(09-021) - PDCA AND PROJECT MANAGEMENT FOR THE CYBERPHYSICAL SYSTEMS DESIGN CLASS

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Any transformation process requires responding to the current needs of the market. Processes are increasingly automated, so cyber-physical systems are integrated into workstations to increase productivity, quality and efficiency in the indicators of any organization. However, the human being, the worker, remains at the center. Students in the Cyber-Physical Systems Design course use powerful design tools such as Factory Plan software and Jack simulation software to evaluate ergonomic conditions in workplaces. Once the risks and needs of the workstation have been identified, they propose assessment tools. industry 4.0 to achieve workstation goals. It is vitally important to have correct and efficient planning to achieve the goal. For this, the teacher plans the activities using PDCA and the students use project management to develop the project for this subject. In the end, the teacher makes an improvement derived from the results and the students come to a reflection evaluating the importance of following a project management methodology.

Keywords: PDCA; Project Management; Work Design; Cyberphysical system

PDCA AND PROJECT MANAGEMENT EN EL DISEÑO DE LA MATERIA DISEÑO DE SISTEMAS CIBERFÍSICOS

Cualquier proceso de transformación requiere dar respuesta a las necesidades actuales del mercado. Los procesos son cada vez más automatizados, por lo que los sistemas ciberfísicos se integran a las estaciones de trabajo para incrementar la productividad, calidad y eficiencia en los indicadores de cualquier organización. Sin embargo, el ser humano, el trabajador, permanece al centro. Los estudiantes en la asignatura Diseño de Sistemas ciberfísicos utilizan herramientas poderosas de diseño como el software Factory Plan y el software Jack simulation para evaluar condiciones ergonómicas en los puestos de trabajo, una vez identificados los riesgos y las necesidades de la estación de trabajo proponen herramientas de industria 4.0 para lograr los objetivos de la estación de trabajo. Es de vital importancia tener una planeación correcta y eficiente para lograr la meta, para ello el profesor planea las actividades usando PDCA y los estudiantes utilizan project managment para desarrollar el proyecto de esta asignatura. Al final el profesor hace una mejora derivada de los resultados y los estudiantes llegan a una reflexión valorando la importancia de seguir una metodología de administración de proyectos

Palabras clave: PDCA; PROJECT MANAGEMENT; Diseño del área de trabajo; Diseño de sistemas ciberfísicos.

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1 Introduction

One of the main aspects for the success of objectives is planning. A strategic planning that allows the development of tasks with monitoring and validation of the fulfillment of activities to make corrections during the process and ensure the achievement of objectives within established timeframes and resources.

The subject of Cyber-Physical Systems Design is a new topic within the Industrial and Systems Engineering career where students develop a project (problem situation) for 5 weeks. The project consists of proposing a workstation that integrates Industry 4.0 technological enablers and thereby impacts organizational indicators such as productivity, efficiency, quality, and utilization. To achieve these objectives, humans are considered a central part of the design, so ergonomic design is critical in the proposal. To evaluate ergonomic conditions, specialized software such as Jack is used. Postural load and material handling are also evaluated through methods such as RULA, REBA, and OWAS. For the design of the workstation, software such as Factory Cad, Factory Plan, and Plant Simulation are used. The work is done in teams of 5 to 6 students who, in addition to making the workstation design proposal using design software, generate a physical prototype where they use Arduino programming and some motors to move conveyors, for example.

The main constraint is the time in which activities must be completed and the thematic content covered in the best sequence, the use of laboratories, and students learning to use the software. The professor of this training unit uses the Deming cycle or PDCA (the acronym corresponds to the initial letter of each stage: Plan, Do, Check and Act) to plan and improve the class each semester the subject is taught, that means PCDA cycle is being used internally to assess and improve the teaching methodology. Students use project planning tools they learned in previous semesters' courses. They define a SMART (Specific, Measurable, Achievable, Relevant, and Time-Bound) objective, declare a planning of activities, establish a work structure, define the resources they must use, and follow up on their planning through the use of ProjectLibre software.

Each team of students generates a space in Drive where the professor has access and can observe the progress of each team regarding planning, resource utilization, and teamwork.

