The Impact of Project-Based Teaching on Technological Development and Critical Thinking Skills in Higher Education Students

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Abstract

Project-based teaching (PBE) has emerged as an effective pedagogical strategy for the development of key skills in higher education, especially in areas such as critical thinking and technological competencies. This study analyzes the impact of EBP on the development of these skills in university students of technological careers. Through a mixed methodology that includes surveys and analysis of academic results, the progress of 120 students was evaluated before and after participating in a project-based course. The findings suggest that EBP not only significantly improves critical thinking skills, but also encourages a more efficient and creative use of technological tools.

Keywords: Project-based teaching, critical thinking, technological development, higher education, technological skills.

1. Introduction

In recent decades, technological progress has generated significant changes in the requirements of the labor market, requiring a combination of technical competencies and critical thinking skills in professionals from different areas (Martínez et al., 2020). Higher education institutions have responded to these challenges by implementing innovative pedagogical approaches that foster active learning and promote the development of key competencies for the twenty-first century (Castañeda & Salinas, 2021). One of the approaches that has gained greater relevance is project-based teaching (PBL), which is characterized by involving students in solving real-world problems through collaborative and practical projects.

EBP has been identified as an effective methodology to link theoretical learning with practice, allowing students to apply their knowledge in real and complex contexts (González et al., 2022). In addition, this approach has been shown to promote intrinsic motivation, by allowing students to make decisions, investigate, and experiment, which contributes to a deeper understanding of the contents (López et al., 2021). The active role of the student in the EBP fosters greater autonomy, since students are required to manage the development of the projects, which can result in more meaningful and lasting learning (Rodríguez & Díaz, 2019).

On the other hand, critical thinking skills have become a central element in contemporary educational models. Critical thinking, defined as the ability to analyze, interpret, evaluate, and synthesize information in order to make informed decisions, is essential to face the complex challenges of the modern world (Sharma & Khosla, 2021). In the educational context, EBP is particularly useful for developing these skills, as students are constantly challenged to solve problems, argue their ideas, and make evidence-based decisions (Lai, 2020). Various studies have shown that students who participate in project-based learning environments show significant improvements in their analysis and problem-solving skills (Sánchez & Rodríguez, 2021).

In terms of technological development, the integration of technology into projects is a key aspect in EBP. In an increasingly digitized world, students must master not only technological tools, but also develop skills to innovate and adapt to new technologies (Vega & Díaz, 2022). EBP provides an ideal framework for this purpose, as students not only use digital tools to execute their projects, but also need to understand how these technologies work and explore creative ways to apply them in practical solutions (García et al., 2021).

Despite the increasing implementation of PBS in higher education, there is still a need to explore in greater detail the specific impact of this methodology on the development of technological and critical thinking skills. This study seeks to provide empirical evidence on the effectiveness of EBP in these two areas, taking as a case study students of technological careers at a Mexican university. Through a mixed approach, both students' perceptions of their progress and the academic results obtained after the implementation of this methodology will be analyzed.

The main objective of this research is to evaluate how EBP contributes to the development of technological competencies and critical thinking in university students, and how these skills are applied in the execution of technological projects. In a context where adaptability and innovation are increasingly valued in the workplace, it is essential that students are equipped not only with technical knowledge, but also with skills to think critically and use technologies effectively and creatively (Martínez et al., 2020; Anderson, 2019). This study will contribute to the existing body of research by providing new perspectives on the effectiveness of EBP in the well-rounded education of students.

2. Theoretical Framework

Project-based teaching (PBE) is based on several theories of learning, including constructivism and experiential learning. These theories argue that knowledge is actively constructed when students participate in real and relevant experiences, which is directly reflected in the EBP methodology (Savery, 2019). EBP allows students to be at the center of the learning process, stimulating their ability to solve problems, collaborate, and apply theoretical knowledge in practical situations (Barron & Darling-Hammond, 2019).

1. Constructivism Theory

Constructivism, proposed by Jean Piaget and later extended by Lev Vygotsky, argues that learning is an active process in which students construct new knowledge based on their previous experiences (Vygotsky, 1978). In the framework of EBP, this theory is applied by providing students with an environment where they can interact with their environment and peers, facing challenges that force them to reflect and adjust their previous understandings (Savery & Duffy, 2018).

