

# PERMEABLE BOUNDARIES. EXPLORING TRANSDISCIPLINARY COLLABORATIONS IN BIODESIGN FOR INNOVATION

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TODAY'S CHALLENGES CANNOT BE SOLVED BY A SINGLE DISCIPLINE; TRANSDISCIPLINARY COLLABORATION IS ESSENTIAL TO ADDRESS COMPLEX ISSUES FROM INTEGRATED APPROACHES. THIS REQUIRES COOPERATION AMONG DISCIPLINES AND THE INCORPORATION OF NON-ACADEMIC ACTORS, TRANSCENDING THE TRADITIONAL BOUNDARIES OF KNOWLEDGE. AT THE FACULTY OF ARCHITECTURE AND DESIGN OF THE UNIVERSITY OF LOS ANDES, THE AREA OF BIODESIGN HAS ESTABLISHED ITSELF AS A SPACE WHERE STUDENTS AND PROFESSORS FROM DIFFERENT AREAS FACE CHALLENGES RELATED TO THE CONSTRUCTION AND VALIDATION OF KNOWLEDGE, STUDENT CONDITIONS, AND THE METHODOLOGICAL DYNAMICS OF CLASSES. THIS ARTICLE ANALYZES TRANSDISCIPLINARY COLLABORATIONS AIMED AT INNOVATION BASED ON A CASE STUDY OF THREE BIODESIGN COURSES. THROUGH INTERVIEWS, OBSERVATIONS, AND A REVIEW OF TEACHING MATERIALS, THE MAIN TENSIONS AND LESSONS LEARNED FROM WORKING TOGETHER WERE IDENTIFIED. THE RESEARCH ANSWERS THE QUESTION: HOW CAN THE DYNAMICS OF COLLABORATION BETWEEN TEACHERS AND STUDENTS BE STRENGTHENED SO THAT THE DIVERSITY OF PERSPECTIVES CONTRIBUTES TO GENUINE COOPERATION? AS A RESULT, A SET OF ANALYTICAL AND DIAGNOSTIC TOOLS WAS DEVELOPED THAT ALLOWS TEACHERS TO RECOGNIZE PROGRESS, STAGNATION, AND OPPORTUNITIES FOR IMPROVEMENT IN THEIR PRACTICES IN ORDER TO ADJUST THEIR METHODOLOGIES AND CONTINUE PROMOTING COLLABORATION AND TRANSDISCIPLINARY LEARNING.

KEYWORDS: BIODESIGN, INNOVATION, TRANSDISCIPLINARY, FRONTIER OBJECTS, PARADIGMS

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## INTRODUCTION

Biodesign is a field that integrates design and biology, involves living organisms in the creative process, and brings together knowledge from fields such as microbiology, engineering, chemistry, art, and architecture to respond to contemporary challenges such as the climate crisis. However, its development faces limitations in terms of disciplinary integration and its transfer to productive and social contexts.

At the University of Los Andes, the 2006 academic reform allowed synthetic biology and biodesign to be incorporated into the Design program. Since 2017, participation in the Biodesign Challenge and in projects such as RootKnit, Pseudofreeze, and Must(go) has consolidated a trajectory that has led to the creation of courses such as Biomoda and Design and Biotechnology, as well as a teaching ecosystem with increasingly transdisciplinary practices.

Based on an analysis of the lessons learned, tensions, and challenges of these projects, the study seeks to understand how collaborations between disciplines are formed, progress, or are interrupted, and how they can be strengthened in biodesign training.

The transdisciplinary approach is understood here as cooperation between disciplines and non-academic actors to produce integrated knowledge. However, in the cases analyzed, this transdisciplinarity manifests itself mainly within academia, in the articulation between design and biology. Incipient links can be observed with contexts and subjects for whom designs are created, in situ prototypes, and efforts to recognize the values, needs, and projections of the communities or environments involved. Although the cases do not directly incorporate external knowledge or actors, they do show initial strategies for methodological expansion and the incorporation of external perspectives, which constitute a starting point for more robust transdisciplinary practices.

