Characterization of the Social Appropriation of Knowledge in the "Operate" Phase of the CDIO Framework: Articulation Between University, Industry, and Community in a University Production Unit

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ABSTRACT

The adoption of the CDIO framework tends to concentrate on the conceive, design and implement stages, while the operate stage remains underdeveloped because of its logistical demands and the difficulty of sustaining relationships with external actors beyond the academic term. If the cycle closes at the prototype, the project's contribution to its territory remains unverified. This article examines the operate stage as a space for the social appropriation of knowledge, drawing on the case of a University of Quindío production unit simultaneously linked to teaching, research and outreach, and using complementary experiences from the Electronic Engineering Program to assess the transferability of the identified mechanisms. A qualitative embedded single-case study design is used, based on documentary analysis of project formulations, requirements, architectures, prototypes, test records, user-validation evidence, manuals, closing dossiers, and records of academic or outreach continuity. The results reveal five recurring appropriation mechanisms: co-definition of the problem, translation of operational knowledge into engineering requirements, iterative validation with users, transfer supported by documentation and technical support, and project continuity beyond a single course. The Operate phase therefore functions as a feedback loop that returns information to Conceive and turns the academic prototype into a solution that can be used, adapted, and sustained by actors in the surrounding environment. The main constraints concern maintenance, compatibility, user availability, institutional continuity, and longitudinal documentation of impact.

Keywords: social appropriation of knowledge, CDIO framework, university-industry relations, university outreach, territorial development.

INTRODUCCIÓN

Latin American universities have incorporated the concept of a "third mission" into their statutes: beyond teaching and research, they are expected to contribute to the development of their surrounding communities. This concept is easy to articulate but difficult to verify. Most institutional reports document activities—such as signed agreements, events held, and beneficiaries served—without establishing whether the knowledge was actually integrated into the recipients' practices. The gap between dissemination and adoption is the core issue.

In engineering programs, this gap manifests concretely in the curriculum. The CDIO framework structures education around the cycle of conceive, design, implement, and operate (Crawley et al., 2014). The first three stages take place within the university setting and can be assessed through academic deliverables; the fourth requires stepping outside, putting the system into use, and evaluating it with real-world users. Yet, this final stage is frequently reduced to a presentation before a faculty panel; when that happens, the cycle formally closes, and the project dies at the prototype stage.

The case of the University of Quindío offers a favorable setting for examining this stage. The institution operates production units that serve simultaneously as spaces for teaching, research, and outreach, maintaining ongoing engagement with the department's producers and communities. In this context, a CDIO project can extend beyond mere presentation: the operational context remains active, stakeholders familiar with the problem are involved, and the system can be validated, adjusted, or continued well after the specific course has concluded.

The concept of the social appropriation of knowledge provides an appropriate framework for analyzing this continuity. Unlike dissemination—which implies a one-way flow from expert to public—appropriation refers to an exchange process in which non-academic actors participate in defining the problem and transform the knowledge they receive based on their own circumstances (Daza-Caicedo et al., 2017). This distinction is not merely semantic; it entails different evaluation criteria and, crucially, the possibility for the project to be modified by its recipients.

While there is a well-established body of literature on the CDIO framework and extensive research on university-industry relations (D'Este & Perkmann, 2011), few studies examine how the final stage of the CDIO cycle functions as a mechanism for territorial engagement. Specifically, there is a lack of research utilizing evidence of use, validation, adaptation, or continuity that goes beyond evaluations conducted solely by faculty and students—a gap this study aims to fill. Consequently, this paper aims to characterize the social appropriation of knowledge within the "Operate" phase of the CDIO framework, focusing on the collaboration between university, industry, and community within a university-based production unit.

THEORETICAL FRAMEWORK

The stage of operating within the CDIO framework

The CDIO framework defines the "operate" stage as the use of the implemented system to deliver the intended value, encompassing its maintenance, evolution, and retirement (Crawley et al., 2014). The requirements differ from those of the preceding stages: whereas conceiving, designing, and implementing are evaluated through deliverables, the "operate" stage can only be assessed based on the system's performance in the hands of a user. CDIO Standards 5 and 7 guide the integration of design-build experiences and the simultaneous learning of disciplinary and transversal competencies, while Standard 8 addresses the use of active learning methods (Malmqvist et al., 2020); however, none of these standards resolve the challenge of sustaining a system in operation beyond the academic calendar.