2 Objectives

The main objective is to instill in students long-term learning through the use of specialized software, simulators, and the construction of a workstation prototype under the guidelines of a well-defined plan with the assistance of PDCA (Plan-Do-Check-Act phases of Deming cycle) and Project Management methodology.

- The professor can teach all the concepts of the subject in five weeks.
- The professor has parameters to help improve their courses semester by semester.
- Students can achieve learning objectives by adhering to a program of activities.
- Students learn to manage resources.
- Students contribute to the project's success by completing tasks within defined team timelines.
- Students learn to manage resources.
- Students incorporate and reflect the importance in environmental considerations by minimizing resource consumption, reducing waste generation, and selecting materials and technologies with low environmental impact.

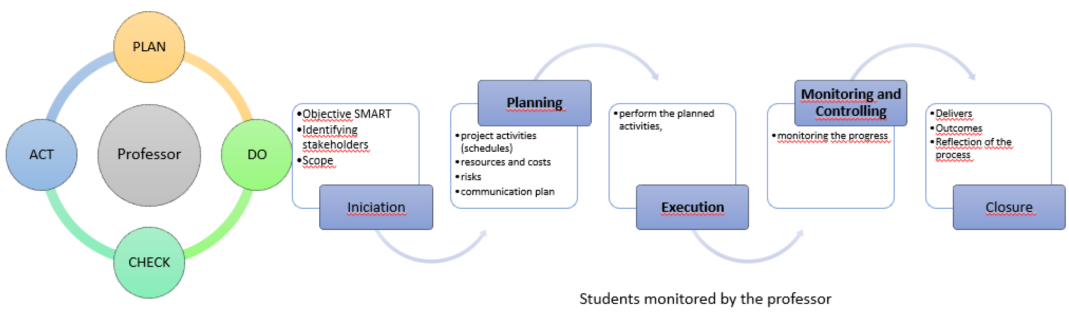
3 Methodology

The Deming cycle is based on four phases that are cyclically repeated, allowing for the reevaluation of processes to optimize them. For this reason, this cycle is also known as the Quality Circle or Spiral of Continuous Improvement and was the basic methodology proposed for the implementation of educational innovation that was used in the subject Design of Cyber-Physical Systems and can be used in all courses at all educational levels since its objective is to achieve the highest quality through continuous improvement. More efficiency and better results. This system is also known as the PDCA Cycle (Plan-Do-Check-Act Cycle or Deming Cycle). This methodology is used by the professor to plan the course and achieve the learning objectives.

Project management is the discipline of planning, organizing, and managing resources to achieve specific goals within a defined timeframe and budget. It involves identifying objectives, creating schedules, allocating resources, and coordinating activities to ensure successful project completion. Project managers uses various tools and techniques to mitigate risks, monitor progress, and communication process. Effective project management helps teams deliver projects on time, within budget, and to the satisfaction of stakeholders. The students work in teams and follow the five steps of Project Management: Initiation (objectives, scope, and feasibility) . Planning: (detailed project plan, tasks, timelines, resources, risks and budgets), Execution: (develop the plan). Monitoring and Controlling (professor and the team are monitoring the progress of the project). Closure: (Final presentation and reflection of the process, including ethical and sustainability.

As we can see in Figure 1, the two methodologies converge, and there is an interface that feeds into the professor's planning system using PDCA and triggers student activity using Project Management (Gholami, 2016).

Figure 1: PDCA and Project Management process



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3.1 PDCA

The innovation implementation process was defined following the Deming PDCA (Plan-Do-Check-Act) cycle. In the "Plan" phase, the objectives of the course, thematic and cross-cutting contents, activities, and course durations are reviewed (Al-Douri, 2009). This involves seeking didactic tools or technological resources that can provide a comprehensive experiential learning experience that contributes to students' competencies. Available tools are validated and incorporated into the course sessions. Deliverables and the timing of activities are defined, along with whether the work will be individual or team based. An indicator is defined to validate the tool's use (Kagansk,2017).

During the "Do" phase (Nadja,2020), the action plan is executed by implementing the use of the technological tools and evidence of the activities carried out by students in this phase is obtained, in this phase is the connectivity with Project manager methodology. Subsequently, in the "Check" phase, the impact of the implementation is reviewed using an indicator (Kaganski, 2017) that serves the professor for their continuous improvement process. Finally, during the "Act" phase, the professor takes improvement actions for the following courses, initiating the cycle again.

