WIP: Engineering students' perception of the competencies development after a challenge-based learning educational experience

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***Abstract*— This research WIP paper provides an innovative, clear, and practical methodology for instructors who wish to assess their teaching practice's impact on their students' competencies. It was carried out in a Mexican Higher Education Institution. It compares students' perceptions from two undergraduate engineering programs participating in a six-week Challenge-Based Learning (CBL) concentration. Studies on CBL in engineering programs analyze its effectiveness compared to traditional and other innovative methodologies and its impact on disciplinary, soft, and cross-disciplinary competencies, mainly in undergraduate programs. To answer the following questions, this study examines the effect of CBL educational experience on the Technical, Methodological, Participatory, and Personal competencies perceived by participant students: Q1) What is the impact of CBL on the perceived acquisition of cross-cutting competencies in students in two engineering programs? Q2) How do students in two interrelated engineering programs perceive the dimensions of crosscutting competencies, and how might these interrelationships influence academic performance? A descriptive, comparative, and correlational approach was used to examine two groups of students from two engineering programs in Biotechnology and Chemical Engineering who learned using a CBL approach. The data corresponded to the responses of 31 students to the Competencies Acquired through CBL (CA-CBLQ) questionnaire, adapted in the wording of the items for the present study. The results showed the positive effect of the CBL approach on the development of methodological competencies. It was also identified that an increase in methodological competencies reinforces the development of technical, personal, and moderately participative competencies. Furthermore, our analysis revealed that contextualized and authentic learning experiences enable students to develop competencies that allow them to apply their theoretical knowledge to practical situations in their personal and professional lives. Given that CBL is supported by other favorable methodologies, such as collaborative learning and situated cognition, future studies can explore contrasts between groups in quasi-experimental conditions by comparing CBL with other associated variables.**

Keywords—challenge-based learning, competencies, STEM, engineering education, higher education, educational innovation

I. INTRODUCTION

Higher Education (HE) faces significant challenges when it comes to educating for the future. Access to HE figures has been on the rise. About 40% of the global population has been able to access higher education, in contrast to reports of access of 10% in the 1970s [1]. The reduction in access gaps, coupled with the growing gender parity of entry to higher education, has been increasing since 1990 [1].

This presents new challenges that need to be addressed in higher education research. Some of these challenges are the quality of education and the relevance of training translated into developing competencies for performance in social and working life. Thinking about the future of education and the subsequent responsibility involved in training professionals is a topic of interest to global organizations such as the OECD.

In the report *Reimagining our Futures Together*, UNESCO insists on studies that compare how teaching and research are done in HE [2]. This is to strengthen the development of educational policies at the international level (for employability), which allows for improving the quality of education. In the particular case of education in STEM careers, there is a gap between the competencies developed in vocational training and those required in the workplace since there is a need for a transdisciplinary approach to teaching and developing competencies. [3].

In the STEM Biotechnology and Chemical Engineering programs, the development of competencies has been transformed, as it is for many programs in other areas. For example, in Chemical Engineering, there have been transformations in the competencies that students develop due to the demands of the global economic context. Traditionally, the emphasis of training for these professionals has been concentrated on mathematics and thermodynamics [4]. In the current context, this training has expanded the range of areas of activity beyond the chemical industry [5]. Something similar happens in Biotechnology Engineering.

Specific competencies training has been developed in an interdisciplinary manner, e.g., microbiology, biochemistry, mathematics, and industrial processes, among others, with other interdisciplinary competencies requiring an understanding of biological theory, mathematics, analytics, and computer science [4], and other transversal competencies [6]. In this way, engineers are trained for optimal professional performance, which equips them with technical and transversal competencies so that they know how to transfer that knowledge when it is required in their work and daily life; for example, if during in engineering training, they are training in creating innovative and sustainable solutions (e.g., chemical design), professional in engineering graduates are expected to comply with safety, government legislation, ethical and sustainability standards (among others) and know how to inform industry and society about the benefits of those innovations. Given this challenging context for higher education on the development of interdisciplinary competencies in Biotechnology and Chemical Engineering professionals, this study aims to provide a methodological and conceptual route for teachers interested in examining the effect of their teaching practices on the development of competencies in their students. This objective is addressed by analyzing and comparing the perceptions about developing competencies through the CBL in two groups of students in the two engineering programs.