## METHODOLOGY

This research adopts a qualitative approach using multiple case studies to analyze the experiences of teachers and students who participated in three biodesign courses at the Faculty of Architecture and Design at the University of Los Andes. The process began with a review of the literature on the relationship between science and design to define biodesign and innovation, and analyze cases of collaboration among scientists, designers, and artists in university contexts.

Empirical information was collected through semi-structured interviews with students and teachers, supplemented by documentary analysis of classroom materials, which allowed for the examination of group dynamics, collaborative practices, and tensions in the educational process. Qualitative analysis for the construction of analytical categories was developed through thematic coding, combining inductive and deductive criteria, based on the recurrence of themes, the contrast between actors, and the comparison between cases.

Subsequently, a cross-sectional comparison and triangulation of sources and perspectives was carried out to identify patterns, divergences, and contextual conditions that influenced the experiences of transdisciplinary collaboration. Based on these findings, a diagnostic tool was designed and tested with the participating teachers, from which pedagogical recommendations were generated to strengthen transdisciplinary collaboration in future courses.

## CASE AND PARTICIPANT SELECTION CRITERIA

The cases corresponded to courses in the biodesign area of the Faculty of Architecture and Design that had teachers from different disciplines or with hybrid backgrounds in design/art and science. They had been taught at least once before by the same professors, and incorporated students from various disciplines, methodologies specific to design and science, and collaborative work within the curriculum.

The selected students belonged to groups that completed the course with solid results and fulfilled all deliverables. In each case, two students were chosen to represent, where possible, diversity in terms of discipline, gender, and roles within the team. All of them actively participated in most phases of the course and were in the final semesters of their academic training.

## DESIGN AND SCIENCE ARE COMPLEMENTARY

According to Owen (2007), contemporary problems require a review of decision-making processes, as scientific thinking is often not heard or taken into account, and design thinking is not used at all. The latter, understood as a complement to the former, “embodies a wide range of creative characteristics, as well as several other special qualities of great value to decision makers” (Owen, 2007, p. 17). The complementarity between the two lies in the fact that design thinking and scientific thinking differ in the way they construct and validate knowledge, and their articulation of thought, according to the author, adequately covers the areas for decision-making.

To explain this, Owen (2007) first considers that creative people tend to work in two ways, as discoverers or creators, and outlines the domains shown in Figure 1.

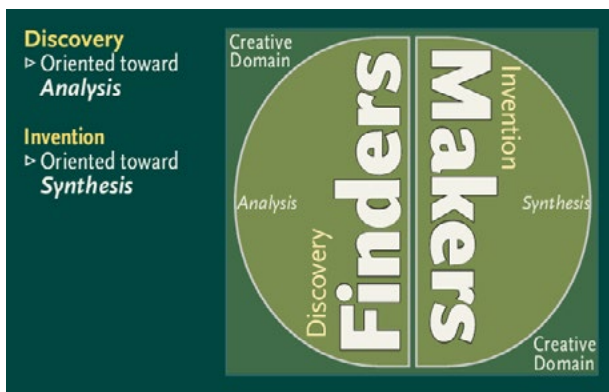


FIGURE 1. The domains of the creative model. Reproduced from Owen (2007, p. 17).

Discoverers exercise their creativity through findings and are motivated by the need to understand and find explanations for phenomena that are not well understood. This is where scientists come in. Creators exercise their creativity through invention and are motivated by the need to synthesize what they know into new constructions, compositions, concepts, etc., that provide tangible and fresh expressions of what can be. The complementarity between science and design becomes even more evident in Figure 2, which shows a division of the domains of the creative model based on the intersection between two axes that accommodate all disciplines within it. The vertical axis represents the symbolic/real dimension according to the content or scope of activity of the disciplinary field, and the horizontal axis comprises the analytical/synthetic component that classifies fields according to the way they work.

In contrast to these positions, the author considers that, where scientists examine facts to discover patterns and perspectives, designers invent new patterns and concepts to address facts and possibilities. In a world with growing problems that desperately need understanding and insight, there is also a great need for ideas that can combine that understanding and insight into creative solutions.