When implementing the Deming cycle (Hsu, 2015) in the Cyber-Physical Systems Design subject, the following information and activities are obtained in each phase of the methodology:

3.1.1 Plan

The objective of the subject is to design a workstation including enabling technologies, where the student understands the importance of productivity and how a correct design of a workstation supported by emerging technologies impacts. The topics of the subject include aspects of industry 4.0, ergonomic design, and productivity.

The project development must be completed within five weeks, so the professor must create an exact agenda of the topics to be covered in each session.

- Week 1: Emerging technologies.
- Week 2: Components of a process and their representation using Factory CAD software or Plant Simulation as showed in figure 2.
- Week 3: Workstation design and ergonomic evaluation using Jack simulation software as is showed in figure 3.
- Week 4: Postural load evaluation using RULA (Rapid Upper Limb Assessment), REBA (Rapid Entire Body Assessment), OWAS (Ovako Work Posture Analysing System).
- Week 5: International standards for environmental and ergonomic factors. Final project presentation.

Figure 2: Plant Simulation (Siemens)

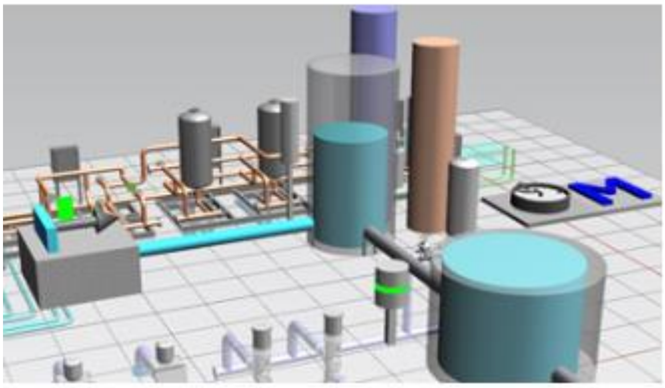
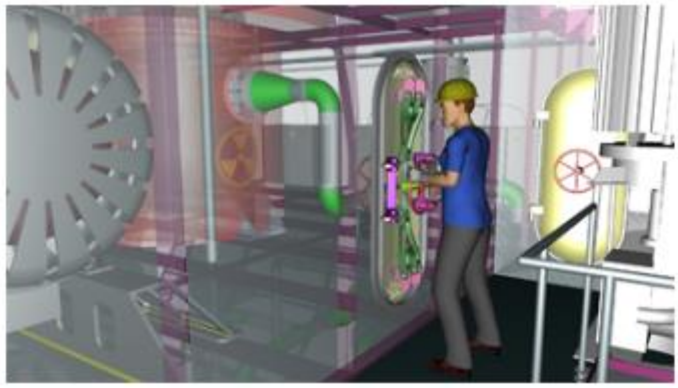


Figure 3: Jack Simulation (Siemens)



3.1.2 Do

Implementation of the activities developed in the previous stage (Hämäläinen,2017). As part of the course, students are required to present a solution proposal to a problem situation, The students need to:

- Explore enabling technologies, their main uses, and benefits when applied to workstations, considering the importance of applying technologies to facilitate human activities as mentioned by Costa (2019).
- Understand the elements of a work area.
- Understand human capabilities and limitations from a design aspect such as Ergonomics, Anthropometry, Repetitive Movements, and Manual Handling (Párraga, 2017).
- Understand the problem and propose solutions.
- Simulate the workstation, where they used the Plant Simulation simulator, Jack and software such as RULA, REBA, and OWAS. In these designs the students must include emerging technologies that make a workstation more efficient by using 4.0 technology (Lee 2015).
- Reflect on the importance of the impact of the use of simulators on the design of workstations by individually writing a paragraph in the final document of their work on the problem situation.