Social appropriation of knowledge

"Social appropriation of knowledge" refers to the process by which non-academic actors understand, value, and utilize scientific and technological knowledge, transforming it according to their own circumstances. It differs from science popularization due to its bidirectional nature and the participation of external actors in defining the problem—a distinction with a direct methodological consequence: evidence of appropriation is not gathered through coverage indicators but by examining the practices of those who received the knowledge. Daza-Caicedo et al. (2017) developed this argument by proposing a set of qualitative indicators, demonstrating that attendance figures do not reveal the actual transformation of practices.

In Colombia, this concept also holds normative status: public policy for the sector guides the two-way circulation of knowledge between scientific communities and other social actors (Minciencias, 2021). This framework aligns with the characterization of a mode of knowledge production organized within the context of application, involving heterogeneous actors and quality criteria that incorporate social relevance alongside disciplinary validity (Gibbons et al., 1994; Nowotny et al., 2001). The productive unit—the setting where knowledge is produced while being applied—corresponds to this description.

Third mission and territorial engagement

The concept of the "third mission" positions the university as an agent of development. A systematic review by Compagnucci and Spigarelli (2020) reveals that the field has been dominated by an economic perspective—focusing on technology transfer, patents, and business creation—while social and cultural dimensions remain underrepresented in research and institutional measurement systems. The "triple helix" model, which characterizes this engagement as a recursive interaction among university, industry, and government, has served as the dominant framework for this perspective (Etzkowitz & Leydesdorff, 2000).

Two adjustments to this framing are relevant here. D'Este and Perkmann (2011) demonstrated that most academics engage with the productive sector to advance their own research rather than to commercialize knowledge, and that joint research, contract research, and consulting are driven by motivations distinct from those behind patenting. Trencher et al. (2014) documented an emerging role of co-creation for sustainability—aimed at transforming a specific territory in partnership with social actors—which differs from the economic focus of the conventional third mission. Both perspectives better describe the relationship a university unit establishes with its environment. In regional economies with low technological density, this relationship is also asymmetrical: rather than transferring technology to an established industrial sector, the university is often the territory's primary actor with technical capacity, explaining why these units function as an interface.

The university production unit as an interface

A university-based production unit is a hybrid institutional entity: it produces goods or services, trains students, and hosts research. This threefold nature allows operations to continue independently of the academic calendar—since the unit remains active after the semester ends—and ensures that the user of the developed system is identifiable and accessible for research, thereby overcoming the primary empirical obstacle to studying appropriation.

METHODOLOGY

Research design and approach

The research adopts a qualitative approach using a single, embedded case study design, in the terms defined by Yin (2018). The aim is not to measure the performance of an isolated artifact, but rather to understand how the "Operate" phase links academic development with the use, adaptation, and continuity of a solution within a real-world context. The embedded nature of the design allows for the examination—within the primary case (the university production unit)—of various moments and projects that embody the CDIO sequence. The case selection is strategic: it combines a real-world production environment, the constant presence of users, and integration with teaching, research, and outreach activities—conditions that enhance its informational value for studying the social appropriation of knowledge (Flyvbjerg, 2006).

Case, subunits, and document corpus

The primary case study focuses on a production unit at the University of Quindío that is integrated with the Electronic Engineering Program. The units of analysis are CDIO projects that originate from operational needs, progress through design and implementation, and generate evidence of validation or actual use. The document corpus comprises problem formulations, current and desired states, problem trees, functional and non-functional requirements, architecture, work breakdown structures, budgets, prototyping records, test plans and results, project closure dossiers, manuals, and evidence of continuity into the "CDIO PROJECT III" academic course, a degree project, or an outreach initiative. For analytical comparison, experiences from the same CDIO ecosystem—developed with community, institutional, and social stakeholders—are included, but only insofar as they allow for verifying whether the mechanisms observed in the production unit also appear in other contexts.

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Sources of evidence and categories of analysis

The primary source of information is a document review of the outputs generated during the CDIO cycle. The analysis was organized into five categories: a) participation of an external stakeholder in problem definition; b) transformation of operational needs into verifiable requirements; c) system validation under conditions approximating real-world use; d) knowledge transfer through demonstration, documentation, training, or support; and e) post-implementation continuity, maintenance, and feedback. These categories make it possible to distinguish a simple academic deliverable from an experience in which knowledge circulates, is utilized, and can be modified by the recipient.