For their part, authors such as Oxman (2016) propose the Krebs Cycle of Creativity (Figure 3) with the aim of representing the anti-disciplinary hypothesis: that knowledge can no longer be attributed to or produced within disciplinary boundaries, but is completely entangled. The goal is to establish a tentative but holistic map of the interrelationship between these domains, where one realm can incite (r)evolution within another, and where a single individual or project can reside in multiple domains. For the most part, it is an invitation to question and modify what is being proposed.

The proposed mapping once again places science and design at opposite ends of the spectrum: science linked to information and knowledge based on perception and nature, and design associated with behavior and utility, anchored in production and culture, reinforcing their complementary nature.

In Figure 4, Owen (2007) points out that behind any discipline, there is a system of objectives, values, and measures that define the construction and assessment of knowledge within it. In the case of science and design, their criteria are marked with the colors yellow and pink, respectively.

However, considering these criteria as the only ones is a limited view, since there is not necessarily always consensus on these forms of validation, and they depend greatly on the branches into which the discipline is divided. Therefore, in this case, they would merely frame the starting point for some of the aspirations and validations of the disciplines.

Regarding the science-design pairing, Owen (2007) considers that both are valuable, but together they provide the best balance between skeptical inquiry and imaginative application.

#### BIODESIGN AS A NEW FORM OF KNOWLEDGE PRODUCTION

In this work, biodesign is understood as a field that integrates design with scientific, technological, and creative knowledge, such as biology, engineering, art, and architecture, to promote joint creation and research. This convergence represents a new way of producing knowledge by combining different modes of thinking and poses challenges for disciplinary adaptation, especially in traditional scientific contexts. At the University of Los Andes, where collaboration with various disciplines and communities is a central part of the curriculum, these proposals are particularly beneficial. Biodesign practices are based on design thinking, defined by Owen (2007) as an inventive, visual, collaborative, and optimistic methodology that combines systemic vision and communication skills. When interacting with other ways of thinking, new ways of validating and producing knowledge emerge, which vary according to the objectives and contexts of each project, reflecting both the emerging nature of biodesign and its potential to generate diverse and innovative approaches.

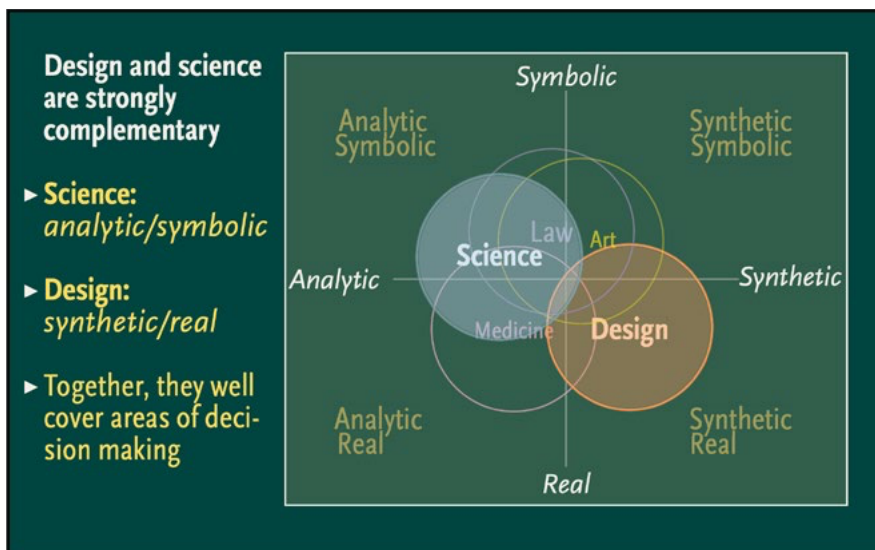


FIGURE 2. Design and science are complementary. Reproduced from Owen (2007, p. 18).