II. BACKGROUND AND RELATED WORKS

A. Challenge-based learning conceptualization

CBL is inspired by pedagogical currents such as constructivism [7], [8] STEM-based education [9], situated learning [10], collaborative learning[11], among others, that privilege learning in authentic situations where students have an active role in their learning. It is recognized as an innovative teaching-learning methodology that favors understanding through practice, student participation, and developing specific, interpersonal, intrapersonal, interdisciplinary, and professional competencies based on using the knowledge acquired to resolve real-world problems. [6], [12], that is, the immediate environment.

According to Taconis and Bekker [6], challenges are open problems (i.e., without much specificity in their definition) that require students to work collaboratively, engage with the problem in its natural environment, identify actors and related situations to have a clear understanding of the problem and from there to generate the proposal from its scope and limitations.

Given these characteristics, CBL has been addressed at different educational levels, with engineering careers being the ones in which it is frequently used. This study was developed within the framework of a CBL.

B. Educational experiences of CBL in Biotechnology and Chemical Engineering

Teaching in engineering careers has significant challenges. Ensuring that students develop relevant competencies to perform optimally in the real context of the STEM industry involves the efforts and preparation of instructors. As documented, the methodological and pedagogical approaches adopted in Biotechnology and Chemical Engineering vary.

From the perspective of CBL, it has been implemented in Biotechnology Engineering. Membrillo-Hernández et al. [13] compared the academic performance of two groups of students who solved epidemiology and virology tasks. Two groups of students addressed task development under traditional teaching and CBL, respectively. The tasks and challenges related to these challenges are 1) understanding the spread and impact of the Zika virus, 2) tracking the evolution and spread of the measles virus, and 3) identifying new variants of influenza viruses. The results showed a better performance in students who learned under the CBL methodology.

In a study with a different approach, Gil et al. [14] examined which aspects of CBL contribute to developing essential competencies for professional performance and which activities improve problem-solving and application of engineering concepts to Biotechnology Engineering students. The results revealed that the students reported that the CBL helped them develop important competencies (teamwork, leadership, pertinent use of information, project planning, communicating well, and knowing real problems) for their personal and professional performance. In addition, they identified that generating strategies such as generating flowcharts and developing calculation activities contributed significantly to applying engineering principles in real situations.

On the other hand, in Chemical Engineering, Rodríguez-Chueca et al. [15] examined the effectiveness of CBL implementation in contrast to the Flipped Classroom methodology in a class on Sustainability and Circular Economy at a Spanish university. The results showed that the two methodologies improved their understanding of sustainability, the circular economy, and motivation to learn Chemical Engineering students. The group of students in the CBL approach commented that it is necessary to increase activities that would allow them to develop specific and transversal competencies and soft skills such as teamwork and creativity.

In another study, Huesca et al. [16] compared the implementation of CBL with the traditional teaching (TT) method on the educational attainment of Chemical Engineering, agricultural engineering, computer engineering, electrical engineering, mechanical engineering, food engineering, industrial engineering, computer science, mechanical engineering, mechatronics, and software engineering program students. The results were analyzed in light of the two thematic areas of the general examination for these careers: communication and specific disciplinary competencies. Overall, no major differences were identified between the groups. Both teaching methods improved students' communicative performance and particular competencies. The TT group had only a marginal advantage, which was not statistically significant.

III. METHODOLOGY

A. Design of the CBL educational experience

Essential drivers to the design of new chemical products include market needs, technological advancements, innovation, and enriching the user experience. To introduce this relatively young subject, the students engaged over six weeks in various research activities. The learning goal was to gain a thorough understanding of the fundamental principles of chemical product design so that for the following ten weeks they could apply chemical engineering principles to the design of chemical products inspired by nature.

We assessed students' expectations at the beginning of the course by a questionnaire. For our CBL approach, students were assigned to propose a nature-inspired, innovative chemical product that was both profitable and sustainable, scalable for industrial production, with rigorous quality controls and safety standards, while complying with government regulations and upholding social, corporate, and ethical responsibilities.

The product would offer an innovative solution to engineering challenges in personal care, pharmaceuticals, and cosmetics. For this purpose, they explored new technology through systematic literature reviews, in-depth analysis, and discussions of academic papers and technology patents. Additionally, they participated in laboratory sessions to master techniques for properly handling equipment, measuring substances accurately, and following experimental protocols. Furthermore, they enhanced their analytical skills by interpreting experimental data, analyzing results, and drawing conclusions from observations. Their critical thinking skills were also strengthened by evaluating experimental designs, predicting outcomes, and making informed decisions based on evidence. Students' perceptions of the competencies they acquired were assessed through a closing survey, utilizing a challenge-based learning questionnaire (CA-CBLQ). This survey evaluated technical, methodological, participatory, and personal competencies.