To strengthen the analysis of the case study, comparisons were drawn with experiences from the Electronic Engineering Program that demonstrate explicit interaction with real-world users. These include the development of an automated food and water dispensing system addressing a need at a university farm; a waste-weighing automation project proposed in collaboration with a recycling organization to improve accuracy, traceability, and transparency; an interactive environment that evolved from a CDIO III project into a capstone project for the COVIDA Foundation; and educational video games focused on environmental awareness that were tested with both users and experts. These cases do not replace the primary case study but serve as comparative evidence to assess the transferability of the identified mechanisms.

Analisys

The analysis followed a thematic logic inspired by Braun and Clarke (2006): familiarization with the corpus, coding of evidence linked to defined categories, grouping of patterns, review of consistencies and discrepancies across project phases, definition of mechanisms, and interpretive writing. The unit of coding was not the mere mention of an activity, but rather evidence of a relationship between an engineering decision and a need, use, adjustment, or continuity condition posed by the environment. Thus, a demonstration was considered evidence of "Operating" only when it was associated with the system's use, validation, feedback, or sustainability.

Criteria for rigor

Rigor was established in accordance with the criteria of Lincoln and Guba (1985). Credibility was supported by triangulation across documents from different stages of the cycle (formulation, design, implementation, testing, and closure) and by comparison with external experiences involving the same program. Transferability was fostered by describing the context and mechanisms, rather than presenting the case as a universal recipe. Dependability was maintained through a traceability matrix linking evidence to analytical categories, while confirmability was ensured by preserving source documents and distinguishing between observed evidence and researcher interpretation.

Ethical considerations

The analysis presented is based on academic and institutional documentation and does not report new interviews or experimental interventions involving human subjects. The names of students and individual users are not included in the manuscript, and experiences are described only to the extent necessary for the analysis. When a CDIO project involves systematic interaction with participants or the collection of personal data, it must comply with the relevant institutional procedures regarding ethics, informed consent, and data protection. This distinction is significant because social appropriation requires contact with users, yet such contact does not, in itself, authorize the use of personal information for research purposes.

RESULTS

Institutional configuration and cycle continuity

The analysis shows that mastery of the material does not depend on an isolated activity at the end of the semester, but rather on how the transition between CDIO stages is organized. Within the Electronic

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Engineering Program, the "CDIO PROJECT II" course focuses on problem formulation, conceptual and preliminary design, architecture, feasibility, and prototype construction; "CDIO PROJECT III" delves into detailed design, integrates sensors, actuators, controllers, power systems, and software where applicable, and results in a minimum viable product ready for validation. The preliminary showcase, the Technology Showcase, functional testing, and the submission of a final dossier introduce public verification milestones that require justification not only of the system's functionality but also of who it serves, the conditions under which it operates, and the supporting evidence.

Co-definition of the problem and translation into requirements

The first mechanism identified is the co-definition of the problem. Projects that are closest to the "Operate" phase do not begin with a predetermined solution, but rather with a gap between a current state and a desired state—a gap documented with evidence, causes, and effects. This formulation allows the external actor's operational knowledge to serve as an engineering input. In a case involving an agricultural production unit, the need to automate feed and water dosing for pigs was translated into an IoT solution and verifiable operational criteria. The significance of this example lies not in the artifact itself, but in the fact that an operational need of the unit is transformed into requirements, architecture, components, testing protocols, and design decisions.

The same pattern appears in an initiative to automate waste weighing, developed in collaboration with a waste-picker organization. In that instance, the social demand was articulated in terms of accuracy, traceability, transparency, and fair payment. A comparison reveals that appropriation begins prior to implementation: when the user participates in defining what needs to be solved, local knowledge ceases to be merely contextual information and becomes part of the system specifications. In the terms used by Daza-Caicedo et al. (2017), the relationship is no longer unidirectional.

User validation, adjustment, and operation

The second set of evidence relates to validation. In the projects reviewed, the sequence of prototyping, testing, pre-sampling, public validation, and adjustment creates an iterative logic that bridges the "Implement" and "Operate" phases. Technical tests—unit, system, and user tests, where applicable—allow for requirement verification; however, successful adoption also requires observing whether the system is usable by the recipient, whether the interaction is intuitive, and whether the artifact's behavior aligns with the context. For this reason, error logs, user observations, subsequent modifications, and change traceability constitute stronger evidence of the "Operate" phase than a final project presentation.