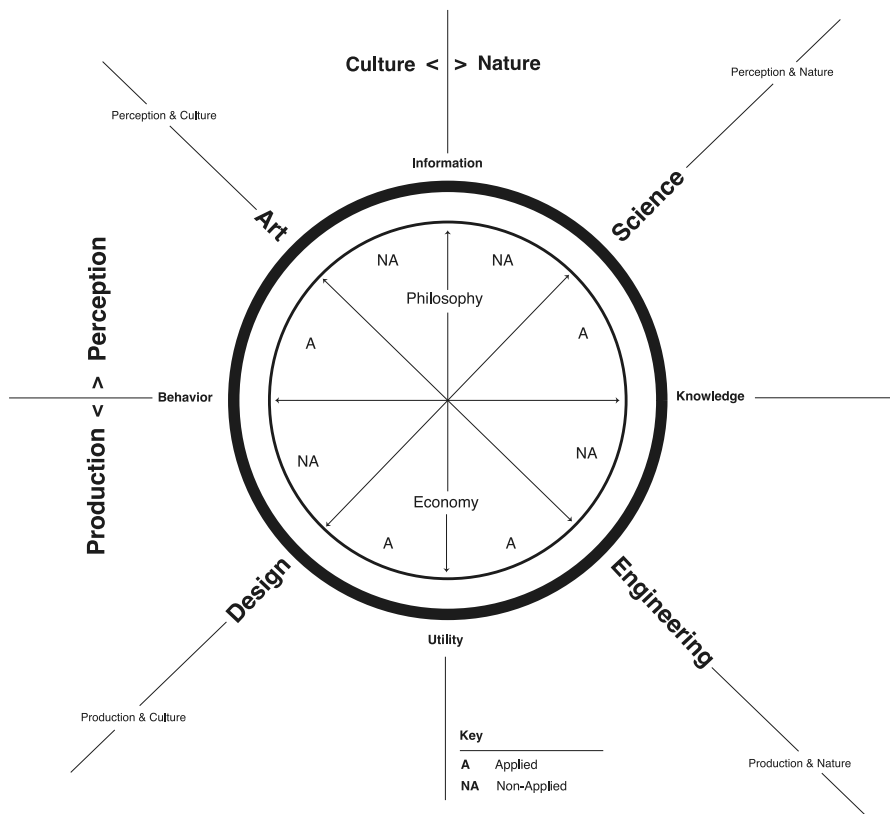


FIGURE 3. The Krebs cycle of creativity. Reproduced from Oxman (2007).

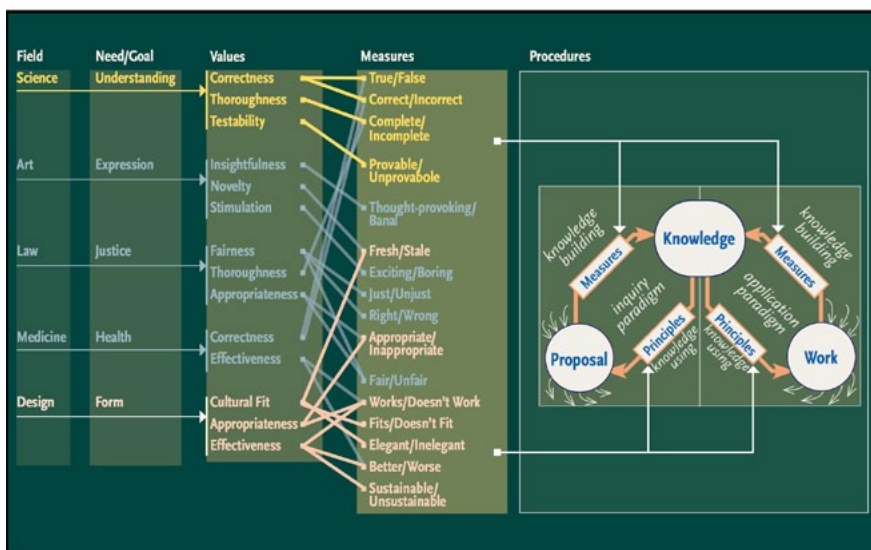


FIGURE 4. Foundations: perspectives and values for science, art, law, medicine, and design. Reproduced from Owen (2007, p. 21).