B. Sample

Fifteen men and sixteen women students from two engineering programs, Biotechnology Engineering (9 women and 10 men) and Chemical Engineering (7 women and5 men), in the second semester of 2023. Participants ranged in age from 21 to 23 years old. Participating students are enrolled in a private university in Mexico.

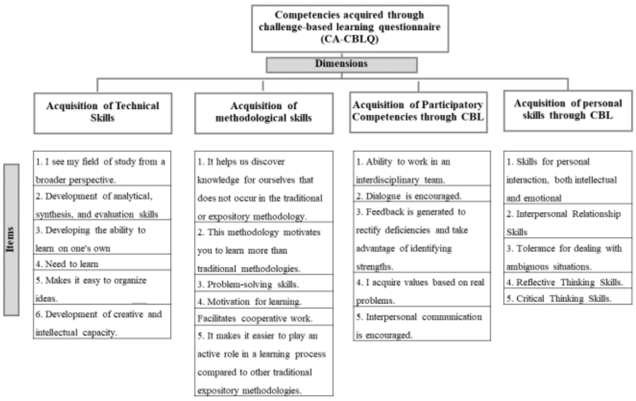

Fig. 1. Competencies acquired through challenge-based learning questionnaire (CA-CBLQ) structure.

C. Data collection

This is a descriptive, correlational study with a cross-sectional design [17], in which perceptions about the development of competencies through CBL were analyzed and compared in two groups of students from two engineering programs after participating in a six-week teaching concentration developed under the CBL methodology.

The data collected correspond to:

1) The final grade (on a 10-point scale) obtained by the students in the final grade in the CBL concentration;

2) The students' responses to the Competencies acquired through a challenge-based learning questionnaire (CA-CBLQ).

This questionnaire was adapted from the original version proposed by Gil-Galván et al. [18], which contained 22 items for the CBL experience. The questionnaire was organized into two parts. The first collected demographic data of the participants (e.g., name, gender, age, and program to which they were enrolled). The second organized the items into four dimensions: technical, methodological, participatory, and personal (Fig. 1). A Likert scale was presented with four response options, with 1 = a lot and 4 = not at all.

The items were presented in affirmations. The questionnaire was provided in Spanish.

The dimension of technical competencies (knowledge) refers to disciplinary knowledge that combines general knowledge (theoretical, scientific, or technical) with the skills required to perform in a professional environment. The dimension of methodological competencies (know-how) is related to the attitudes and reactions that are displayed when it is necessary to put into practice the relevant knowledge for the problem situation. The dimension of participatory competencies (knowing how to be) involves understanding the scenarios in which they operate and assuming the responsibilities derived from their role in their environment. Finally, the dimension of personal competencies (knowing how to be) is related to responsible, self-managed, constructive, and communicative action in academic, professional, and individual contexts.

IV. RESULTS

The reliability analysis of the CA-CBLQ questionnaire showed good internal consistency and reliability of the instrument ($\alpha = 0.895$), coinciding with the results of Gil-Galvan and colleagues [18] in the items corresponding to the competencies ($\alpha = 0.938$) of the four dimensions analyzed in this study.

A. Q1: What is the impact of CBL on the perception of the acquisition of transversal competencies in students of two engineering programs?

It was found that when analyzing the differences between the groups using a T-Student test (Table 1), it was determined that, although BE students had slightly lower scores in Technical ($p = 0.687$) compared to CE students, there were no statistically significant differences.

TABLE I. T-STUDENT T-TEST OF AVERAGE RESPONSE IN EACH DIMENSION BY PROGRAM

Independent Samples T-Test			
Competencies	t	**df**	**p**
Technical	-0.408	29	0.687
Methodological	0.292	29	0.773
Participatory	0.061	29	0.952
Personal	1.235	29	0.227

There were also no differences between the students of these two programs when comparing Methodological ($p = 0.773$) and Participatory ($p = 0.952$) competencies.

In Personal, a statistically significant difference was found ($p = 0.227$) since BE students identified that CBL contributed to developing personal competencies.

B. Q2: How are the dimensions of transversal competencies perceived by students in two interrelated engineering programs, and how might these interrelationships influence educational attainment?

