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PRACTICAL WORK IN CHEMICAL ENGINEERING WITH ACCESS TO COGNITIVE TOOLS THROUGH QR CODES

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ABSTRACT: This paper presents the results of a project aimed at designing and evaluating a learning support strategy for planning practical work and the proper use of laboratory equipment in chemical engineering through the use of QR codes. The proposal consists of facilitating immediate access to multimedia content from the practical work environment itself, with the aim of promoting the use of ICT as teaching and research resources in an experimental context. The work was developed based on the content of the Comprehensive Laboratory I course in the Chemical Engineering program at the National Technological Institute of Mexico and was implemented in the Chemical Engineering Laboratory at the Technological Institute of Pachuca. Infographics and reference materials were created, and cards with QR codes were installed on various pieces of laboratory equipment. The use of these resources, integrated into previously defined activities, contributed to conceptual reinforcement and the development of practical and research skills in a more agile and autonomous manner. It also encouraged interaction among students and improved the efficiency of collaborative work in the laboratory.

KEYWORDS: Teaching strategy, comprehensive laboratory, ICT, QR codes.

Introduction

The evolution of society has been strongly influenced by information and communication technologies (ICT), whose use in education has grown rapidly, being integrated into curricula to facilitate learning. However, institutional adaptation to these advances has been limited, and traditional practices persist that reveal deficiencies in students' information management.

In engineering education, the practical application of knowledge is fundamental. In the Chemical Engineering (IQ) program at the National Technological Institute of Mexico, comprehensive laboratory courses seek to transform theory into meaningful learning through practical activities and experimentation. This requires strategies that modernize laboratory work and promote the relevant use of ICT.

The Pachuca Institute of Technology (ITP) has a Chemical Engineering Laboratory (LIQ) equipped with teaching devices relevant to professional training. Through its use, students apply the theoretical principles acquired in previous courses, strengthening both specific and generic skills that contribute to their professional development.

In the Comprehensive Laboratory I (LII) course, students are expected to carry out theoretically grounded practices aimed at solving problems specific to their discipline. To do so, they must demonstrate that they can operate the equipment properly and perform the necessary experimental checks or investigations. This process integrates two essential components: (1) documentary research that allows them to understand the theory related to the phenomenon they are studying and (2) the structuring of the practice, which enables them to relate variables and evaluate their effects. However, during the first sessions, students often face difficulties in designing or properly planning their experiments, which reveals the need for more specific information about the equipment and practices.

In response to this need, a teaching strategy was developed based on the use of Quick Response (QR) codes placed on laboratory equipment, which allow access from mobile devices to basic information about its operation, scope, care, and theoretical principles. The material includes slides, manuals, and tutorials designed to support understanding of the equipment without replacing face-to-face instruction.

These resources, developed for LII students, can also be used by other students and teachers due to their accessibility and educational usefulness.

Framework

Teaching strategies are conceived as resources that facilitate meaningful learning, and within them, digital technologies offer advantages due to their versatility and ability to enrich academic activities. Moreira (2019) highlights that learning is built on prior knowledge and that ICTs favor this process by expanding the possibilities for accessing, managing, and using information. In this sense, technologies have established themselves as key tools for improving formative assessment and meeting student needs.

Several studies indicate that the incorporation of ICT in education is now a necessity. Granda, Espinoza, and Mayon (2019) affirm that these technologies support new educational paradigms by offering innovative methods and fostering collaborative and autonomous environments. In higher education, particularly at IQ, active student participation is encouraged at all stages of practical work, which is reflected in approaches such as the "flipped classroom." Research such as that by Fernández et al. (2021) and Bautista et al. (2015) shows that this model promotes more meaningful learning than traditional methods.

Following the COVID-19 pandemic, the use of ICT in higher education expanded significantly. According to Zuñiga (2023), tools such as videoconferencing, virtual platforms, social networks, and mobile applications took on a central role in teaching. Regarding the use of QR codes, initial studies—such as that by Álvarez, Izquierdo, and Cháfer (2014)—demonstrate their potential to facilitate access to information, although at the time they faced technological limitations that have now diminished.

Finally, several authors emphasize that the pedagogical use of ICT requires not only access and technical mastery, but also didactic foundations. Falla, Osso, and Camacho (2021) and Morán et al. (2021) point out the need for teacher training to select appropriate resources and use them effectively in assessments and academic activities.

Theoretical foundations

The construction of knowledge

Engineering education requires critical thinking and reflection to promote autonomous and meaningful learning. In this context, constructivism remains one of the most influential pedagogical trends, conceiving the student as the protagonist in the construction of their knowledge based on previous experiences and diverse contexts (Macías and Barzaga, 2019, cited in Pareja, Aguirre, and Guanillo, 2023). Its theoretical foundations come mainly from Piaget, Vygotsky, Bruner, and Ausubel.