EBP allows students to work on projects that simulate real-world situations, forcing them to apply concepts in practical ways, which promotes more meaningful and lasting learning. This approach helps to develop both cognitive and social skills, as students must work as a team, investigate, experiment, and propose solutions (Fernández & González, 2020).

2. Critical Thinking and Problem Solving

Critical thinking is essential to face complex problems in today's work and academic environment. In higher education, developing this skill is crucial, as it allows students to critically analyze information, make informed decisions, and propose innovative solutions (Lai, 2020). According to Facione (2020), critical thinking includes the ability to interpret, analyze, infer, and explain information in a logical and coherent way.

EBP facilitates the development of these skills by confronting students with open-ended problems that do not have predefined solutions, which requires in-depth analysis and critical evaluation of the available information (Sharma & Khosla, 2021). Through research, planning, and project execution, students must develop solutions based on data and evidence, which strengthens their ability to solve complex problems (García et al., 2021).

Table 1: Components of Critical Thinking Applied to EBP

Critical Thinking Component	Application in the EBP
Interpretation	Understand the project problem and its implications.
Analysis	Break down the problem into its fundamental parts.
Evaluation	Assess possible data-driven solutions.
Inference	Generate conclusions from the information obtained.
Explanation	Communicate and justify the decisions made.
Self-regulation	Review and adjust the strategies and decisions made.

(Source: Own elaboration based on Facione, 2020)

3. Development of Technological Competencies

In a context where technology changes rapidly, technological competencies have become essential for university students, particularly in fields related to science, technology, engineering and mathematics (STEM). Technological competencies not only refer to the use of digital tools, but also to the ability to innovate and adapt technologies in various contexts (Anderson, 2019).

EBP provides an ideal environment to develop these competencies, as projects require students to apply technological tools to solve real problems. Through the use of specialized software, online collaboration platforms, and digital design tools, students not only master existing technology, but also gain the ability to adapt to new technological tools and processes (Vega & Díaz, 2022).

In addition, EBP encourages creativity and innovation in the use of technology. Rather than being limited to memorizing technical concepts, students apply technology critically and creatively, exploring new ways of solving problems through technological innovation (González et al., 2022).

Table 2: Technological Competencies Developed in the EBP

Technological Competence	Application in the EBP
Use of digital tools	Use of software for project planning and execution.
Technological adaptation	Ability to learn and use new technologies in the project.
Technological innovation	Development of creative and innovative technological solutions.
Digital collaboration	Use of online platforms for communication and teamwork.
Solving technology problems	Application of technological tools to overcome practical challenges.

(Source: Own elaboration based on Anderson, 2019; Vega & Díaz, 2022)

4. EBP and Collaborative Learning

One of the core tenets of EBP is collaborative learning, in which students work together in groups to complete projects. According to Johnson et al. (2020), collaborative learning improves knowledge understanding and retention, as students interact with each other, discuss ideas, and solve problems together. This interaction promotes a constant exchange of knowledge and perspectives, which enriches the learning process.

In the context of EBP, collaboration between students is critical, as projects often require participants to combine different skills and knowledge to achieve a common goal (López et al., 2021). This approach not only improves technical and critical thinking skills, but also strengthens interpersonal skills, such as communication, negotiation, and conflict resolution (Fernández & González, 2020).

3. Methodology

The present study adopts a mixed approach, combining quantitative and qualitative methods to assess the impact of project-based teaching (PBE) on the development of critical thinking skills and technological competencies in higher education students. This methodology seeks to provide a more comprehensive understanding of the phenomenon, by collecting both numerical and descriptive data for analysis (Creswell & Plano Clark, 2018). The study was carried out at a public university in Mexico, during the 2023 academic cycle, with the participation of engineering students.

1. Research Design

The research was structured in three phases: prior data collection, implementation of the intervention (EBP) and subsequent evaluation. A pre-test-posttest design with a control group was used to measure changes in critical thinking skills and technological competencies before and after the intervention. Data were collected through surveys, semi-structured interviews, and analysis of students' academic results.