One experience that illustrates this distinction is RECONEXIÓN, initially developed under Project CDIO III and subsequently continued as a degree project for the COVIDA Foundation. The system evolved into a low-cost interactive environment featuring therapist-guided operation, basic session logging, and Arduino-Python integration. Operational validation demonstrated stability, ease of use, and acceptance within the intended scope, without positioning the system as a substitute for professional care. This continuity allowed observations gathered during use to inform adjustment decisions, demonstrating that the "Operate" phase serves as a source of new requirements rather than merely marking the administrative conclusion of the project.

Transfer, documentation, and appropriation in other contexts

The third mechanism is supported handover. Handing over the artifact loses value if instructions, testing criteria, technical documentation, designated support personnel, and minimum maintenance conditions are lacking. In the CDIO experiences reviewed, the inclusion of a work breakdown structure, budget, quality records, manuals, test results, lessons learned, and a project closeout dossier helps ensure that knowledge is retained even when the student team changes. This documentation serves a dual purpose: it provides evidence of the engineering process and reduces the user's reliance on the original developers.

Experiences with educational video games demonstrate this same mechanism in a different domain. Across two training cohorts, solutions were developed addressing topics such as mathematics, exam preparation, tourism, heritage, civic culture, and environmental conservation. Projects like "Lotrina, la exploradora" incorporated dialogue with users or experts, functionality and usability testing, observation, surveys, rubrics, and—where applicable—pre- and post-intervention assessments. Even though the product is digital, the "Operate" phase presents challenges similar to those of a physical system: maintenance, compatibility, distribution, updates, and impact documentation. This reinforces the idea that "Operate" is a category of user relationship rather than a property of a specific type of technology.

Institutional continuity and obstacles to appropriation

The fourth mechanism is continuity across academic spaces. The evidence reviewed shows that some projects advance from CDIO II to CDIO III and—when justified by need and maturity—continue as capstone projects, outreach initiatives, or further developments. This trajectory extends the time available for testing, refinement, and technology transfer. The university-based production unit offers an additional advantage: the operational context does not vanish at the end of the semester, allowing the system to be evaluated against ongoing operations and by users who retain institutional memory regarding the problem.

The main obstacles identified are consistent across the experiences analyzed: discontinuity between student cohorts, changes in project leadership, insufficient maintenance, hardware or software compatibility issues, limited user availability for further testing, difficulties in sustaining technical support, and a lack of longitudinal documentation regarding impact. An asymmetry in documentation is also evident: projects record design and testing phases in greater detail than the adoption phase occurring months after delivery. Consequently, while available evidence confirms the existence of mechanisms for adoption and conditions for use, it does not justify attributing long-term territorial impacts without subsequent monitoring.

DISCUSSION

To operate as a mechanism of appropriation

The results allow us to answer the research question by indicating that the social appropriation of knowledge occurs when the "Operate" phase maintains an active relationship among the system, the user, and the university team. It is not enough to simply transfer information or demonstrate that a prototype meets technical specifications. Appropriation emerges when the external actor participates in defining the problem, recognizes their needs within the requirements, uses or validates the solution, offers feedback, and possesses the means to sustain or adapt what has been received. This finding aligns with Daza-Caicedo et al. (2017), who argue that appropriation is evidenced by the transformation of practices and the bidirectional flow of knowledge, rather than by coverage indicators.

From the CDIO perspective, this interpretation alters the linear representation of the cycle. "Operate" is not merely the fourth stage; it is the moment when actual performance provides feedback to the "Conceive" stage. Usability issues, maintenance constraints, contextual changes, or user-introduced modifications serve as inputs for redefining the problem and initiating a new iteration. Consequently, the cycle is better represented as C-D-I-O-C than as a sequence that concludes at O. The pedagogical contribution of this feedback loop is significant: it compels students to reconcile design decisions with usage outcomes and to gain an understanding of the system's lifecycle.

The productive unit as a third-mission interface

The university-based production unit mitigates one of the most common issues encountered during the "Operate" phase: the disappearance of the user once the course concludes. By maintaining productive activity, employing staff familiar with the process, and remaining linked to teaching, research, and outreach, the unit serves as a stable interface between the academic calendar and operational timelines. This arrangement aligns the case more closely with the concept of territorial co-creation described by Trencher et al. (2014) than with a narrow view of technology transfer.

