

Analysis of the Contribution of Active Learning Through Video Game Development within a CDIO Curriculum: An Educational Experience in Electronic Engineering and Agro-Industry

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DOI: <https://doi.org/10.51244/IJRSI.2026.1308000177>

Received: 23 August 2026; Accepted: 28 August 2026; Published: 12 September 2026

ABSTRACT

Engineering education faces the demand to combine technical competencies with collaboration, communication and social responsibility, while content-transmission teaching models offer limited room to develop them. This article analyses a curricular experience in which the development of educational video games operated as the integrating axis of a CDIO-oriented curriculum in the Electronic Engineering programme at the University of Quindío. The aim was to examine how video game production, understood as a complete conceive–design–implement–operate project, contributes to the development of technical and transversal competencies among undergraduate students. A design-based research approach articulated with the four CDIO stages was applied between 2020 and 2024 across four undergraduate seminars and one diploma course, involving seventy-two students organised into multidisciplinary teams. Evidence was gathered through participant observation, semi-structured interviews, documentary review of project outputs, CDIO-based rubrics and perception surveys. The resulting products addressed problems in basic education, agro-industry, regional tourism, health and environmental conservation, and were presented to partner institutions. Findings show progress in C# and Unity 3D programming, in project management and in teamwork skills, together with effective engagement with actors outside the classroom. The experience suggests that video game development constitutes a replicable pedagogical vehicle for engineering curricula seeking to integrate active learning, interdisciplinarity and social relevance.

Keywords: engineering education, CDIO framework, project-based learning, educational video games, transversal competencies.

INTRODUCTION

Over the past two decades, the discussion regarding the competencies an engineer should possess upon completing their education has shifted from a focus on mastering disciplinary content to the ability to address real-world problems. This shift is not merely rhetorical; it responds to an observation frequently made by both employers and engineering schools: graduates arrive with a solid grasp of concepts but struggle significantly to coordinate a team, adhere to a schedule, communicate technical decisions, or take responsibility for a product after delivery. The gap lies not in knowledge itself, but in the experience of putting that knowledge into practice.

The CDIO framework emerged precisely to address this gap. Initially developed at the Massachusetts Institute of Technology and subsequently expanded to an international consortium of engineering programs, it proposes that the full cycle of conceiving, designing, implementing, and operating should serve as the context for

teaching engineering, rather than being an add-on to theoretical instruction (Crawley et al., 2014). Its standards guide the integration of personal and interpersonal competencies into the curriculum, the creation of design and build spaces, and the use of active learning methods (Malmqvist et al., 2020). Adopting this framework therefore raises a practical question: what type of project offers students a cycle comprehensive enough to cover all four stages within the constraints of an academic semester?

Video game development offers a largely unexplored avenue within electronic engineering programs. From an educational standpoint, a video game is a demanding artifact: it requires defining a problem and a target audience, designing a software architecture, modeling and animating graphic assets, programming mechanics, testing gameplay with real users, and maintaining the product after its release. In other words, it encompasses the entire CDIO cycle. Unlike a conventional electronic prototype, it also incorporates a narrative dimension and direct interaction with end-users, compelling the student to step beyond technical language.

Literature on serious games and gamification partially supports this intuition, though it should be approached with caution. Available meta-analyses report moderate positive effects of digital games on learning and motivation, noting considerable heterogeneity across studies and a strong dependence on the instructional design accompanying the game (Clark et al., 2016; Wouters et al., 2013; Sailer & Homner, 2020). However, almost all such evidence concerns students **playing** games. The case examined here is different: students do not consume the game; they produce it. The learning object is not the video game's content but the process of building it, placing the experience closer to project-based learning than to gamification in the strict sense (Deterding et al., 2011; Landers, 2014).

This paper addresses that gap. While there is abundant literature on the use of video games as an educational resource and well-established literature on implementing the CDIO framework, there is little documentation of experiences where video game production serves as an integrative project within an electronic engineering curriculum—particularly with evidence systematically gathered across multiple student cohorts. The experience at the University of Quindío offers a case study spanning four years, featuring products that successfully reached external institutions. The research aims to answer the following question: How does the development of educational video games, structured according to the stages of the CDIO framework, contribute to the development of technical and transversal competencies in Electronic Engineering students? Accordingly, the objective of the manuscript is to analyze the contribution of active learning through video game development within a CDIO curriculum, based on an educational experience in Electronic Engineering and agro-industry.