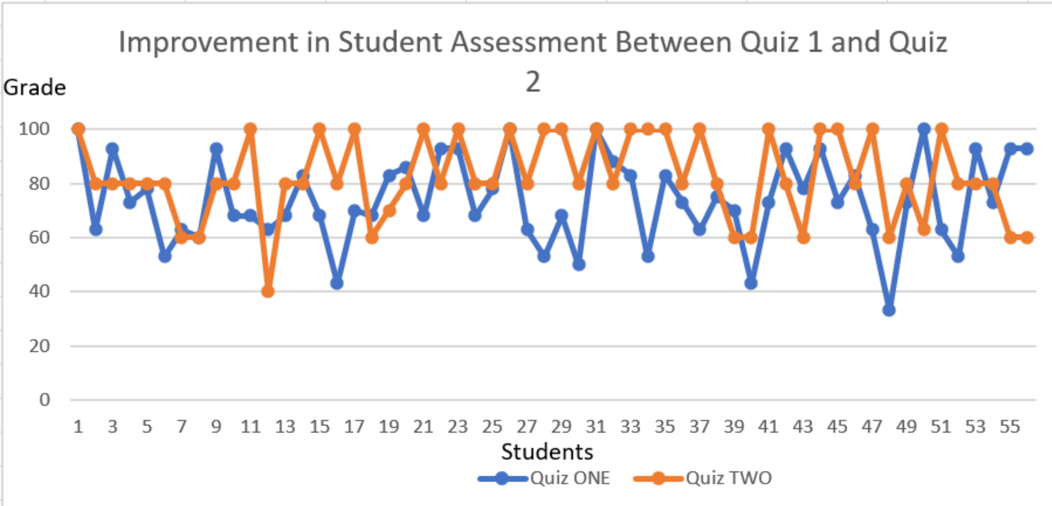
To achieve their project, students must work in teams (six members) and follow the Project Management methodology for five weeks.

3.1.3 Check

At the end of the course the students response an survey with questions related with the field and the experience that they lived in the topic. The comments of the students' reflections were reviewed, and the vast majority agreed that the activities using the simulators had been of great contribution to their academic training. However, several of the students mentioned that it had not been easy to install Jack and Plant Simulation. With respect to online software to assess postural load and maximum manual load, there were no areas for improvement. The students appreciated the use of project management methodology.

To validate the impact of the software in the learning process, the professor includes two quizzes one before use of the technology and quiz two after use of the technology as is shown in figure 4 where the average grade in quiz one is 73 and after the use of the software the grade increases in quiz two with an average grade of 82.

Figure 4: Improvement in students chart



Professor analyzed the opportunities to improve use of software in the course as is shown in table 1.

Table 1: Check process, analyzing simulation softwares

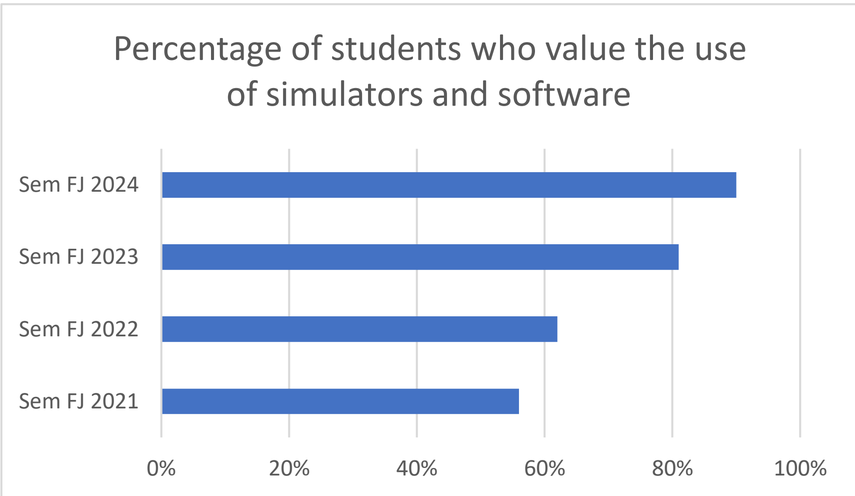
Simulation Software	Objective of the simulation	Benefits for implementation	Limitations to implementations
Plant Simulation	Graphical representation of manufacturing scenarios	Free academic version. Easy to download on Androi personal computer. Friendly environment, easy understanding of the use of the software. A Lot of Props to Represent Manufacturing Scenarios	Not compatible with Mac
Jack	Ergonomic work area design	Academic version free to download on personal computer. Contains pdf tutorials for installation and guided practices. Animation of the character (Jack or Jill) inside the workstation. Moving scenarios of the person within the workstation are represented. Dimensions can be included within the workstation	Academic version does not contain all props, including anthropometric measurement adjustments. Difficulty in installation Not compatible with Mac
RULA REBA OWAS	Determine Postural Load	An online job task is evaluated. Well explained methods. It contains images that allow easy use and understanding of the method.	It does not download to the computer. Reports cannot be downloaded.