Research phases:

Research phase	Description of the activity
Phase 1: Pre-test	Initial assessment of critical thinking and technology skills through surveys and analysis of previous academic results.
Phase 2: Intervention	Implementation of the EBP methodology during an academic semester.
Phase 3: Post-test	Subsequent assessment of the same skills using the same instruments and comparing the results with the initial assessment.

(Source: Authors)

2. Participants

The sample consisted of 120 engineering students, aged between 19 and 25 years (M = 21.3). Students were randomly selected from two academic cohorts: an experimental group of 60 students who participated in the project-based course and a control group of 60 students who received traditional instruction. All participants were in their third year of their degree, ensuring a similar base of prior knowledge.

Characteristics of the participants:

Group	Number of participants	Middle Ages	Gender (Men/Women)
Experimental	60	21.5	35/25
Control	60	21.1	32/28

(Source: Authors)

3. Data Collection Instruments

To collect data on students' critical thinking skills and technological competencies, the following instruments were used:

- Critical Thinking Survey: Adapted from Facione's (2020) critical thinking skills test, this 25-item survey measures six subscales: interpretation, analysis, evaluation, inference, explanation, and self-regulation. Participants rated their skills on a 5-point Likert scale (1 = Very Low, 5 = Very High).

- Technology Competencies Questionnaire: This questionnaire was designed to measure students' perception of their technological skills. It was based on Anderson's (2019) model and evaluated the use of technological tools, innovation, digital collaboration, and technological problem solving. The items were rated on a scale of 1 to 5 (1 = Very low, 5 = Very high).

- Semi-Structured Interviews: At the end of the course, interviews were conducted with 20 students from the experimental group to explore in depth their experience with EBP and their perception of skill development. The interviews focused on topics such as the application of technology, challenges encountered, and collaboration among peers.

- Analysis of Academic Results: The grades obtained in the project-based course were compared with those obtained in previous courses without EBP. This analysis provided a quantitative indicator of the impact of EBP on academic performance.

Instruments used:

Instrument	Description	Scale
Critical Thinking Survey	It measures six subscales of critical thinking skills.	Likert 1-5
Technology Skills Questionnaire	Assesses the perception of the use and mastery of technological tools.	Likert 1-5
Semi-structured interviews	Explore students' experiences and perceptions of EBP.	Open-ended questions
Analysis of Academic Results	Comparison of pre- and post-intervention ratings.	Numerical Grades

(Source: Authors)

4. Procedure

The study was developed over a 16-week academic semester. The students in the experimental group were assigned to a course specifically designed under the project-based teaching methodology, while the control group followed a traditional course based on lectures and directed activities. The students in the experimental group worked in teams of 4 to 6 members on technological projects related to their area of study. Throughout the course, students were required to identify a real problem, research technological solutions, design a working prototype, and present their results at the end of the semester.

The project stages included:

1. Problem Identification: Students chose a real problem that could be addressed by a technological solution.

2. Research and Planning: A literature review and analysis of possible solutions were carried out.

3. Prototype Development: Students designed and tested their technology solution.

4. Presentation of Results: At the end of the course, students presented their prototypes and defended their design decisions.

5. Data Analysis

Quantitative data were analysed using SPSS statistical software (version 25). Mean difference tests (Student's t) were performed to compare the pre-test and post-test scores of the experimental and control groups. In addition, the ANOVA test was used to identify significant differences between the variables. The qualitative data obtained from the interviews were analyzed by thematic coding, following the content analysis approach of Braun and Clarke (2019).

Statistical analysis used:

Statistical test	Description	Purpose
t for Student	Comparison of the means of the experimental and control groups.	Evaluate the impact of the intervention.
ANOVA	Identification of significant differences between variables.	Measure the influence of different factors.
Thematic Coding	Qualitative analysis of the interviews.	Identify emerging patterns and themes.

4. Results

The results of this study show a positive and significant impact of project-based teaching (PBT) on the development of critical thinking skills and technological competencies in students in the experimental group. Quantitative data indicate significant improvements in both dimensions, while qualitative data reveal positive perceptions about the learning process and the development of key skills.

