

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Soparat, S., Arnold, S. R., & Klaysom, S. [2015]. [The Development of Thai Learners' Key Competencies by Project-Based Learning Using ICT](#). *Online Submission*, 1[1], 11-22.

Background

Castañeda, C., Pimienta, M. C., & Jaramillo, P. E. [2003]. [Uso de las TIC en la Educación Superior](#). *Universidad de los Andes, Bogotá*.

Basics

Castillo-Martínez, J. A., & Fernández Pérez, J. A. [2023]. [Impacto de las competencias tecnológicas de la industria 4.0 en la educación](#). *Ciencia Latina Revista Científica Multidisciplinar*, 7[4], 852-870.

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Supports

Espinosa, R. C., Zuluaga, C. M. M., & Pitre, I. J. [2022]. [Aula inversa desde la virtualidad para la Investigación Aplicada e Innovación del Centro Metalmeccánico SENA Distrito Capital](#). *CITAS: Ciencia, innovación, tecnología, ambiente y sociedad*, 8[2], 4.

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Diferences

Soparat, S., Arnold, S. R., & Klaysom, S. [2015]. [The Development of Thai Learners' Key Competencies by Project-Based Learning Using ICT](#). *Online Submission*, 1[1], 11-22.

Discussions

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