		Use traffic light scale in risk assessment	
NIOSH Equation	Determine the Maximum Manual Load	Used online Use traffic light scale in risk assessment. It uses images of the operator performing a load. Easy to use	It does not download to the computer. Reports cannot be downloaded.

3.1.4 Act

The comments of the students were taken into consideration, the use of plant simulation and Jack is not easy, so the professor developed tutorials in Spanish in video format with detailed explanation of the process. Videos were also recorded with examples of how to use the software. For the second edition of the subject in February June 2022, the modality of the class was hybrid, which allowed the use of a new simulator that is installed in the laboratories of the campus, this was the Siemens Factory CAD, allowing in this phase of improvement, that students could make use of the simulator at the university. Like the Jack is installed on campus and used by students who have Macs computers. The students' perception of the proper use and importance of the simulators is improving, as shown in the graph in Figure 5, thanks to the fact that the teacher plans his class using the Deming cycle.

Figure 5: Improvement in students' perception of using specialized software

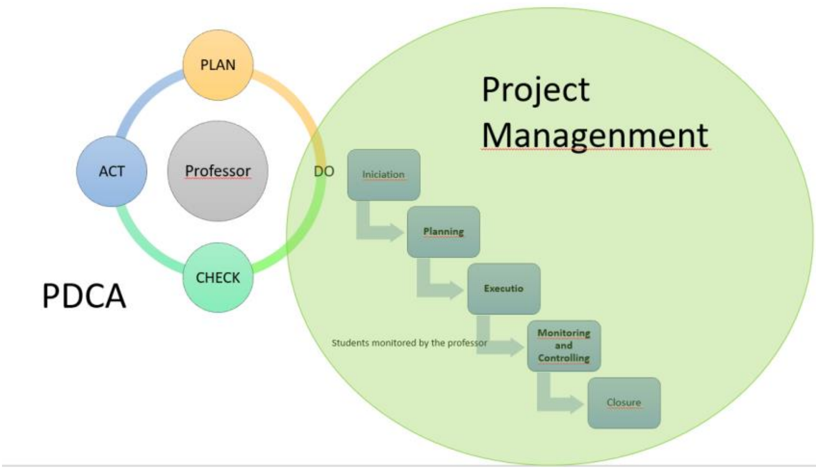


Time was another factor that had to be adjusted. A week was dedicated to explaining the topic of ergonomics and anthropometry. That time exceeded the planned duration, so the professor recorded a video explanation on how to determine percentiles, and flipped classroom methodology was used in the following semester.

3.2 Project Management

To perform the problem situation (project), the students used the Project Manager methodology (Nikhil, 2019) that was learned in previous semesters. This is the interface the "DO" phase of Deming cycle with Project Management Methodology as is shown in figure 5.

Figure 5: PDCA and Project Management interphase.



3.2.1 Initiation

The students work in teams (6 members). They define SMART Objective; they select the traditional workstation as the basis on which they will apply Industry 4.0 tools. The students define the scope.

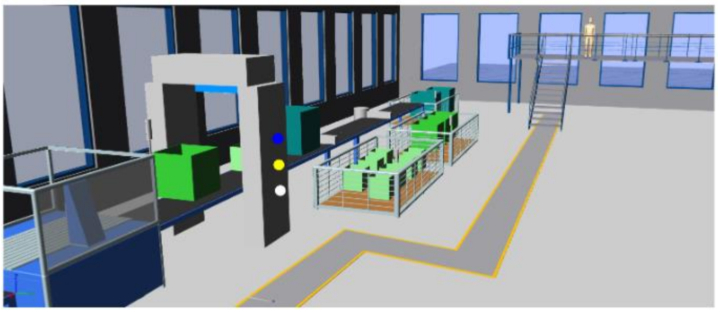
3.2.2 Planning

During this phase, each team develop a detailed project plan outlining tasks, timelines, resources, and budgets for their project and their physical prototype They also identify risks, define quality criteria, and establish a Google Drive as communication strategies (Zwikael,2016).