#### COLLABORATIVE PURPOSES

The study of collaborative purposes in biodesign allows us to understand how knowledge is constructed and validated at the intersection between design and science. According to Bénony and Maudet (2020), complementing Driver et al. (2011), these collaborations can be aimed at supporting the commercialization of new technologies, guiding the direction of research, or communicating science (Figure 5); for this research, we will address the first two purposes. In the biodesign classes at the University of Los Andes, interdisciplinary dynamics with transdisciplinary aspirations predominate, although the equitable integration of academic and non-academic actors remains a challenge. Previous studies show similar tensions, such as the difficulties in translating biological knowledge into design (Kennedy et al., 2015), and the evolution of the roles between scientists and designers toward functions of mediation, mutual learning, ethical provocation, and guidance (Bénony & Maudet, 2020).

In this study, based on interviews with biology and design students and professors, the roles that each discipline assumes according to the stage of the project were identified. In the discovery phase, the designer was invited and the biologist acted as a guide; in the definition phase, the biologist acted as an influencer and the designer as an “elastic mind”; in the development phase, the designer was an apprentice and the biologist a supervisor; and in the delivery phase, the designer became a solitary creator and the biologist was excluded. In summary, both disciplines advanced experimentally from their own approaches, although significant differences were evident in their interaction and validation of knowledge (Table 1).

Based on the information gathered previously and an initial approach based on personal experience with biodesign class projects, the following hypotheses on transdisciplinary collaborations are proposed (Table 2).

Beyond refuting or confirming hypotheses, the cases analyzed demonstrate the ways in which these paradigms operate and the differences with respect to the frameworks of thought that govern each discipline.

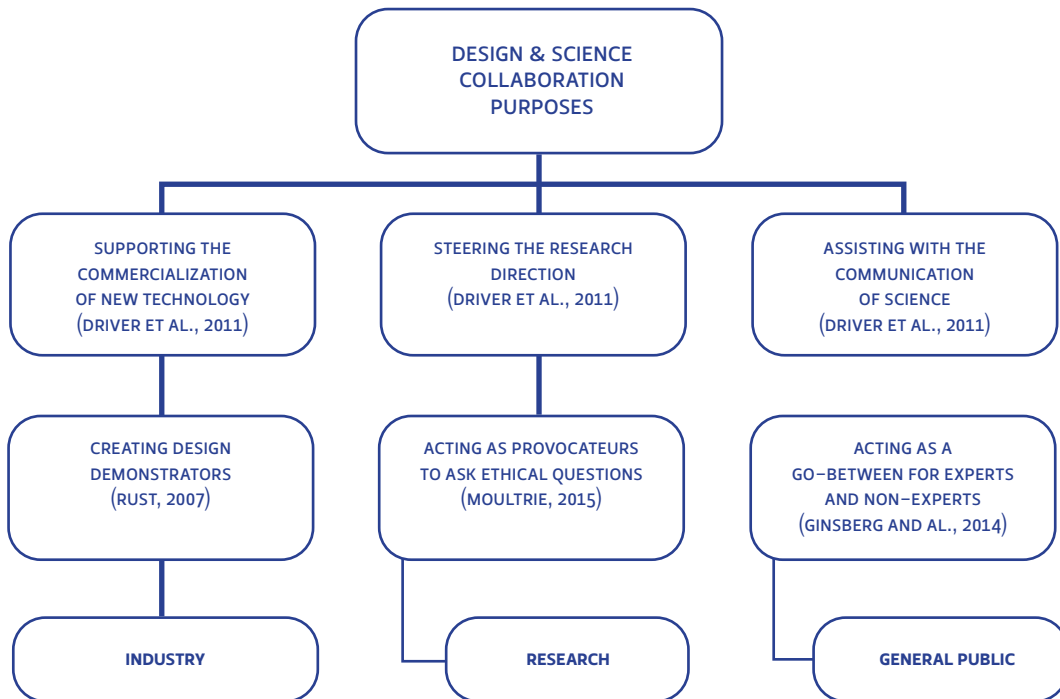


FIGURE 5. Collaboration objectives between design and science. Adapted from Bénony and Maudet (2020, p. 559).

