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Scientific articles

Clases en línea y presenciales en la etapa de postpandemia utilizando la adquisición de conocimientos basados en la metodología 4MAT

Online and face-to-face classes in the post-pandemic stage using knowledge acquisition based on the 4MAT Methodology

Aulas online e presenciais na fase Pós-pandémica utilizando a aquisição de conhecimentos baseada na Metodologia 4MAT

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Resumen

En este artículo se describe la implementación de un estudio piloto para evaluar la factibilidad de continuar con la educación en línea después de la crisis de la pandemia del COVID-19 en el campo de la ingeniería, promoviendo la asimilación de conocimientos con base en la metodología 4MAT, cuyos elementos son motivación, adquisición, práctica y extensión. Se diseñó un curso de programación de dispositivos embebidos usando 4MAT para estudiantes de Ingeniería Automotriz, y se aplicó a dos grupos, a uno se le denominó grupo de estudio, quien tomó la asignatura en línea, mientras que el segundo, al que se le consideró grupo de

control, tomó la misma materia de forma presencial. La finalidad era analizar el efecto del proceso de enseñanza-aprendizaje de los estudiantes de nivel superior, en ambas modalidades. Este trabajo pretende ser una reflexión crítica frente a las necesidades actuales, a través de un análisis cuantitativo, tomando en cuenta que el fin último de cualquier actividad curricular debe ser la formación integral de sus estudiantes en todas sus dimensiones, desde la cognitiva hasta la afectiva. Como resultado se puede observar que el uso de los recursos TIC promovió un mejor desempeño de los alumnos, y su percepción es que se aprovecharon las destrezas aprendidas durante la pandemia. Se concluyó que utilizar la metodología 4MAT es una buena opción para el desarrollo de la educación en línea en el área de programación, para lograr una mayor equidad e inclusión en los estudiantes hoy en día.

Palabras clave: aprendizaje integral, competencias, ingeniería.

Abstract

This article describes the implementation of a pilot study to evaluate the feasibility of continuing online education after the COVID-19 pandemic crisis in the engineering field, promoting knowledge assimilation based on the 4MAT methodology, whose elements are Motivation, Acquisition, Practice and Extension. A Programming course was designed using 4MAT for Automotive Engineering students, and was applied to two groups, one of which was called the study group, who took the subject online, while the second, which was considered the control group, took the subject in person. The purpose was to analyze the teaching-learning process of higher education students in both modalities. This work is intended as a critical reflection on current needs, through a quantitative analysis, considering that the ultimate goal of any curricular activity should be the integral formation of students in all its dimensions, from the cognitive to the affective. As results, it can be observed that the use of ICT resources improved student learning, besides the skills learned during the pandemic were used. Concluding that using the 4MAT methodology is a good option for the development of online education in the area of programming to achieve greater equity and inclusion in students today.

Keywords: comprehensive learning, learning skills, engineering.

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Resumo

Este artigo descreve a implementação de um estudo piloto para avaliar a viabilidade da educação continuada online após a crise pandémica da COVID-19 na área da engenharia, promovendo a assimilação do conhecimento com base na metodologia 4MAT, cujos elementos são Motivação, Aquisição, Prática e Extensão. Foi concebido um curso de Programação utilizando a metodologia 4MAT para estudantes de Engenharia Automóvel, que foi aplicado a dois grupos, um dos quais foi designado por grupo de estudo, que frequentou a disciplina online, enquanto o segundo, considerado grupo de controlo, frequentou a mesma disciplina presencialmente. O objetivo foi analisar o processo de ensino-aprendizagem dos alunos do ensino superior nas duas modalidades. Este trabalho pretende ser uma reflexão crítica sobre as necessidades actuais, através de uma análise quantitativa, tendo em conta que o objetivo último de qualquer atividade curricular deve ser a formação integral dos seus alunos em todas as suas dimensões, desde a cognitiva à afectiva. Os resultados mostram que a utilização dos recursos das TIC melhorou a aprendizagem dos alunos, e as competências aprendidas durante a pandemia foram bem aproveitadas. Concluímos que a utilização da metodologia 4MAT é uma boa opção para o desenvolvimento da educação online na área da programação, de forma a alcançar uma maior equidade e inclusão nos alunos de hoje.

Palavras-chave: aprendizagem integral, competências, engenharia.

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Introduction

At this moment in the history of education, very special characteristics have come together, one of them being immersion in the information society, which allows for globalized education. In addition, the use of learning management systems, or LMS, has been promoted (Leiton-Quintero, Mesa-Bejarano, and Ortíz-Carabali, 2022). Another important aspect was the forced introduction of virtual education during the COVID-19 pandemic. This fact placed online education as a real possibility in the public educational field, since before this event it was seen as a partial possibility or in some cases its gradual insertion was very slow (De la Cruz-Flores, 2020). Therefore, it is necessary to investigate and define methodologies that ensure quality online education.

In the 2019-2020 school year, according to what was presented by the National Institute of Statistics (INEGI, 2020), of the 54.3 million people aged 3 to 29, 62.0% (33.6

million) were enrolled in the 2019-2020 school year. Of the above, it is estimated that 2.2% (738.4 thousand people) did not complete the 2019-2020 school year and more than half (58.9%) did so for a reason related to COVID-19. In addition, a relevant fact that the same INEGI provided, in relation to the reasons associated with the COVID-19 pandemic, and for which, many students did not enroll in the 2020-2021 school year, was that 26.6% considered distance classes as not very functional for learning; 25.3% indicated that one of their parents or guardians had lost their job, and 21.9% did not have a computer, any other device, or did not have an internet connection (INEGI, 2020).