THEORETICAL FRAMEWORK

The stage of operating within the CDIO framework

The CDIO framework organizes engineering education around a four-stage cycle that mirrors the lifecycle of a technical system. **Conceive** entails identifying a need, defining its scope, and establishing requirements. **Design** involves translating those requirements into architecture and specifications. **Implement** means building, integrating, and testing. **Operate** involves putting the system into use, evaluating it, and maintaining it (Crawley et al., 2014). This proposal is not merely another teaching methodology but a principle of curriculum organization: it maintains that personal, interpersonal, and system-building competencies should be taught within disciplinary courses rather than in separate ones.

The CDIO standards specify this orientation. Standard 5 requires design-build experiences integrated into the curriculum; Standard 7 requires the simultaneous learning of disciplinary and transversal competencies; and Standard 8 mandates the use of active and experiential learning methods (Malmqvist et al., 2020). Taken together, these three standards leave little room for ambiguity: the curriculum must include real-world projects, not merely illustrative exercises.

The framework has been compared with other project-based education models. Edström and Kolmos (2014) demonstrated that while CDIO and problem-based learning share the same assessment regarding the limitations of transmissive teaching, they differ in their starting point: whereas problem-based learning begins

by reorganizing the learning process, CDIO starts by defining the expected graduate outcomes. This distinction is significant for the case analyzed here, as the choice of a video game as the project is justified not by its appeal, but by its capacity to cover the full set of expected outcomes.

Video games, serious games, and learning

Research into video games and learning has followed two distinct paths that should not be conflated. The first examines the effect of playing. Gee (2003) argued early on that high-quality video games incorporate sophisticated learning principles: graduated difficulty, immediate feedback, tolerance for error, and situated learning. Subsequent meta-analyses confirmed positive effects on learning and retention, albeit with moderate effect sizes and wide variation across studies (Clark et al., 2016; Wouters et al., 2013). The second path examines the effect of incorporating game elements into non-game contexts—a practice known as gamification (Deterding et al., 2011). Here, too, the evidence is favorable but qualified: Sailer and Homner (2020) found small yet significant effects on cognitive, motivational, and behavioral outcomes, noting that the impact depends on the design rather than the mere presence of badges or scores.

Neither of these paths accurately describes the experience analyzed here. In this instance, the student assumes the role of the designer rather than the player. Landers (2014) provided a useful framework by distinguishing between game elements and the learning behaviors mediated by those elements: what generates learning is not the game itself, but the behavior the game elicits. Applied to the context of production, this distinction suggests that the educational value of the video game lies in the technical and coordination decisions that its creation necessitates.

Design-based research

Studying ongoing curricular innovations presents a well-known methodological challenge: the intervention itself changes while it is being studied. Design-based research embraces this condition rather than treating it as a flaw. Its aim is to simultaneously generate practical improvements and theoretical insights into the conditions that enable them, utilizing iterative cycles of design, implementation, analysis, and redesign within real-world contexts (Barab & Squire, 2004; Anderson & Shattuck, 2012). This approach is particularly relevant to an initiative spanning five cohorts over four years, where each implementation cycle informed the next.

The experiential component of the cycle is grounded in Kolb's (2015) experiential learning theory, which posits that knowledge is created through the transformation of experience via a cycle comprising concrete experience, reflective observation, abstract conceptualization, and active experimentation. While the alignment with the four stages of the CDIO framework is not exact, it is sufficient to justify concluding each stage with a phase of documented reflection rather than merely a technical deliverable.

METHODOLOGY

Research design and approach

The research adopted a mixed-methods approach with a predominantly qualitative orientation, structured as design-based research and aligned with the four stages of the CDIO framework. Each cohort constituted a complete cycle of design, implementation, analysis, and redesign, such that adjustments derived from one cohort were incorporated into the next. The quantitative component provided performance and perception indicators, while the qualitative component provided an interpretation of the decisions, difficulties, and lessons learned reported by the participants.

Context and participants

The initiative was carried out within the Electronic Engineering and Animal Science programs at the University of Quindío in Armenia, Colombia, between 2020 and 2024. Four undergraduate seminars and one diploma course were conducted, involving seventy-two students. A non-probabilistic, purposive sampling

method was used, involving students who had expressed an interest in programming, interactive design, or digital media. Each cohort was organized into multidisciplinary teams, allowing for the distribution of technical, graphic, and coordination roles.