**TABLE 1. TRENDS ASSIGNED TO BIOLOGISTS AND DESIGNERS IN INTERDISCIPLINARY WORK BASED ON THE CASE STUDIES REPORTED IN BÉNONY AND MAUDET (2020)**

SCIENTIST	DESIGNER
They care about how things are.	They worry about how things should be.
Science explores the unobservable.	Explore the observable.
They produce new knowledge.	Create new experiences.
They lead the project content.	They lead the process.
They find their place through interest (they translate the concerns of wnon-scientists into their own terms).	They generally take the lead in organizing the project's schedule and activities.
	They treat biology as a material for design, rather than as a scientific field or discipline in its own right.

**TABLE 2. HYPOTHESES ON TRANSDISCIPLINARY COLLABORATIONS. ADAPTED FROM BÉNONY AND MAUDET (2020)**

SCIENTIST	DESIGNER
Designers tend to view science (in this case, biology and microbiology) as an input for design rather than as a discipline with which to collaborate. Science is used as a means to an end.	One of the main challenges when carrying out transdisciplinary work is ensuring the equitable participation of all members throughout the project.
Throughout the project, biologists become the bridges between ideas and reality.	Tools such as prototypes, maps, and field journals, among others, act as boundary objects and significantly mediate contributions between designers and biologists. They can help improve communication and promote more equitable participation throughout the process.
Collaboration between biologists and designers is generally approached through challenge/project-based learning methodology in teams.	Designers are usually the ones who take the lead in organizing the project process and who make the most use of the tools proposed in this process due to their familiarity with them.
Biologists generally feel more comfortable and participate more in the research and prototyping stages of a project. Designers tend to exclude biologists from the communication stage and feel more comfortable in the problem definition and ideation stage.	The creation of meaning and validation of the biodesign process is negotiated according to the collaborative purpose and the stage of the project.
Including the stage of biologizing the problem in the problem-based biodesign methodology can encourage greater participation by biologists by incorporating scientific techniques and tools.	The roles of the biologist and the designer change substantially depending on the methodology used to approach the biodesign project (problem-based, solution-based, nature-inspired, etc.) and the stages within it (although they vary depending on the class, they are generally: explore, interpret, ideate, test, evaluate, and communicate) (Figures 13 to 15).
Biodesign competitions and entrepreneurship are practices that promote successful collaborations between designers and biologists/microbiologists.	

#### INNOVATION AS A COLLABORATIVE PURPOSE

At this point, it is necessary to identify the values that underpin biodesign and guide the construction and evaluation of knowledge, following a logic similar to that proposed by Owen in Figure 4. This analysis seeks to establish a common objective that articulates the various areas that make up biodesign, recognizing innovation as a core value of the field and understood not only as the introduction of new ideas, but also as maintaining, applying, and generating transformations from them. Understanding biodesign from this value allows us to approach it in a more comprehensive way, considering the multiple dimensions necessary for innovation to be effective and sustainable.

#### MODELS AND TOOLS FOR WORKING TOGETHER

##### BORDER OBJECTS

The concept of border objects is key to facilitating collaboration between disciplines with different languages and methods, such as design and science. According to Vålk et al. (2019), these objects are flexible enough to adapt to the needs of each actor, but stable enough to maintain a common identity that enables the translation and transfer of knowledge. In multidisciplinary contexts, diagrams, models, or prototypes function as means to represent, learn, and transform knowledge, generating shared meaning. Heinemann et al. (2011) point out that material objects in innovation workshops expand collective cognition and foster creativity by building mutual understanding in a situated way. In the studies by Vålk et al. (2019), designers took on exploratory roles, using frontier objects to materialize ideas, while scientists contributed specialized knowledge; prolonged work on the same object improved the quality of the proposals, highlighting its generative, exploratory, and recording functions. Although the resulting learning is ambiguous, situated, and contextual, it is essential for interdisciplinary innovation. Thus, applying this concept to the design of transdisciplinary tools allows for the creation of meeting points, the negotiation of meanings, and the construction of collective knowledge.