This research implemented the instructional methodology that promotes student motivation, knowledge acquisition, practical application of it, and the extension of the application of knowledge, based on the model known as "4MAT Learning", which is the acronym for its English words *Motivation, Acquisition, Transformation, Extension* (Thitiporn, Punsrigate, and Srikoon, 2023), with the aim of evaluating the effectiveness of teaching online education using 4MAT, in contrast to its application in traditional face-to-face classes at the engineering level in the programming area. In the Interdisciplinary Professional Unit in Engineering and Advanced Technologies of the National Polytechnic Institute (UPIITA-IPN), interdisciplinary careers are taught in the area of engineering, but there are no online education programs associated with the careers taught, so it is necessary to investigate the effectiveness of an online education applied in that field of knowledge.

For the implementation of the methodology, a group of students from the Automotive Engineering degree in the subject Programming of Immersive Systems was chosen. This subject is taught in the seventh semester, which is in the last third of their academic training. The purpose of this subject is for the student to be able to carry out the analysis, as well as the design and implementation of real-time systems that allow interaction with physical environments (ISISA-IPN, 2024) "Evaluate the formal methodologies and programming standards for the analysis, design and implementation of real-time systems that interact with physical environments" (ISISA-IPN, 2024), considering that immersed computing systems are those designed for microcontrollers and that allow controlling from a car engine to more complex systems, such as stability control, or automotive, air, or rail traffic; then an understanding and application of the knowledge acquired in solving engineering problems is required (Stankovic, 1996). The course was taught online to a group of 21 students and was monitored using *software* that allows asynchronous communication, such as synchronous communication, for the assignment and monitoring of activities proposed by the teacher

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(Guijarro, Rodríguez, & Castro, 2021; Ortiz, Tarango, & Romo, 2019). The same course was also taught to the control group, but in person, and the same methodology was used; the difference was that traditional resources were used for its delivery within the university facilities.

Regarding the 4MAT methodology

The need in online education for innovative and engaging practices for students to retain their motivation, attention and interest in learning, makes it necessary to find teaching systems that allow a deep understanding of the subjects and that favor the development of skills, to transfer that knowledge to the solution of problems in real conditions, considering factors such as their learning styles, cognitive abilities, lateralities and hemispheric specificities (Romero, Chávez and Castillejos, 2023). The 4MAT system takes into consideration the way people perceive, process, understand and communicate information, and integrates them into a learning cycle that promotes the understanding and communication of knowledge (Thitiporn, Punsrigate and Srikoon, 2023). According to Berenice McCarthy (1982), the 4MAT system is based on an instruction cycle consisting of four quadrants , which are related to the learning styles of the Kolb model of 1984 (Agudelo, Salinas and Mortera, 2010). The learning styles according to Kolb are:

a) Divergent: the student is imaginative, visualizes specific situations from different perspectives, formulates ideas, is emotional and is interested in others.

b) Assimilator: actively conceptualizes, is observant, has great skills for theoretical models, has inductive reasoning, is less interested in people and more in abstract concepts.

c) Convergent: likes to put ideas into practice, has hypothetical deductive reasoning, is not very emotional, and prefers objects to people.

d) Accommodator: likes active and concrete experiences, carrying out plans, getting involved in new experiences, risky and intuitive, depends on other people, feels comfortable with people.

The working group adapted the 4MAT model to Kolb's learning styles as shown in Table 1. In Figure 1, the four quadrants of the methodology proposed by McCarthy (Alshankyty, 2021) can be seen and the two steps included in each of the quadrants can also be observed.

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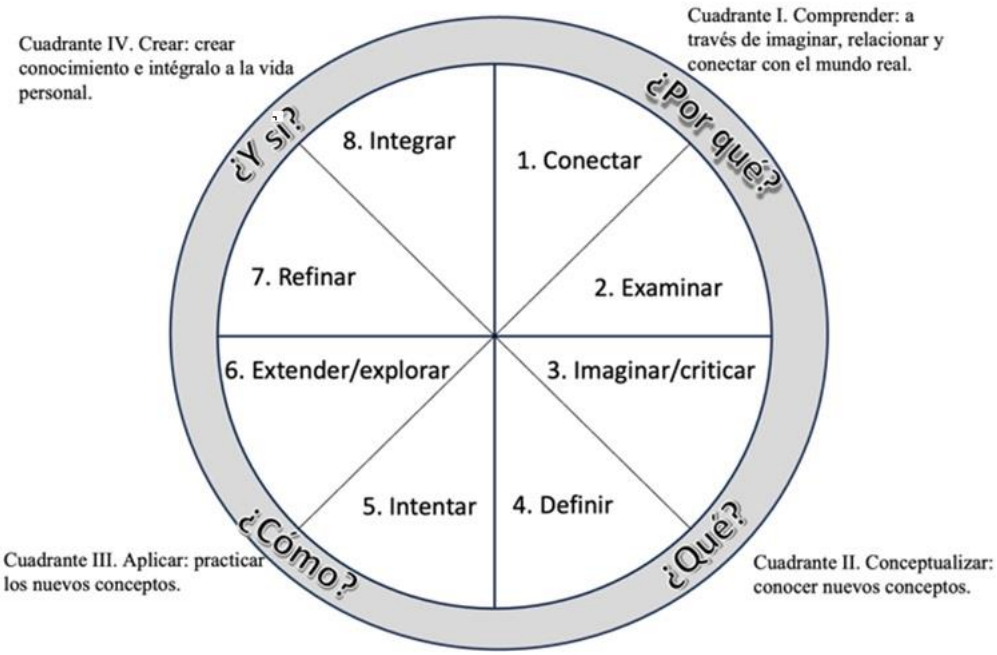
Table 1. Quadrants of the learning model association and the 4MAT model.

Kolb	McCarthy	Quadrant	Questions
Divergent	Imaginative	I. Understand	Because?
Assimilator	Analytical	II. Conceptualize	That?
Convergent	Common sense	III. Apply	As?
Usher	Dynamic	IV. Create	And if?