Methodological structure

The process followed four iterative phases aligned with the stages of the CDIO framework and the principles of design-based research. Table 1 summarizes the correspondence between stages, activities, tools, and expected outputs.

Table 1. CDIO methodological structure aligned with design-based research

Stage	Activities	Tools	Product
Conceive	Identification of real-world problems in education, tourism, health, and the environment. Ideation workshops. User analysis. Definition of objectives, target audience, narrative, and technical requirements.	Ideation workshops, interviews with external stakeholders, requirements matrix	Project concept document
To design	Development of conceptual prototypes. Asset modeling and animation. Definition of software architecture, interfaces, and narrative flow.	Unity 3D, Blender, Mixamo, UML diagrams, storyboards	Conceptual prototype and design documentation
Implement	Mechanics programming. Iterative testing of functionality, gameplay, and usability. Peer code review.	C#, Unity 3D, version control, CDIO rubrics	Executable version of the video game
Operate	Presentation to academic panels and partner institutions. Measurement of satisfaction and pedagogical relevance. Feedback for continuous improvement.	User surveys, focus groups, demonstration sessions	Released product and evaluation report

Source: Prepared by the author

Instruments and data collection

Data collection drew from four sources. Participant observation documented the teams' work during the sessions. Semi-structured interviews explored the students' experiences at each stage of the cycle. A document review analyzed the outputs of each project: conceptual design documents, diagrams, code, and test reports. Perception surveys were administered at the end of each cohort. Performance assessment was conducted using

rubrics based on CDIO standards 5, 7, and 8, evaluating achievements in design, integration, and active learning.

Analysis techniques

The quantitative analysis involved descriptive statistics of rubric scores and perception-based responses. The qualitative analysis followed the thematic analysis procedure proposed by Braun and Clarke (2006): familiarization with the material, generation of initial codes, searching for themes, and reviewing, defining, and writing up the findings. The coding was reviewed by a second researcher. The integration of both components was achieved through triangulation during the interpretive phase, by cross-referencing rubric scores with participants' accounts and documentary evidence from the projects.

Ethical considerations

Participation was voluntary and did not affect course grades. Participants provided written informed consent. Data were anonymized using alphanumeric codes. Academic products are used with the express authorization of their authors, and the developed video games retain the authorship of the teams that created them.

RESULTS

Developed products

The teams produced video games addressing problems identified in the regional environment. Table 2 summarizes the most representative cases.

Table 2. Video games developed and scope of application

Product	Scope	Educational or social purpose
University Magic-Pro	Higher education	Support for preparation for national standardized tests
World of Maths	Basic education	Mathematics learning in primary education
Quindío Tour	Regional tourism	Promotion of the department's heritage and tourist destinations
Lutrinia Longicaudis	Environmental conservation	Raising awareness about biodiversity and species conservation

Source: Prepared by the authors based on outputs from the seminars and the diploma program, 2020–2024

The set of projects also encompassed topics related to health, agriculture, and the promotion of the academic program. This thematic diversity was not a deliberate goal but rather a consequence of the design: the conceptualization stage required identifying a real problem involving a specific user, and students drew upon their own surroundings.

Technical skills

The rubrics tracked progress across three fronts. The first was C# programming proficiency within the Unity 3D environment; for most teams, this evolved from a beginner level to the ability to independently implement functional mechanics and debug errors. The second was the modeling and animation of graphic assets using Blender and Mixamo—a skill set absent from the participants' prior training. The third was technical

documentation—class diagrams, software architectures, and storyboards—which, unlike in the initial cohorts where they were created after programming, preceded implementation in the later cohorts.

Transversal competencies

The thematic analysis of the interviews identified four recurring themes. Team coordination emerged as the most frequently cited initial challenge: students described the distribution of tasks among team members with diverse profiles as a source of tension during the early weeks and as a key learning experience by the project's conclusion. Time management issues arose during the implementation phase, as the scope defined during the conceptualization stage consistently proved too extensive to be executed within the available timeframe. Communication with non-technical users became a factor during the operational phase, when teams presented their products to K-12 teachers and partner institutions. Finally, tolerance for error was reported because of the iterative nature of playtesting.