3.2.3 Execution

In the execution phase, the project plan is put into action (DeHaan, 2017). They represent your workstation using the specialized software of Plant simulation as showed in figure 6.

Figure 6: Workspace distribution using Plant Simulation.



They do ergonomic and postural load assessment as showed in figure 7 and evaluate the anthropometric factors using Jack simulations as showed in figure 7.

Figure 8: Workstation distribution using Jack simulation.

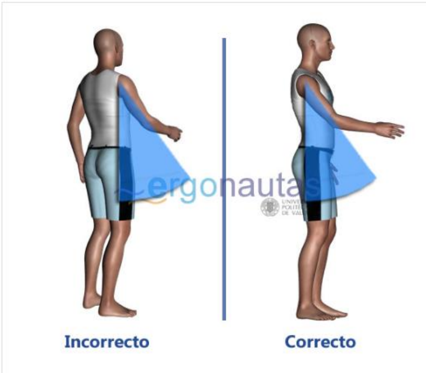
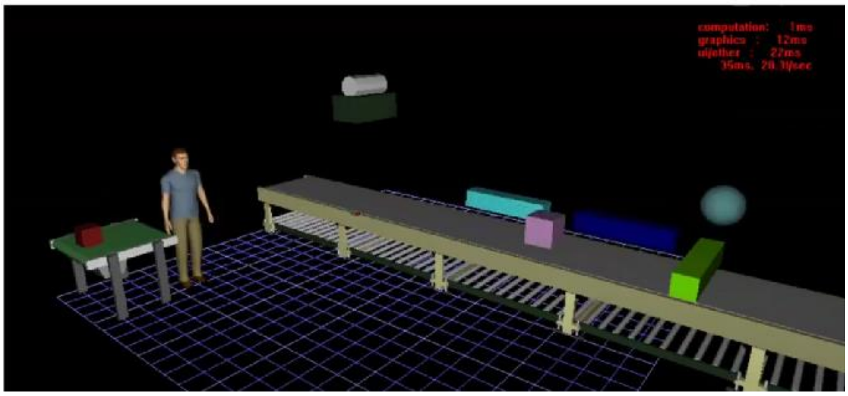
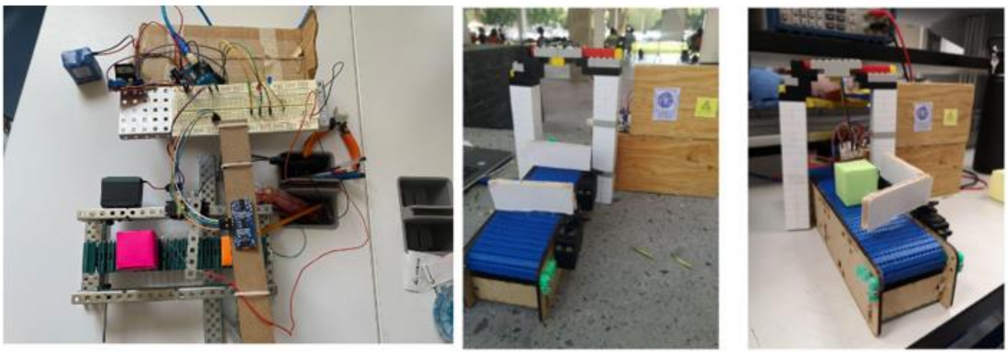


Figure 8: Workstation distribution using Jack simulation.



The students evaluate the performance of their workstation and build their prototype as shown in Figure 9.

Figure 9: Workstation distribution using Jack simulation.