Source: Adapted from sources (McCarthy, 1982; Agudelo, Salinas and Mortera, 2010)

Figure 1. 4MAT methodology diagram.



Source: adapted from sources (Conde, 2017, McCarthy, 1982).

Quadrant I. Understanding

This quadrant is divided into two: connect and examine, which allows to answer the why of knowledge (Conde, 2017; McCarthy, 1982). Therefore, in the first session, previous personal experiences in programming and use of the embedded systems are shared, an orderly discussion is promoted to reflect on the degree of knowledge that each student has and to make an initial connection with the new knowledge.

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Quadrant II. Conceptualize

By integrating experiences and after guided analysis, the need to acquire more knowledge within our context arises, to solve problems identified in the previous quadrant. In this quadrant, analysis is carried out through imagining or criticizing, and then defining the new knowledge. By imagining, the need to express and associate this new knowledge is generated and, in the definition, concepts and skills are learned about what is being addressed, answering the "what?" (Salinas, 2008, McCarthy, 1982).

Quadrant III. Apply

After the student understands the new knowledge, he or she is then ready to use that knowledge in typical examples or conditions. Here it is possible to explore and implement, to answer the "how?" question (McCarthy, 1982). By assimilating the examples, exploring their variants and solving new challenges, the student can internalize and take ownership of the knowledge, to the point of developing original applications and adapting them to personal needs.

Quadrant IV. Create

In this quadrant, the ability to extend the scope of the knowledge already assimilated is fostered, to refine the strategies for its application, to identify possibilities for integrating it with other knowledge and to detect how to collaborate in the solution of more complex problems. Then you are ready for the "what if?" (Conde, 2017; McCarthy, 1982).

Some modalities of education

Identifying the classification of the modalities or forms of education (Oradini, Barrientos, Yáñez, Pennanen and Aparicio 2022), allows defining the context where this teaching-learning methodology was applied. Face-to-face education is that which requires the physical presence in the classroom or laboratory of both the students and the teacher; it is known as a synchronous modality. One characteristic is that it is usually not recorded or stored in a digital repository, where the teacher usually uses the blackboard and a textbook or notes, which is known as traditional education (Arias- Velandia, Rincón-Báez and Cruz-Pulido, 2021). In contrast, virtual education is an asynchronous model and has the characteristic that the teacher assigns educational material through virtual platforms such as Canvas, BlackBoard, Classroom (Ortiz, Tarango, & Romo, 2019; Romero, Chávez, & Castillejos, 2023), and keeps in contact with his students to resolve doubts or provide feedback through group forums or by email. In these cases, students do not have to be present

at the same time and physical space with the teacher. In turn, the teacher makes use of automatic evaluations and monitoring of assigned activities. An example is the open courses available online for free (MOOC, Massive Online Open Courses).

Finally, online education, according to Moreira and Delgadillo (2014), is a modality in which students and teachers are in different physical spaces at the same time. In this modality, teachers and students participate and interact in a digital environment, through technological resources, making use of the facilities provided by the Internet and computer networks synchronously, that is, these must coincide with their schedules for the session. Computer programs such as Zoom, Meet and Microsoft Teams are used to carry out video conferences. In addition, the characteristics of virtual education are also included, since work can be assigned on different platforms, and asynchronous feedback can be given through chats, forums and email. Some of the advantages of online education are: 1) the economy, since the expenses involved in the use of physical spaces are reduced, as well as the expense of transfers; and 2) openness, because it expands access to information while reducing geographical barriers, by allowing users to join courses, regardless of their location (Ruiz, 2013).

It is also important to make a distinction between online education and distance education. According to Quezada (2006), distance education can be partly in-person and partly virtual, although this depends on the institutions where it is taught. In this modality, students have control over the time, space, and pace of their learning, because an internet connection or computer resources are not required, as in other modalities. The materials used are generally physical, such as notebooks, pens, crayons, among others, but digital resources can also be included. There are even programs that send educational material and lessons by postal mail (Chávez, 2016). An example of this is what was experienced in the pandemic of 2020 and 2021, where at the primary level in Mexico, distance education was given through open television channels, which was implemented by the Ministry of Public Education in Mexico (SEP, 2020). There have been other cases such as the “open high school” program, in which students have the educational material in physical form and go to the institution to receive some advice and take the exams.

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Aim

The objective of this work is to compare the efficiency of the implementation of the 4MTA method in online and face-to-face education in the area of programming at the engineering level, through both the perception of the students, as well as the coverage of the objectives of each stage of the process and the result of its evaluation, taking advantage of the benefits of technology.

Materials and methods

The scope of the research was descriptive (Hernández-Sampieri, 2018) and a quantitative methodology was used because the study variables were measured through a questionnaire and a statistical analysis was carried out. The following research variables were defined: a) implementation of 4MAT in the online course using digital resources; b) verifying whether an online course allows students to develop original applications and adapt them to their own ideas in the same way as a face-to-face course; and c) verifying whether an online course motivated students to apply new topics and analyze the relevance of the content for their career, in the same way as a face-to-face course.

The population is represented by 7th semester Engineering students, from a total of nine semesters that make up the Automotive Systems Engineering (ISISA-IPN) degree at the National Polytechnic Institute and who take the Immersive Systems Programming course. As a background, there is a programming course in C language with a structured paradigm. For this course, only one group is open per semester. The study was divided as follows: in the semester from January to June 2023, the course was taught online (experimental group), using the 4MAT methodology; and in the semester from August to December 2023, it was taught also using 4MAT, but with the group in a face-to-face mode (control group). The sample is defined as random because both groups were made up of students who registered to take the course. 100% of the students participated voluntarily in the research (Hernández-Sampieri, 2018). Table 7 describes the characteristics of the sample.