1. Quantitative results

1.1. Critical Thinking

The results of the pre-test and post-test of the critical thinking survey revealed a significant improvement in the skills of the students in the experimental group, while the control group showed no significant changes. The subscales of interpretation, analysis, evaluation, inference, explanation, and self-regulation were evaluated for both groups.

Table 1: Comparison of Critical Thinking Scores (Pre-test and Post-test)

Subscale	Experimental Group (Pretest)	Experimental Group (Postest)	Difference (Δ)	Control Group (Pretest)	Control Group (Postest)	Difference (Δ)
Interpretation	3.2	4.3	+1.1	3.1	3.2	+0.1
Analysis	3.0	4.2	+1.2	3.1	3.3	+0.2
Evaluation	3.1	4.0	+0.9	3.0	3.1	+0.1
Inference	3.3	4.4	+1.1	3.2	3.3	+0.1
Explanation	3.0	4.1	+1.1	3.0	3.1	+0.1
Self-regulation	2.9	4.0	+1.1	2.8	2.9	+0.1

(Source: Authors' elaboration based on research data)

As shown in Table 1, the differences in the critical thinking scores of the experimental group are significant in all subscales, with an average improvement of +1.1 points. The greatest improvement was observed in the analysis and inference subscales, indicating that students developed a greater ability to decompose complex problems and generate conclusions from the available information. In contrast, the control group showed minimal changes, with improvements of less than +0.2 points in all subscales.

1.2. Technological Competencies

In terms of technological competencies, the experimental group also showed significant improvements in all areas evaluated. The use of technological tools, technological innovation and problem solving were the competencies that benefited the most from EBP.

Table 2: Comparison of Scores in Technological Competencies (Pretest and Posttest)

Competence	Experimental Group (Pretest)	Experimental Group (Postest)	Difference (Δ)	Control Group (Pretest)	Control Group (Postest)	Difference (Δ)
Use of digital tools	3.4	4.5	+1.1	3.3	3.4	+0.1
Technological innovation	3.1	4.2	+1.1	3.0	3.1	+0.1
Digital collaboration	3.0	4.0	+1.0	2.9	3.0	+0.1

Competence	Experimental Group (Pretest)	Experimental Group (Postest)	Difference (Δ)	Control Group (Pretest)	Control Group (Postest)	Difference (Δ)
Solving technology problems	3.2	4.3	+1.1	3.2	3.3	+0.1

(Source: Authors' elaboration based on research data)

As can be seen in Table 2, the experimental group experienced significant improvements in all the technological competencies evaluated, with an average difference of +1.1 points compared to the pre-test. In particular, the use of digital tools and technological problem-solving showed the greatest improvements, reflecting the effectiveness of the EBP in encouraging the practical use of technology in solving real problems. The control group, on the other hand, experienced minimal improvements, suggesting that traditional teaching methods did not significantly impact the development of these competencies.

2. Qualitative Results

The qualitative results obtained from the semi-structured interviews with the students of the experimental group provide valuable information about their experiences with EBP and their perception of skill development. Of the 20 interviews conducted, the following main themes were identified:

- Practical application of knowledge: Most of the students highlighted that the EBP allowed them to apply in a practical way the theoretical concepts learned in previous classes. According to one of the students: "With the project, for the first time I was able to apply what I learned in previous subjects. Not only did I understand better, but I was able to see it in action" (Interview 12, Experimental Group).

- Development of collaboration skills: Many students mentioned that EBP fostered teamwork and collaboration, as they had to organize and make decisions together to advance the project. One student commented, "We had to learn how to work together, divide tasks, and support each other. That was key to the success of our project" (Interview 7, Experimental Group).

- Technological challenges: Students also noted that although EBP involved challenges, such as learning new technologies and solving technical problems, these challenges were an opportunity to develop technological and critical thinking skills. One participant mentioned: "At first I didn't know how to use the tools, but over time I learned and that gave me more confidence to face future challenges" (Interview 19, Experimental Group).