THE DIMENSIONS OF INNOVATION FOR UNDERSTANDING BIODESIGN CASES  
According to Arocena and Sutz (2003), the relationships among science, technology, and innovation have entered a stage of

greater interdependence, where innovation is understood as a social process that both induces and requires change. They add that: “social innovations became intertwined with technical and productive innovations: companies grew... and the set of ideas that could be put into practice increased for that reason” (Arocena and Sutz, 2003, p. 80). Within this framework, Chanal et al. (2011) propose three key dimensions for analyzing innovation: market, technology, and social appropriation, which must interact continuously to achieve sustainable processes. These three dimensions originate in disciplines related to these principles (Figure 6) and, ideally, should constantly interact with each other for an innovation to be successful and sustainable.

Understanding biodesign projects from these dimensions allows us to identify necessary adjustments to achieve successful innovation that, among other things, successfully transitions from academia to the real world. The relationships between the dimensions can be represented by a triple helix system (Figure 7), where each dimension permeates and transforms the others, symbolizing the growth and evolution of the innovation process. Each dimension responds to different types of innovation depending on the type of novelty, where it occurs, who has control over it, and who supports it. As Pinch and Bijker (2008) point out, innovation has historically been understood as a novelty that, mediated by discovery, arises from science and technology, although other simultaneous forms are now recognized. Figures 8 to 10 summarize some of the most important characteristics of each type of innovation, and Figure 11 incorporates the concept of open innovation, which arises when the three dimensions operate in a balanced and dynamic manner. This paradigm, described by Chesbrough (2003) and cited by Miralles et al. (2012), combines internal and external ideas to create value through flexible business models, while Miralles et al. (2012) highlight its emphasis on collaborative knowledge management through networks, intellectual property, entrepreneurship, and R&D. Open innovation promotes cooperation, transparency, and mutual learning, although it poses challenges in terms of knowledge integration, results evaluation, and knowledge rights. Even so, it constitutes a desirable horizon that offers adaptive and collective conditions with respect to the current challenges of knowledge production.

#### Dimensions of Innovation

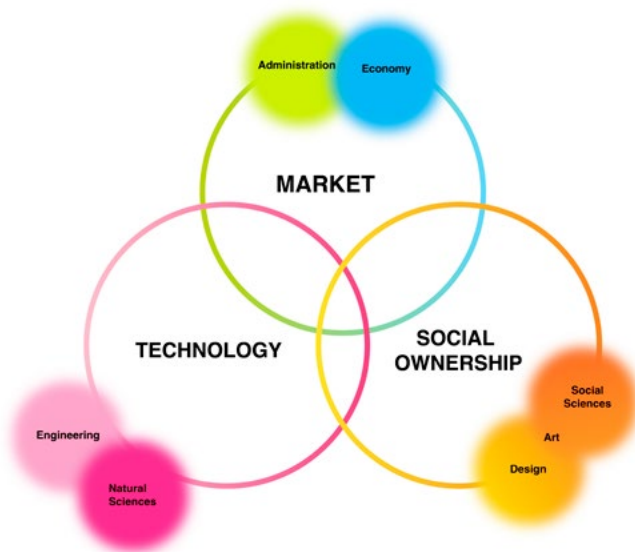


FIGURE 6. Dimensions of innovation. Adapted from Chanal et al. (2011).



### 1. Social Innovation: guided by behavior and uses (culture)

- It is mediated by participatory action-research methodology and the co-creation among different actors including governments, companies, non-profit organizations, and communities.
- It occurs and is measured through its impact on communities.
- Although it does not yet have strong institutional support, it is mainly backed by NGOs, grassroots groups, international cooperation organizations, and entities such as Prosperidad Social.
- It involves transdisciplinary collaborations.