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Table 7. Sample characteristics

Feature	Virtual Course	In-person course
School	UPIITA-IPN	
Career	Automotive Systems Engineer	
Subject	Immersive Systems Programming	
Class hours	Hours/week/theory: 4.5 Hours/week/practice:1.5	
Semester	January-June 2023	August – December 2023
Students	21	30
Group rating (mean ± standard deviation)	91.8±23.0	93 ±25.3
Desertions	1	2

Source: Own elaboration

The subject that was worked on with both groups, the experimental one (which was online) and the control one (which was in-person), was Immersive Systems Programming. The skills of an automotive engineer must allow him to carry out systematic processes, solve practical problems, propose solutions according to the context, administer and manage complex manufacturing processes in work teams (Galárraga, Izaguirre and Orellana, 2021). These skills must be encouraged throughout the engineer's training, in a transversal way in the students' curriculum. Immersive systems programming is a knowledge where these skills can be consolidated, and previous experience in face-to-face education has shown that the synchronous teaching and learning process gives results using the classroom and assigned laboratories; it happens that in this modality, elements of the 4MAT model are often naturally involved, that is, in an implicit way based on our experience. However, dropout statistics during the pandemic revealed the need to seek structured strategies using emergency online classes, as in this case, where through the systematic application of a methodology such as 4MAT, the aim is to ensure that elements are provided to go through the four stages of the learning cycle.

Implementation of 4MAT

In order to achieve the implementation of 4MAT in online education, it is necessary to use Information and Communication Technologies (ICT) (Tirado and Roque, 2019), seen as modules of expression through virtual sessions that can be carried out synchronously or asynchronously, with dynamic and interesting materials for the student, such as videos, games, digital presentations, joint practices, projects. In addition, ICTs represent a communication channel for collaboration and exchange, they are considered as an instrument

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to process information, educational resource management tools, evaluation tools, teaching aids, playful media and means to learn to develop social skills such as communication, teamwork, planning, organizing and reconciling (Graells, 2013). Table 2 describes the tools used in the implementation of 4MAT in this proposal.

Table 2. Electronic resources for online education

	Resource	Characteristics
1	Microsoft Teams	Environment for communication (Guijarro, Rodríguez and Castro, 2021). a) Presentations by the teacher. b) Asynchronous communication through scheduled tasks c) Chat for quick and short communication between the teacher and the group d) Small group meeting space e) Record class for asynchronous distribution and replay.
2	Google Classroom	*Software* specialized in the management of academic activities (Ortiz, Tarango and Romo, 2019; Romero, Chávez and Castillejos, 2023). a) Create activities, tasks, assessments, rubrics, etc. b) Store student work c) Disseminate indications, changes, notices d) Design and manage grades for school activities on an individual and group basis.
3	YouTube	Free video storage and distribution service (Ramírez-Ochoa, 2016). a) It was used to show examples of the main characteristics of Object-Oriented Programming (OOP). b) They were selected and recommended as complementary material.
4	Canva	Graphic design web tool (Romero, 2019). a) Making presentations b) Book making c) Video making
5	Microsoft Whiteboard	Electronic whiteboard built into Teams. It is used like a whiteboard in a face-to-face class, with the advantage that it is possible to record. All students can use it in a shared manner, and everyone can see what is being drawn or written at the time.
6	Microsoft Breakout rooms	Tool for remote small group work, built into Teams.
7	Chat	Tool for remote and instant text communication.
8	Google Chrome	Internet information search engine, which has intelligent search tools, translators, specialized searches such as Google Patents and Google Academic.
9	Lucidchart	Online tool specialized in diagramming that allows users to collaborate and work together in real time. Flowcharts, UML designs, organizational charts, website schematics, and *software prototypes can be created* (Rueda and Vázquez, 2018).

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10	IntelliJ IDEA IDE	Integrated development environment for the design and implementation of computer programs (software), where you can collaborate in real time, in the creation of code, refactoring of it and detecting errors during programming.

Source: own elaboration.

The 4MAT is based on the learning cycle and is designed so that people can learn in a meaningful way. According to Moreira's definition (2012), meaningful learning "is that in which ideas expressed symbolically interact in a substantive and non-arbitrary way with what the learner already knows" (p. 2). Learning becomes meaningful to the student when he or she manages to apply knowledge in solving a problem or situation, that is, when he or she has gone from theory to putting it into practice, since that is when he or she makes sense of what he or she has seen in the classroom or in a book or a source of information. This process of information translation is achieved when at a cognitive level the student has achieved an interaction between knowledge and his or her experience.

Therefore, it is necessary to go through the four quadrants with their two stages associated with the typical activities of the functioning of the left and right hemispheres. In the left hemisphere, the typical activities in learning are the analysis and integration of verbal information (which facilitates the learning of symbols such as language) and arithmetic. Meanwhile, the typical functionalities of the right hemisphere are creative tasks, such as music; physical education and psychomotor education (Navarro, Iglesias and Caballero, 1990). Starting with quadrant 1 and following these eight sequential steps, any content or process can be taught. The 4MAT methodology allows to establish the personal meaning that the programming of the embedded systems has for automotive systems; Through the quadrants, students can make personal associations of experiences, such as using examples of terms related to their field when programming the functionalities, and through a guided discussion about their programming experience and its use in their studies, which will lead them to identify under which conditions the previous tools were insufficient. This will motivate the student to design and implement projects that, in turn, allow them to analyze the usefulness and relevance of the course content for improving safety and comfort in cars, followed by practical application, through simulations and prototypes at scale or in a laboratory for real implementation.

All students are expected to be able to develop their skills and to be able to work independently, organize, identify and describe the functions of automotive systems. When they are working in their strong area, they will also could share their strategies and develop other areas by working with their peers. When their skills are less developed, the proposal

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will allow them to integrate and reinforce them. All skills will form the learning cycle. Table 3 concentrates the phases that correspond to quadrant I.