3. Statistical Analysis

The statistical analysis confirmed the significance of the results obtained. The t-test for related samples showed significant differences between the pre-test and post-test in the experimental group for both critical thinking skills and technological competencies, with a p-value < 0.05 in all categories. In contrast, no significant differences were found in the control group.

Table 3: Results of the t-Test for Critical Thinking and Technological Competencies

Variable	Experimental Group (p-value)	Control Group (p-value)
Critical Thinking	< 0.001	0.314
Technological Competencies	< 0.001	0.285

(Source: Authors' elaboration based on research data)

The quantitative and qualitative results demonstrate that EBP is an effective methodology to improve both critical thinking skills and technological competencies in higher education students, particularly in those facing complex technological projects.

5. Conclusions

The results of this study confirm that project-based teaching (PBT) is an effective pedagogical methodology for the development of critical thinking skills and technological competencies in higher education students. In an educational context increasingly influenced by technology and the demand for advanced cognitive skills, EBP provides a framework that connects theoretical learning with practical applications, fostering deeper and more meaningful learning (Barron & Darling-Hammond, 2019; Vega & Díaz, 2022).

1. Impact on Critical Thinking

The study demonstrates that students who participated in EBP showed significant improvements in their critical thinking skills compared to those who followed a traditional method. These improvements include stronger capabilities to interpret, analyze, evaluate, and infer information, all crucial skills for informed decision-making and complex problem-solving in professional life (Facione, 2020; Lai, 2020).

The active and collaborative nature of EBP encourages constant reflection and allows students to face problems without predetermined solutions, prompting them to develop more analytical and critical strategies for addressing challenges. This result coincides with previous research suggesting that project-based learning not only facilitates cognitive development, but also personal development, by stimulating self-regulation and metacognition (Rodríguez & Díaz, 2019).

2. Development of Technological Competencies

The study also shows a notable increase in the technological skills of the students who participated in the EBP. This approach allowed students not only to use digital tools, but also to face real technological problems that demanded creative and innovative solutions. The development of these competencies is key in the current context, where mastery of technology and the ability to adapt to new technological environments are fundamental skills for professional success (Anderson, 2019; González et al., 2022).

In addition, students in the experimental group reported gaining confidence in their ability to solve technological problems, reflecting the positive impact of EBP on their job market readiness. This confidence comes from direct experience with technology and the ability to see the tangible results of their projects, giving them a deeper understanding of technological tools and processes (Vega & Díaz, 2022).

3. Relevance of Collaboration and Autonomous Learning

Another key takeaway from this study is the importance of collaboration and autonomous learning in EBP. Students highlighted that working on group projects encouraged the exchange of ideas and the development of interpersonal skills, such as effective communication and conflict resolution. This aspect is especially relevant, as teamwork skills are increasingly valued in today's work environments (López et al., 2021; Fernández & González, 2020).

The autonomous approach to EBP, where students are responsible for the development and execution of projects, also correlates with a greater sense of ownership over their learning. This empowerment not only contributes to academic development, but also improves intrinsic motivation, which promotes more active and engaged learning (Rodríguez & Díaz, 2019).

4. Limitations and Future Research

Despite the positive findings, it is important to recognize some limitations in this study. First, the research was conducted in a specific university setting, which may limit the generalizability of the results to other educational contexts or disciplines. In addition, the length of one semester may not be sufficient to observe the long-term effects of EBP on skill development. Future research could explore the impact of this methodology on other academic fields and examine how acquired skills are transferred to the professional environment.

It would also be valuable to investigate the impact of EBP on students with different learning styles or on those who face barriers to accessing technology, to identify strategies that make this methodology more inclusive and effective in a wider range of contexts (Sharma & Khosla, 2021).

5. Final Conclusion

In summary, project-based teaching has proven to be an effective pedagogical approach to preparing higher education students for the challenges of the 21st century. By integrating problem-solving, collaborative work, and the use of emerging technologies, EBP promotes learning that transcends the classroom and prepares students to face real problems in critical, creative, and technological ways (Vega & Díaz, 2022; García et al., 2021). The implementation of this methodology should be considered a priority in the curricular design of higher education institutions that seek to train professionals capable of adapting and thriving in a constantly changing world.

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