The observed relationship also nuances the traditional university-industry model. As D'Este and Perkmann

(2011) argue, such linkages go beyond the mere commercialization of knowledge. In the projects analyzed, value is derived from solving context-specific problems, fostering learning, validating technology, and building operational capacity among external stakeholders. The university contributes technical knowledge and an educational framework, while the external partner provides process knowledge, relevance criteria, and operational constraints. The solution emerges from this interdependence.

Proposed coordination framework

Based on the identified mechanisms, a five-stage coordination framework is proposed. First, conceptualize *with* the stakeholder rather than merely *for* them, documenting the gap between the current state and the desired state, as well as evidence of the problem. Second, design for adoption, incorporating functional and non-functional requirements related to usability, maintainability, security, compatibility, and context. Third, implement with traceability, ensuring that every decision can be linked to a specific requirement and test. Fourth, operate using real users or representative conditions, while recording usage, failures, observations, adjustments, and support responsibilities. Fifth, provide feedback for the next cycle by transforming operational findings into new requirements or projects focused on continuity, maintenance, or technology transfer.

This framework requires an additional institutional condition: a mechanism for project stewardship. Continuity cannot rely solely on the student who developed the prototype. There must be a documentation repository, a clearly designated person responsible for follow-up, minimum handover criteria, and a pathway for the system to transition to another team, a thesis project, an outreach initiative, or the end-user unit. Without such stewardship, the "Operate" phase remains vulnerable to the natural turnover of student cohorts and risks being reduced to a mere demonstration.

Scope and limits of generalization

While this case does not allow for statistical generalization, it does permit analytical generalization in the sense described by Flyvbjerg (2006): the mechanisms can be tested in other settings involving an external actor, a genuine need, and the potential for continued use. Complementary experiences in recycling, health, education, and environmental appropriation demonstrate that the identified logic is not sector-specific. However, the available evidence is primarily documentary and focuses on the process leading up to validation and immediate continuity. Longitudinal monitoring of adoption, maintenance, and impact remains less systematic than the documentation of design and implementation. Consequently, while this article identifies the conditions and mechanisms of appropriation, it does not claim to demonstrate long-term causal effects on productivity, learning, or social transformation.

Documentary evidence

Once the work with the external sector has been concluded and documented, specific instruments—such as semi-structured interviews and opinion surveys—must be applied to facilitate the adoption of the model. By analyzing its strengths and shortcomings, the aim is to achieve a genuine impact regarding its transferability to real-world contexts.

In parallel, standardized monitoring tools will be developed to systematically track the sustainability of the proposed framework over the short, medium, and long term, thereby documenting the resulting changes and impacts.

The framework will be progressively refined by weighing barriers and facilitators based on their observed frequency or severity; this will clarify implementation priorities and ensure the model is easily replicable, ultimately fostering a coherent process of social appropriation of knowledge.

CONCLUSIONS

The analysis leads to the conclusion that CDIO projects foster the social appropriation of knowledge when the

"Operate" phase is conceived as an ongoing relationship with the user rather than merely the final presentation of a prototype. Key mechanisms include the co-definition of the problem, the translation of operational knowledge into requirements, iterative validation, knowledge transfer accompanied by documentation and support, and project continuity beyond the scope of a single course. Together, these mechanisms transform academic knowledge into a solution that can be understood, used, questioned, and adjusted by stakeholders in the surrounding environment.

The university-based production unit offers particularly favorable conditions for this process because it preserves the context of use, maintains relationships with stakeholders, and integrates teaching, research, and outreach. Its primary contribution is not to serve as an extended laboratory but to function as an interface: it allows engineering work to confront real-world operational constraints and enables those constraints to feed back into the curriculum in the form of new problems, requirements, and design decisions.

The proposed framework—conceiving with the stakeholder, designing for appropriation, implementing with traceability, operating based on evidence, and feeding back into a new cycle—can be transferred to other projects involving productive, institutional, or community stakeholders. To ensure sustainability, the framework requires documentation repositories, designated personnel for monitoring, handover criteria, maintenance plans, and pathways for continuity—such as advancing to CDIO Project III, a capstone project, outreach initiatives, or other institutional modalities.

The main limitation is that the evidence analyzed is primarily documentary and covers only the short to medium term; therefore, it is insufficient on its own to confirm sustained territorial impacts. Future research should incorporate longitudinal monitoring of installed systems, usage and maintenance indicators, records of user-made modifications, and comparative studies across production units. Such measures would make it possible to move beyond merely verifying that a project reached the "Operate" phase and instead determine the extent of knowledge actually appropriated and which transformations were sustained over time.

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