Table 3. 4 MAT implementation of quadrant I.

Subject	Immersive Systems Programming
Issue	Introductory concepts of Object Oriented Programming (OOP)
Quadrant I. Know the academic background of the students with respect to the concepts and definitions of OOP, as well as analyze the applications known by the group.	
Phase 1. Connect the terms with real-life things and representation in programming. Phase 2. Examine the different examples and relate them to the concepts of what an object is in real life with the characteristics of objects in OOP.	
Activity	Generate a dialogue with students through examples from their daily lives, defining and classifying objects, describing their characteristics and their functionalities; for example, a car, a computer, a student, a teacher, a pet, etc.; using the whiteboard to summarize the information. Digital presentations are used to support the dynamic. It is complemented through videos.
Teacher	Organizes small groups for discussion, organizes group debate, shows examples directing students to analyze and reflect.
Student	Participate in the small group debate and then in the group debate. Support your presentation of the topic with your personal experiences, reflect and analyze the scope of the knowledge to be learned.
Resources	Teams, YouTube, Canva, Whiteboard and Breakout Rooms.

Source: own elaboration

Table 4 shows the phases that made up quadrant II.

Table 4. Implementation of 4 MAT of quadrant II.

Subject	Immersive Systems Programming
Issue	Introductory concepts of Object Oriented Programming
Quadrant II . Conceptualizes and defines the characteristics of OOP.	
Phase 3. Imagine/critique through the definitions and concepts necessary to develop your own examples of OOP. Phase 4. Define each of the OOP characteristics applied to tangible real-world examples in programming.	
Activity	Define and learn the concepts: classes, objects, attributes and methods under the Object-Oriented Programming paradigm. Identify and recognize the code in the programming language for the implementation of these definitions.
Teacher	Using videos, presentations and examples in the programming environment, the student is guided to define and learn new concepts. For example, presenting the characteristics of OOP in a graphical form of a dog, then transferring it to the rules of programming, the association must be made element by element so that the student achieves conceptualization through a real example. Digital platforms are used to present the concepts with the electronic whiteboard. Student participation is allowed through the session's microphone and camera. Additional information, as well as complementary activities, are sent through the Classroom platform.
Student	Listen and observe what the teacher is saying. Students make comments and ask their classmates questions that allow them to understand and reflect on new concepts, following the example of the dog to show how each of the elements of OOP associated with the characteristics and functionalities of a dog is represented. Interact through questions in the chat, reactions on the Microsoft Teams platform, opening your microphone and camera. Complete the proposed activities and submit the resolution of your activity.
Resources	Teams, Classroom, YouTube, Canva, Whiteboard, Chat, Lucid Chart, IntelliJ.

Source: own elaboration.

Table 5 shows the activities and phases corresponding to quadrant III.

Table 5. Implementation of 4 MAT of quadrant III.

Subject	Immersive Systems Programming
Issue	Introductory concepts of Object Oriented Programming
Quadrant III. Apply the concepts through exercises proposed by the teacher and with his support and advice the student must be able to solve them.	
Phase 5. Complete the exercises and criticize the results through conclusions and reasoning, after solving the exercises and complementary activities proposed by the teacher. Phase 6. Extend/explore: the student must investigate what type of problems arise in his/her area of training and how they are linked to the proposed exercises. Transfer the proposed problems directly to that field and explore new solutions based on this knowledge.	
Activity	Development of programs with the Object-Oriented paradigm. It should range from simple examples to more complex exercises. Assignment of exercises with learning in the computer lab and autonomous learning. The exercises should be oriented to solve problems in your career, such as simulating a car's speedometer or simulating the monitoring of a car's air conditioning.
Teacher	Assign students to small groups. Direct and support the solution of the work in the virtual or physical laboratory. The teacher should enter the small groups for a short period of time to verify understanding of the problem and to ensure good coordination and assignment of work between students, as well as to resolve doubts.
Student	Enters into small groups, participates in defining the work strategy, actively participates in solving the exercises proposed by the teacher, pays attention to the observations and comments of his/her group mates and is able to explain to the teacher his/her solution strategy and his/her participation in it.
Resources	Teams, Classroom, Breakout Rooms, Lucid Chart, IntelliJ.

Source: own elaboration.

Table 6 shows the activities used in quadrant IV:

Table 6. Implementation of 4 MAT of quadrant IV.

Subject	Immersive Systems Programming
Issue	Introductory concepts of Object Oriented Programming
Quadrant IV. Create	
Phase 7. To refine and deepen the application of knowledge, the student proposes his or her own problems that solve an everyday situation. Phase 8. Integrate OOP concepts into the solution to real-life problems. Be able to identify the potential use of new knowledge.	
Activity	Analyze, design, and program the solution to a situation or problem in your specialty, for example, simulate controlling the speed of a car, monitor the condition of a car's tires, monitor the climate of a car, etc.
Teacher	Direct the development of the project to be developed by assigning time and team members. Develop an evaluation rubric. Evaluate and provide feedback to the student with the objective of promoting the identification of the elements required for the development of projects using this new knowledge.
Student	Create knowledge and integrate it into personal life by identifying problems to be solved in their specialty, organize themselves into small groups to solve the project, guided by the professor in the analysis of their resources and proposed solutions. Investigate and go beyond what is proposed in class. Communicate with the professor and work team, asynchronously in case of having doubts. Present the solution to the problem for the professor to evaluate.
Resources	Teams, Classroom, YouTube, Canva, Breakout Rooms, Chat, Chrome, Lucid Chart, IntelliJ.

Source: own elaboration.