3.2.4 Monitoring and Controlling

Throughout the project lifecycle, progress is monitored against the project plan, and performance is assessed to ensure alignment with objectives. Any deviations from the plan are identified, and corrective actions are taken to keep the project on track. The students and professor monitoring Google Drive and involve managing changes and addressing issues as they arise. (Serrador,2015):

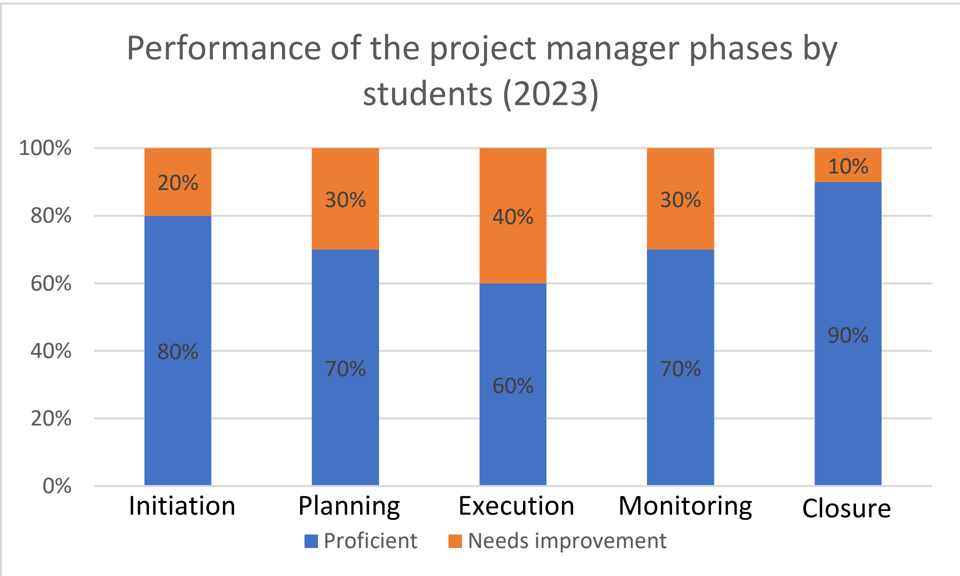
3.2.5 Monitoring and Controlling

Students present the result to the professor, some inviting professors, and their classmates. A final reflection on the ethical and sustainable impacts of the workstation is made.

3.3 Results

The results found both in the application of the Deming cycle in the planning of the professor's activities, as well as the performance of the students in the realization of their project of the subject Cyber-physical Systems Design, have been carried out since the first edition of 2021, just for Deming Cycle and for the use of Project Management since 2023. Below are the results that have allowed teachers to work on continuous improvement in order to achieve significant learning in their students as is shown in figure 10.

Figure 10: Performance of the project manager phases by students.



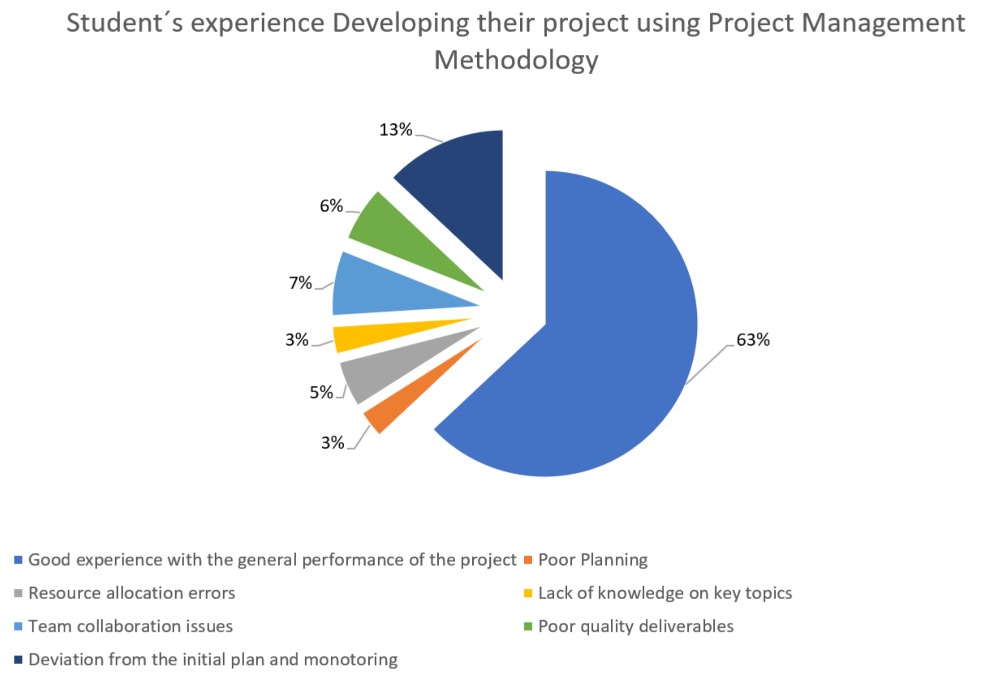
- Initiation: 80% of students are clear about the objective of the project and the construction of the prototype and know how to define a Smart objective, scopes, constraints, and resources for its realization. 20% fail to state the Smart goal, specifically that it is achievable and measurable.
- Planning: During the planning, the time to execute the activity is limited to five weeks, 70% of the student teams make an equitable assignment of activities and establish those responsible for each task, define the resources that they must use for the construction of the prototype and the times to carry them out, they also have well defined the partial deliveries of the project. 30% of the teams fail to correctly define the budget for the