The correlation results between the dimensions of the CA-CBLQ (Fig. 2) showed a high association between the Methodological Competencies (Know-how/use knowledge) and the development of Technical Competencies

(Knowledge/acquired knowledge) (r = 0.754) and with the Personal competencies (Knowing how to be/act appropriately) (r = 0.627).

There is also a moderate association between Methodological and Participative competencies (Knowing how to be/knowing how to perform in the area's role) (r = 0.449). That is, the development of practical competencies (Methodological) favors the development of technical, personal, and participatory competencies in students, which allows them to perform effectively when they apply their technical knowledge responsibly and favorably in various academic, personal, and everyday situations.

The latter is also visible in the high associations between Technical and Personal competencies (r = 0.552) and the moderate associations between Participative and Personal competencies (r = 0.465).

V. Discussion

The study examined the perceptions of transversal competencies of two groups of engineering students after completing a CBL educational concentration. It identified that, in general, the two groups used CBL at a similar level to develop their technical competencies (disciplinary knowledge/content-learned applications). This coincides with the results obtained in previous studies [13] [14] [15] on the levels of favorable use of CBL in developing specific problem-solving skills in the real context of BE and CE (application of technical, disciplinary knowledge in the industry) and transversal and personal life skills (e.g., communication, teamwork, problem-solving).

The results on the relationship between the types of competencies that the students identified as being enhanced by the CBL allow us to recognize that the strategies used in the educational process that would enable reinforcing the methodological competencies will have positive effects on how students participate and in which they can transfer their knowledge to their immediate personal lives. This affirms the holistic training effect of CBL, as it allows teachers and students to learn together about fundamental issues in their real environment. In addition, it will enable students to increase their competencies by reflecting on their learning and the impact of their solutions on their professional field [19].

VI. Study implications and conclusions

We identify two significant implications of this work that are useful for teaching and pave the way for future research in education and pedagogy.

First, in this study, we examine competencies in the technical, methodological, personal, and participatory dimensions to gain insight into the impact of CBL. Although we did not conduct a control group, our adapted instrument helped us understand students' perceptions of their educational experience in each dimension. Our analysis revealed that contextualized and authentic learning experiences allowed this group of students (N=31) to develop competencies that will enable them to apply their theoretical knowledge to practical situations in their personal and professional lives. The findings obtained from this group of students revealed an association between the methodological, individual, and participatory dimensions, emphasizing the value of CBL for learning.

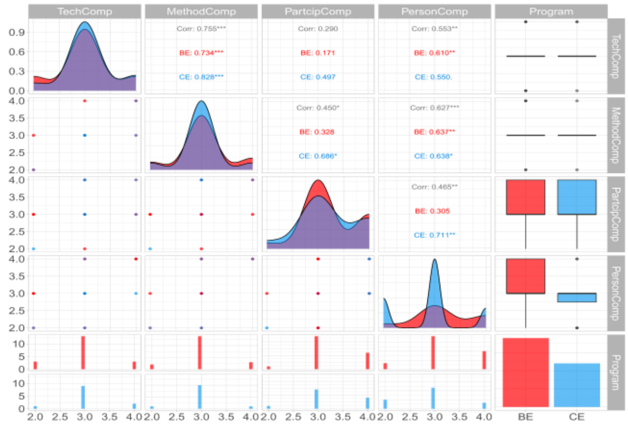

Fig. 2. Correlations of transversal competencies differentiated by program.

Second, it refers to the solid pedagogical structure that underlies the CBL. Since CBL is based on other favorable methodologies, such as collaborative learning and cognition, it is possible to expand the analysis in future studies so that cross-group contrasts can be made under quasi-experimental conditions, in which the effect of CBL is analyzed with other variables of a personal nature, such as cognitive style, or with others of a group nature, such as the Transactive Memory System. Since this initial study was developed with a few participants, future work may explore quasi-experimental designs with more groups or longitudinal designs that allow us to know if the perception of the competencies perceived by the students undergoes changes or is maintained over time. This would provide valuable insights into how CBL contributes to bridging competency development gaps in engineering programs.

Finally, it is essential to continue studying the implementation of CBL in engineering careers and expand it to different areas of knowledge so that there can be a state of understanding of CBL, strategies that can be favorable to enhance the development of competencies, and the achievements of successful practices that motivate and enrich its use in higher education.

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