To verify the student's perception of their learning, a questionnaire was applied to each student, relating the questions to the objective of each quadrant of the methodology. The validity of the questionnaire was obtained through the review of two teachers who teach the subject. The observations made by both teachers were considered, which allowed us to justify each item of the questionnaire. The seven questions were of the Likert type and the levels of achievement of the objective of the proposed strategy by quadrant were divided into 1 = almost never, 2 = usually not possible, 3 = occasionally possible, 4 = usually possible, 5 = almost always possible. Table 7 shows the questions of the questionnaire and the justification given by the teachers.

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Table 7. ***Questionnaire*** for the analysis of student perception of their learning.

Quadrant in 4MAT	Section in 4MAT	Number of questions in the questionnaire applied to students	Ask	Validity or justification
Yo	1	1	Did the course topics allow you to relate experiences with a personal meaning?	Check if the student finds personal value, which is important to increase motivation from the beginning of learning.
	2	2	Did the course activities allow you to reflect and analyze the problems you had to solve?	Check for emotional connection, and whether the content was meaningful and relevant in a broader context.
II	3	3	Were the concepts you learned in this subject sufficient to solve the problems posed in the practices and projects?	Verifies the student's reflection on the acquired knowledge that allowed him/her to solve problems through a meaningful integration of the contents.
	4	4	Were the exercises, practices and projects sufficient to use the concepts learned in the course?	It measures the depth of understanding and internalization of the content. It verifies whether the student not only understands the theoretical concepts but can also solve practical problems.
III	5 and 6	5	Did the projects allow you to explore, develop original applications and adapt them to your own ideas?	Verify the effectiveness of the exercises and practical activities that allowed the student to learn the contents. Validates whether the student feels capable of applying the contents in new problems or exercises.
IV	7	7	Did the projects motivate you to integrate, apply new themes and make them more complex than requested?	Check whether the student is able to transfer knowledge to new situations. In this way, we can observe that the student has internalized the knowledge and is ready to apply it in a real context.
	8	6	Did the projects allow you	Check whether the student

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			to analyze the usefulness and relevance of the course content for your professional career?	feels motivated and able to use what he or she has learned in a creative and innovative way. This is important in technical and professional fields.

Source: own elaboration.

To evaluate the reliability of the questionnaire, m=51 participants were considered, for n=7 questions. The internal consistency of the questions was evaluated with the Cronbach coefficient (α), which was calculated using Excel, since it allowed obtaining both the sum of the variances and the variance of the sums.

In addition, the split-half test was calculated considering questions 1, 3, 5 and 7 as the first block and questions 2, 4 and 6 as the second block, which allowed measuring the correlation between the results of comparing the averages per participant of each block and calculating the correlation using the Spearman coefficient, since it adjusts the correlation by considering that the variable is not continuous and that the distribution of the samples is not Gaussian.

Results and statistical analysis

The Cronbach coefficient was 0.97, which implies excellent reliability (see Table 8 and Annex 1).

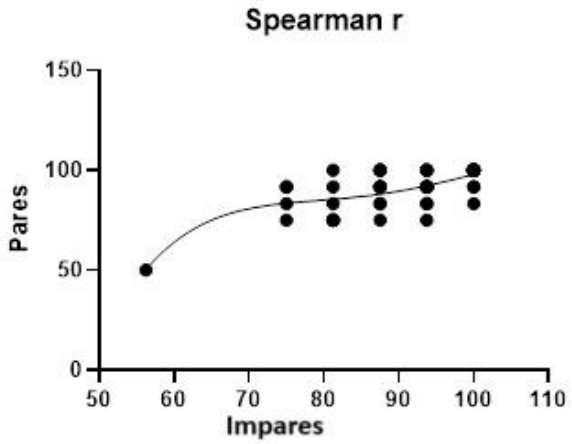
Table 8. Values obtained to obtain the Cronbach alpha coefficient.

Variable	Worth
K	7
Summation of variances	5451.26874
Variance of the sum of the items	32400
Coefficient	0.97037

Source: own elaboration.

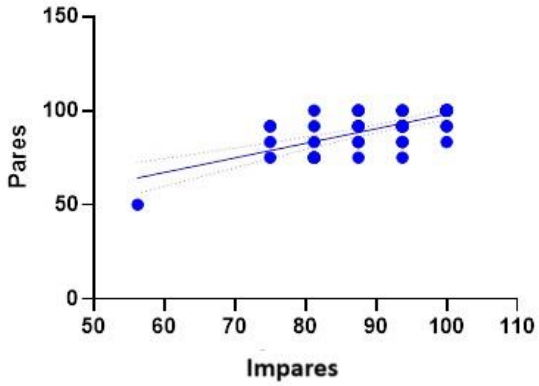
As for the correlation of the two halves, the Spearman coefficient was 0.622 ($p<0.0001$), with a 95% confidence interval, which was [0.4112 to 0.7697]. In the graphs in Figures 1 and 2, a positive correlation is observed between the blocks of questions.

Figure 1. Graph resulting from block 1 (odd questions).



Source: own elaboration.

Figure 2. Resulting graph of block 2 (even questions)



Source: own elaboration.

The Pearson coefficient and the linear fit of the question blocks was 0.6924 with a confidence interval of [0.5151 to 0.8129], but because it is not a continuous variable, it is not as precise as Spearman.

It was observed that there was a higher dropout rate in the face-to-face course, and when comparing the two groups with the t-student test with $\alpha = 0.05$, no significant difference was found ($p < 0.05$) between the performance of the two groups, while the evaluation shows that both groups satisfactorily completed the course.

The research provided information to analyze the cause-effect of 4MAT in online courses.

The results obtained from the implementation of 4MAT in the two groups were compared by question based on what was reported by the students, such as the perceived achievement in each of the areas involved in the learning cycle.

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Table 9 shows the reported level of achievement (1 to 5 according to the scale), considering 5 as the highest level (80-100%) and 1 as the level in which the objective was almost never achieved, which would correspond to between 0 and 20%, in addition to the percentage of responses from the student groups, that is, the percentage of the sample of students who are considered to have obtained that level. The values highlighted in bold are the maximum prevalence per question and the sum of the percentages in each row per column must equal 100%, since it corresponds to the total number of students.