generation of the activities because they do not have clarity in their prototype, other teams do not correctly define their quality criteria in the deliveries (Riemer,2017).

- Execution: This phase is critical as it is observed that a little less than half of the teams (40%) do not carry out the established plan. Mainly because, during the planning stage, they do not consider the anticipation needed to generate some parts of their prototype using the 3D printer in the laboratories. Also, because they are not familiar with the use of design software. Another reason is because team members don't work equally. In the final survey of the subject, about 37% expressed in their comments related to the difficulty of the project due to the lack of planning of the team, not following the plan and because they did not have enough knowledge to develop them as is showed in figure 4.
- Monitoring and Controlling: 30% of teams do not have a good follow-up manager. It doesn't continually review deadlines, commitments, and deliverables. In the absence of such leadership, there is no follow-up and, consequently, there is no control and adjustments to the program of activities.
- Closure: 90% of the teams successfully completed their projects, correctly represented the workstation using Plant Simulation or Factory Cad software, performed an ergonomic and anthropometric assessment using Jack, and analyzed postural load using RULA, REBA and OWAS methods. They discussed the ethical and sustainable impact of their workstation proposal and showed the class how their scale workstation prototype worked using trickery, 3D printing, and engines.

The professor reviews the students' comments on their experience with the project performance. As seen in Figure 11, more than 60% of the students mentioned that they had a good experience in the overall development of the project. However, 13% said they had changes regarding their initial planning or the monitoring and tracking. Between 6% and 3% commented that they had changes in resource allocation, experienced communication problems with their teams, or made errors in their planning.

Figure 11: Student´s experience developing their project using project management Methodology



3.4 Conclusiones

The combination of the Deming cycle and project management offers students a solid and effective methodology for project execution. The Deming cycle, with its focus on continuous improvement through the Plan-Do-Check-Act (PDCA) cycle, provides a framework for constant reflection, adaptation, and ongoing learning throughout the project. On the other hand, project management offers structured tools and techniques for planning, executing, and controlling each phase of the project, from defining objectives to final delivery.

By integrating the Deming cycle into project management, students not only learn to set clear and measurable goals (Plan), but also gain the ability to effectively implement these goals (Do), monitor progress and outcomes (Check), and make adjustments or improvements as needed (Act). This cyclical approach fosters continuous improvement and problem-solving skills, essential both in academia and in the professional world. The students of Cyber-physical system can developed the following skills:

Organization: a structured approach to planning, executing, and controlling the project. This helps to organize tasks, resources, and timelines effectively.

Clarity of Objectives: can clearly define project objectives, scope, and deliverables.

Risk Management: identifying, assessing, and mitigating risks throughout the project lifecycle.

Resource Optimization: can allocate resources efficiently, budget, and materials are utilized optimally.

Communication: facilitates clear communication among team members and the professor. It establishes channels for reporting progress.

Quality Assurance: to ensure that deliverables meet predefined standards.

Adaptability: to be flexible and adaptable to changing requirements and environments. This enables teams to respond quickly to changes.

In summary, the use of the Deming cycle and project management in student projects provides a solid framework for success by promoting effective planning, efficient execution, and continuous improvement, preparing students to tackle real-world challenges and achieve optimal outcomes in their projects.

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