Engagement with external stakeholders

The "operate" phase yielded the least anticipated outcome. The need to present the products to real users led to establishing contact with educational institutions, cultural entities, and environmental organizations in the region. This interaction altered the projects: several teams redesigned mechanisms or interfaces based on user feedback. The experience suggests that the "operate" phase—often the weakest link in CDIO framework implementations due to its logistical demands—is also the one that offers the greatest educational value.

DISCUSSION

The results lend themselves to an interpretation that requires clarification. Video game development did not foster learning simply because of its playful nature; rather, it did so by requiring students to navigate a complete production cycle culminating with an identifiable end user. This observation aligns with Landers's (2014) caveat regarding behavioral mediation: game elements do not directly influence learning but rather act through the behaviors they elicit. In the case analyzed, the key behavior was sustaining a project over the course of a semester with an external recipient in mind.

The integration of the CDIO framework with design-based research proved productive for a structural reason. Both approaches are iterative and treat real-world context as a fundamental condition rather than as "noise" (Anderson & Shattuck, 2012; Crawley et al., 2014). This affinity allowed adjustments made for one cohort to inform the next without compromising the study's coherence—a practice that, in a conventional experimental design, would have threatened validity.

This study occupies a distinct—and likely complementary—position relative to the existing literature on serious games. Available meta-analyses evaluate the impact of **playing** on the learner (Clark et al., 2016; Wouters et al., 2013; Sailer & Homner, 2020), whereas this study documents the impact of **producing** on the creator. Direct comparison is not possible, and it would be a mistake to present these results as a confirmation of those earlier findings. What can be asserted, however, is that the production of interactive artifacts constitutes a type of integrative project that warrants its own line of inquiry within engineering education research.

It is also important to note the limitations regarding the conclusions that can be drawn from this experience. The study design lacked a comparison group, utilized purposive sampling, and involved participants who joined based on expressed interest—factors that introduce significant selection bias; it is plausible that students with a prior interest in programming and digital media might have demonstrated similar progress in other educational settings. Furthermore, medium-term competency retention was not measured. These limitations do not invalidate the description of the curricular framework—which constitutes the primary contribution—but they do qualify any causal claims.

Future research will assign a significant role to the alternative approach of project-based learning, enhancing interdisciplinary contributions from the agro-industrial sector itself. This will enable video games to reach rural communities, thereby establishing tools that foster genuine social appropriation of knowledge.

Quantitative analysis—incorporating rubrics, statistical tests, and growth metrics—will continue to be utilized to improve specific competencies that contribute to video game development across various contexts.

Similarly, longitudinal studies will be conducted to evaluate technical and transversal competencies among students and active community members over the short and medium term, yielding significant insights for video game design.

Furthermore, although this study does not explicitly demonstrate the impact on the productive sector, attention must be paid to resulting employability outcomes, given the video game industry's growing prominence across numerous economic sectors.

It is also important to highlight additional studies across various disciplines and engineering institutions; these strengthen the generalizability and positioning of a broader model for innovation in engineering education and other fields of knowledge.

CONCLUSIONS

The study's guiding question investigated how the development of educational video games—structured according to the stages of the CDIO framework—contributes to the technical and transversal competencies of Electronic Engineering students. Evidence gathered across five cohorts indicates that this contribution occurs in three ways: the technical demand of building a functional software product; the organizational demand of sustaining teamwork throughout a complete cycle; and the communicative demand of delivering the product to a user who does not share the same technical language.

The primary contribution of this work is the documented description of a replicable curricular mechanism. The structure presented in Table 1 can be adapted to other engineering programs without substantive changes, provided that a crucial condition is maintained: the "operate" stage must involve the actual delivery of the product to an entity outside the university.

The identified limitations shape the agenda for future research. A study design incorporating a comparison group would allow for the estimation of the mechanism's net effect; delayed measurement would enable an assessment of competency retention; and extending the experience to other programs within the faculty would make it possible to distinguish between outcomes attributable to the specific artifact chosen and those resulting from the overarching CDIO framework.

DECLARATIONS

Previous publication. A preliminary version of this experience was presented as a paper at the EIEI-ACOFI 2024 International Engineering Education Meeting. The present manuscript expands upon that version regarding the theoretical framework, methodological approach, and analysis, and does not reuse tables or figures from that document.

Use of artificial intelligence. AI was used to improve the writing, but all data are the product of research conducted within the institution.

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