Table 9. Results of the quantitative analysis of students' perception.

Quadrant/ Ask		Online (21 students) (Achievement level, % students)	In person (30 students) (Achievement level, % students)
Yo	1	(3,4.8%), (4,14.2%), (5,81%)	(3,6.7%), (4,50%), (5,43%)
	2	(2,9.5%), (4,14.3%), (5,76.2%)	(2,3.3%), (4,50%), (5,46%)
II	3	(4,14.3%), (5,85.7%)	(4.30%), (5.70%)
III	4	(3,4.8%), (4,9.5%), (5,85.7%)	(4.40%), (5.60%)
	5	(2,4.8%), (4,9.5%), (5,85.7%)	(4,46.7%), (5,53.3%)
IV	6	(3,4.8%), (4,28.6%), (5,66.7%)	(3,3.3%), (4,16.7%), (5,80%)
	7	(3,4.8%), (4,4.8%), (5,90.5%)	(3,6.7%), (4,46.7%), (5,46.7%)

Source: own elaboration.

If we consider that the effect is positive from level 3 (60-80% achievement), then we have that, in both types of course, it was always possible to complete the 4MAT cycle, from identifying their previous experience to the appropriation of knowledge and resolution of projects. It can be seen in Figure 3 that more than 70% of the students met the objective of each stage. However, the online course group tends to have a higher perception of achievement of each of the stages throughout the process , and only in the identification of real examples in their field of knowledge was the face-to-face method higher. This may be due to the fact that the directed discussion in the classroom encourages the participation of the students and the teacher to identify dubious participation attitudes that can be encouraged.

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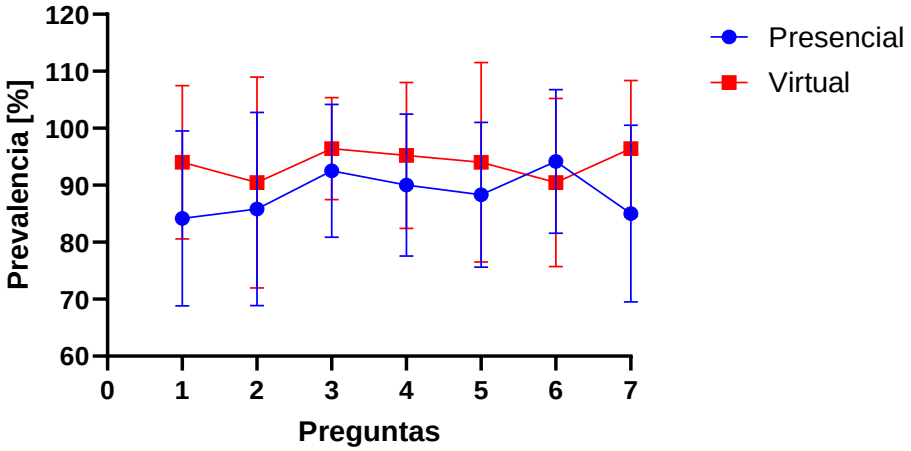
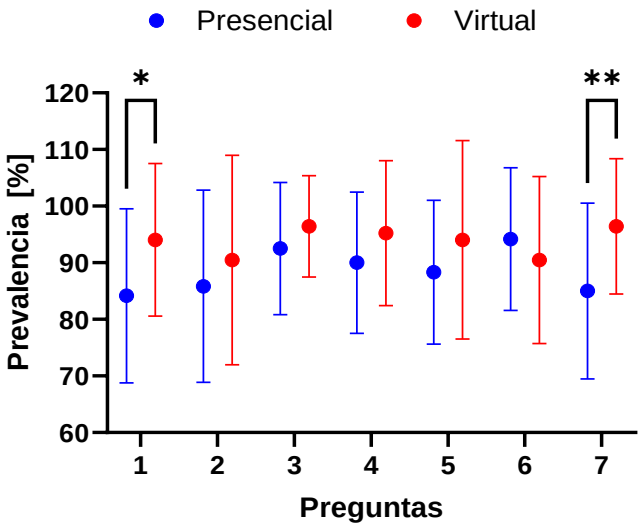
Figure 3. Prevalence of responses [0-100] % compliance with the objective of each stage in face-to-face and virtual classes.



Source: own elaboration.

Comparisons were made for an analysis with a type III multiple effects model, without assuming sphericity, with alpha of 0.05, where the Tukey method was used to compare all the averages of the questions of the two groups with each other (figures 4 and 5).

Figure 4. Comparison of the perception of compliance with the objectives of face-to-face and virtual classes, obtained from the questionnaire questions, with *P adjusted <0.05, **p adjusted<0.005



Source: own elaboration.

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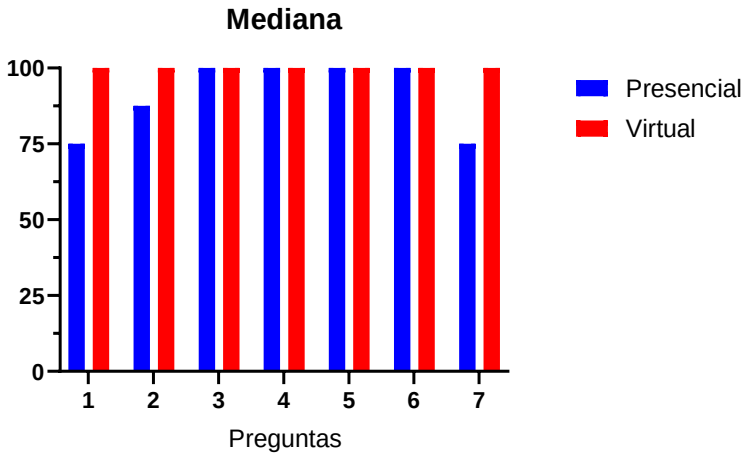
Figure 5. Median of the perception of compliance with the 4MAT objectives of face-to-face and virtual classes .