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Piaget contributes the processes of assimilation and accommodation as mechanisms of cognitive adaptation, while Bruner emphasizes discovery learning and the ability to "learn to learn." Ausubel argues that meaningful learning occurs when new knowledge is linked to the student's prior knowledge (Bryce & Blown, 2024). For his part, Vygotsky highlights the role of social interaction and the Zone of Proximal Development (ZPD), supported by educational scaffolding as a temporary guide for advancing to higher levels of competence (Chávez, 2013).

ICT in higher education

In higher education, ICTs are considered key pedagogical tools for promoting regulated, autonomous, and collaborative learning (Salinas, 2011). Their conceptualization has evolved from "New Technologies" to "Learning and Knowledge Technologies" (Grande, Cañón, & Cantón, 2016).

Among these resources, QR codes stand out, as they allow quick access to digital content and their use has spread from industry to education, dissemination, and marketing (Leiva, 2012; Paz, 2017). Likewise, cognitive tools— —understood as means that support knowledge construction without replacing the student's cognitive process—favor critical, creative, and complex thinking (Aparicio, 2018). Among these, knowledge construction tools stand out, such as multimedia content editors and digital platforms, which facilitate the organization, representation, and reflection on learning.

Methodology

In this work, a teaching strategy was implemented through specially developed resources, and a **descriptive and comparative analysis** of the results obtained was carried out.

The design and implementation of the teaching strategy was structured in five successive stages:

a) exploration of the learning modes, resources, and styles preferred by the students ;

b) development of digital content and products;

c) pilot application with a group of LII students;

d) initial evaluation and adjustments to the tool and process; and

e) implementation over a full period, followed by a comprehensive evaluation.

Table 1 summarizes the activities carried out and their relationship to the objectives and instruments used.

Results

Initial exploration

A mixed survey was administered to 40 chemical engineering students to identify their habits and preferences in the use of information media for practical activities. The main results are presented in Table 2.

The last question included the open-ended option "Other." The responses were grouped into the following categories:

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No.	Activity	Objective	Technique and tool
1	Exploratory research on preferences and styles of use of support tools.	Identify the tools that students use and prefer to reinforce knowledge.	Application and analysis of surveys.
2	Development of content and its placement in digital spaces or social networks.	Develop cognitive resources in the selected formats and place them in the relevant spaces.	Digitization of manuals, bibliography management, use of free software and public platforms.
3	Generation of QR codes and placement in visible areas of laboratory equipment.	Facilitate immediate access to information from equipment using mobile devices.	Generation of codes and affixing them to equipment with resistant material.
4	Pilot implementation and adaptation of the tool.	Apply the tool to a group of students in the course and improve it based on the results.	Teaching work in the laboratory and technical adjustment of the tool.
5	Final application to all LII groups and evaluation.	Validate the effectiveness and advantages of the resource for permanent use.	Teaching work, final survey, and checklist.

Table 1. Activities carried out

Pregunta 1:	Al momento de investigar el fundamento y el funcionamiento de los equipos, ¿a que medio recurres principalmente?						
Respuesta (4 mayor)	**Libros**	**Videos you tube**	**Videos Tic Tok**	**Artículos Tec/cientif.**	**Manuales del equipo**	**Infografías/ presentación**	**Consulta a profesores**
4	13	31	6	13	44	13	25
3	37	25	13	19	25	6	31
2	31	25	6	19	6	19	13
1	6	13	19	19	19	31	19
0	13	6	56	30	6	31	12
Pregunta 2:	¿En que orden de importancia, utilizas los medios de información?						
Respuesta (1 primera)	**Libros**	**Videos you tube**	**Videos Tic Tok**	**Artículos Tec/cientif.**	**Manuales del equipo**	**Infografías/ presentación**	**Consulta a profesores**
1	6	6	6	6	56	0	20
2	13	0	25	30	19	0	13
3	20	0	31	25	6	13	6
4	19	0	13	13	6	18	31
5	30	13	19	13	6	6	13
Pregunta 3:	¿En qué medio consideras que encuentras la información que buscas?						
Respuesta	**Libros**	**Videos you tube**	**Videos Tic Tok**	**Artículos Tec/cientif.**	**Manuales del equipo**	**Infografías/ presentación**	**Consulta a profesores**
Lo necesario	44	0	0	13	25	12	38
Complemento	31	50	12	50	31	19	31
Regular	6	37	12	31	25	45	25
Poca	19	13	12	6	13	12	0
Nada	0	0	64	0	6	12	6
Pregunta 4:	¿Con qué herramienta consideras que aprendes mejor?						
Respuesta	**Libros**	**Videos you tube**	**Videos Tic Tok**	**Artículos Tec/cientif.**	**Manuales del equipo**	**Infografías/ presentación**	**Consulta a profesores**
Mucho	50	64	19	50	50	25	69
Regular	44	30	25	37	37	64	31
Poco	6	6	56	13	13	13	0
Pregunta 5:	¿En que medio te gustaría encontrar más información para aprender mejor los						
Respuesta	**Libros**	**Videos you tube**	**Videos Tic Tok**	**Artículos Tec/cientif.**	**Manuales del equipo**	**Infografías/ presentación**	**Consulta a profesores**
Mucho	50	64	19	50	50	25	69
Regular	44	30	25	37	37	64	31
Poco	6	6	56	13	13	13	0