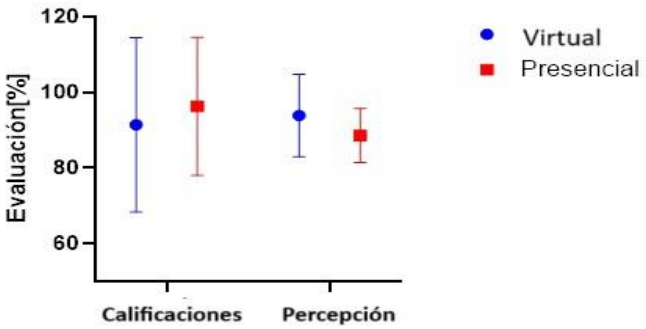


Source: own elaboration.

If we do not assume that the distribution of the samples is Gaussian, and considering that the Likert questionnaire is by ranges, then it is convenient to analyze the medians, there the differences in the tendencies of both groups throughout the learning cycle are more evident (4MAT).

Finally, the means, standard deviation and number of participants were considered to make a comparison between the changes in course performance and the general perception of student achievement, to verify whether there is any difference between the two teaching methods, with the ordinary TWO-WAY ANOVA comparison method and α=0.5. It is observed that there are no significant differences between the two modes of teaching the course, and that the quality of the course is maintained, as shown in Figure 6.

Figure 6. Comparison of the perception of objective achievement and the grades obtained as a group with 4MAT applied in face-to-face and virtual classes .



Source: own elaboration

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Discussion

According to the research variables, it can be observed in the statistical analysis carried out that it was possible to implement the 4MATE methodology both in a face-to-face course and in the virtual course. Figure 5 shows that the percentages were always greater than 70%, which indicates that in both cases the student considers that he usually or almost always covered the objective of the stage considered within the 4MAT, which is reflected in the evaluations through exams applied in the course, both in the students who attended the virtual course and those who attended the face-to-face course. Throughout the learning cycle, there was a greater perception of achievement in the virtual course than in the face-to-face course, however, in the rest of the steps of the 4MAT there was not always a significant difference between both groups.

Regarding performance in the quadrants, in the first and last ones, a lower perception of achievement was observed in the group that took the face-to-face course compared to the virtual one, since there was less manifestation on the part of the students in the way they perceived, processed and communicated the information in relation to the course that was taught virtually, therefore, according to what was indicated by Thitiporn, Punsrigate, and Srikoon (2023), the 4MAT system was better integrated into the learning cycle in the virtual modality, although it also reached a good level in the face-to-face form. In questions 1 and 2, which refer to reflecting on experiences with a personal meaning, the value obtained in the virtual course was higher than in the face-to-face course, this was because the student was able to connect to the internet and examine the topic to complement the discussion using the digital tools available on computers. This result coincides with what Tirado and Roque (2019) and Graells (2013) pointed out, when they pointed out that the ICTs used in virtual education represent a communication channel for collaboration and the exchange of information, which allows the different stages of methodologies used in the teaching and learning process to be carried out. Question 7 is associated with the fourth quadrant, where the aim is to integrate new knowledge into the student's useful tools to solve problems, and it was observed that in virtual classes there was a greater perception of achievement compared to face-to-face classes, in which students were also motivated to integrate, apply new topics and develop more complex proposals than requested, this due to the possibility of simultaneously observing the development, evolution and delivery of the projects of each of the students as a group. This was possible thanks to tools such as Microsoft Teams, which allow synchronous meetings, in addition to sharing the screens of each of the students and

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observing everything that the others do. These results that were obtained support one of the characteristics of the 4MAT methodology, referring to the fact that it leads the student to meaningful learning, according to the definition reviewed by Moreira (2012).

Although throughout the learning cycle, the virtual course had a higher perception of achievement than the face-to-face course, in the rest of the steps of the 4MAT there was no significant difference between both groups; the grades in the virtual course were slightly lower than in the face-to-face course, but less dropout was observed.

Conclusions

The pilot study allowed to evaluate the feasibility of continuing with online education in the subject of "Immersive Systems Programming" taught in one of the Academic Units of the IPN, for which it is essential that the professor prepares the plan of his classes according to the 4MAT methodology, including activities, problems and exercises related to the student's career. It is also required that the digital platform where the classes will be taught has components such as a virtual whiteboard so that annotations can be made, the ability to divide students into small groups and assign them to different rooms for each team, microphone and camera of the session for student participation, host digital material and resources such as notes, slides, etc.

It was found that the assimilation of knowledge by students was promoted, based on the 4MAT methodology, through the design of the course, where it is observed that the results in a group of students through online education and in a control group in a face-to-face manner, were similar and that in some aspects such as connecting, examining and integrating, they were greater in the virtual course than in the face-to-face course. This work aims to be a critical reflection of design options for online courses as a possible response to the current needs for universal access to education. The use of ICT resources, combined with LMS, and a design based on 4MAT, allow maintaining the quality of the courses, keeping motivation as a relevant factor in the student's attachment to the course of subjects that are usually taught in person.

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Future lines of research

The research was carried out with a subject belonging to the computing area, in an Academic Unit belonging to the IPN, so as a future work it is proposed to expand the study considering other subjects, such as Basic Sciences, which includes the different disciplines of mathematics and physics. Another future line of research would consist of evaluating how the information on the learning profiles of students proposed by Kolb can impact the teaching-learning relationship within online courses.

It is also proposed to carry out an analysis that includes other technological tools and virtual spaces that allow the correct use of the proposed methodology. Finally, another future line of research would consist of the use of the methodology in the case of face-to-face classes.

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