Table 2. Results of the initial survey in percentages

- mobile applications;
- websites;
- integrating links to resources;
- Facebook pages;
- detailed equipment manuals;
- electronic libraries;
- discussion groups.

Three main findings emerged from the analysis:

1) a marked preference for electronic resources over printed materials;

2) a tendency to prioritize ease of access to information;

3) recognition of the teacher as a guide, coexisting with a growing interest in self-directed learning.

Development of the digital resource

Based on these results, eight digital resources were designed for the same number of LIQ teams. Each resource was designed based on the course syllabus and the characteristics and scope specified in the teams' own manuals. In each case, it was organized into a portal accessible via QR code and consisting of:

- **Home page**, which presents an infographic with topics related to the equipment, applications, experimentation variables, and links to other resources.
- **Secondary pages**, which include the equipment manual, technical data sheet, and two formats of tutorials on how to use the equipment (videos on YouTube and TikTok).

Generation and placement of QR codes

Cards with the corresponding QR codes were created and affixed to the equipment. An example is shown in Figure 1.

Figure 1 QR code placed on laboratory equipment

Pilot implementation and adjustments

A pilot implementation was carried out with a group of students. Based on direct observation and feedback received, minor adjustments were made to the content and organization of the portal.

Final application and evaluation

Over a full period, the students in the two LII groups carried out 14 practical exercises, of which 8 corresponded to equipment with QR codes and 6 to equipment without this resource, allowing for comparisons to be made. Table 3 summarizes the work carried out. The preliminary reports generated are included. These are documents prepared by the work groups prior to the completion of the practical exercises, in which they mainly describe the situation or problem that led to the experiment, their hypothesis, rationale, and methodology.

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Students involved	33
Working groups	8
Internships completed	14
Internships without QR	6
Internships with QR	8
Preliminary reports generated (14*8)	112

Table 3 Data on the work in the LIQ

The impact of the new methodology was assessed on the basis of:

a) a final survey with open-ended questions about perceptions of the resource; and

b) a comparison of the grades obtained in the preliminary reports, evaluated using a checklist.

Student perception. The comments collected show a positive assessment of the resource, highlighting that:

- it facilitates understanding of the theory-practice relationship;
- it complements the pre-report guide and speeds up its preparation;
- it has an appropriate format with short, clear videos;
- it is a flexible, non-restrictive guide;
- it provides assurance for the correct use of equipment.
- The suggestions included:
- extending the resource to all equipment;
- periodically updating the information;
- increasing the detail of the technical data sheets.

Performance in preliminary reports. Table 4 summarizes the results obtained in the first and second attempts— —after the necessary feedback from the teacher, differentiating between practices with and without QR.

The survey results show students' acceptance and preference for the use of QR codes and the tool developed for practical work, while the grade results show better academic performance in practices supported by QR codes, with higher pass rates and higher grades.

Conclusions

The students expressed widespread acceptance of the resource, highlighting its usefulness for planning practical work and understanding experimental procedures. Likewise, the academic results showed a substantial improvement in the practical proposals developed with the support of the resource, evidencing a positive effect on the organization, rationale, and quality of the preliminary reports.

Overall, the findings suggest that the use of QR codes as a support tool in the laboratory is an effective alternative for strengthening autonomous learning, improving preparation prior to practice, and promoting safer and more informed use of equipment.

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	Practices without the use of QR		Practices with the use of QR	
	First attempt	Second attempt	First opportunity	Second opportunity
Total pre-reports approved	20	27	29	40
Total pre-report not approved	10	3	11	0
% of preliminary reports approved	67	90	72.5	100
% of preliminary reports not approved	33	10	27.5	0
Average grades/100	45	77	64	87

Table 4. Grade results after each attempt

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