### 2. Business Innovation: guided by success in the market

- It occurs through the market (supply and demand).
- It does not control the preferences or evaluations of innovation.
- It incorporates characteristics of technological and social innovation.
- It is supported, among others, by funding from STARTUPS.
- It is mediated by R&D and I+D+i in order to create new knowledge and apply it effectively in the market. It requires collaboration among different disciplines and actors.

### 3. Technological Innovation: guided by science

- It occurs in laboratories.
- Control is total regarding the accreditation and use of knowledge.
- Generally relies on internal resources.
- Protection of intellectual property.
- It is regulated by institutions such as Colciencias, MINTIC, universities, international entities, innovation centers, among others.
- It is mediated by the discovery or invention process.
- Applied research in universities and knowledge centers.
- Its importance is recognized for economic progress and productivity improvement.



FIGURE 7. Dimensions of innovation and open innovation. adapted from chanal et al. (2011), including concepts described by arocena and sutz (2003).

BIODESIGN CASES IN CLASSES AND TOOL EVALUATION

Three classes from the biodesign program were analyzed as case studies; the information for each was summarized in a table (Figure 12). The three cases are: 1) Nature-inspired design, focused on applying biological principles to sustainable solutions; 2) Biomoda, aimed at developing biomaterials for the textile industry; and 3) Designing biological systems, which integrate design and microbiology to create devices based on microorganisms. The analysis sought to understand how students relate to learning and interdisciplinary collaboration tools, evaluating their usefulness and articulation with the dimensions of innovation. In case 1, students valued two tools, including the prototyping workshop for its ability to generate ideas, promote collective learning, and facilitate transdisciplinary interaction, acting as a boundary object without requiring full consensus (Figure 13). In case 2, scientific tools such as characterization plans and annotated bibliographies were perceived by designers as unintuitive (Figure 14), highlighting the need to adjust them to the project's objectives. Finally, in case 3, it was observed that different tools can perform similar functions with varying levels of effectiveness, underscoring the importance of their selection and adaptation to the collaborative context (Figure 15).

## Diseñando sistemas biológicos / Biología sintética: diseñando el futuro

(nombre de la clase para la Facultad de Arquitectura y Diseño)

(nombre de la clase para la Facultad de Ciencias)

**Tipos de clase** Electiva  
**Tiempo** 8 semanas

**Profesoras**  
Darcy Rincón (Departamento de Diseño)  
María Francisca Villegas (Departamento de Ciencias Biológicas)

**Dirigido a**  
Estudiantes de Diseño y Ciencias Biológicas (biología y microbiología)

**Descripción de la clase**

En un mundo en constante evolución, donde surgen retos y necesidades tanto humanitarias como ambientales, se reconoce la urgencia de crear oportunidades revolucionarias. La biología sintética permite diseñar organismos o construir "fábricas vivas" para que estos produzcan o realicen funciones o procesos deseados en la industria. En este curso exploraremos, la construcción creativa utilizando componentes biológicos, en una sinergia única entre creación y ciencia. Se busca que los estudiantes desarrollen la capacidad de identificar y proponer alternativas innovadoras en desafíos locales con aplicaciones globales al combinar estrategia y biología sintética en diferentes contextos industriales, abordando así de forma crítica los retos y posibles impactos de llevar la biología sintética más allá del laboratorio.

**Metodología**

Aprendizaje por medio de proyectos y prácticas de laboratorio. Estas últimas diseñadas para introducir y afianzar el conocimiento de biología sintética.

Etapas del pensamiento de diseño:

- Identificar
- Crear
- Validar
- Presentar

**Ajustes de validación**

Para que la clase pueda ser validada como electiva para los programas de ciencias biológicas tiene que cumplir requisitos como:

- Utilizar un contexto industrial
- Hacer uso de microorganismos

"Algoa ciencias biológicas está haciendo un proceso de transformación. Pasaron de tener un páramo súper cuadrado a ser más abiertos, entonces, se están metiendo al tema de innovación con emprendimiento. También crearon unas electivas por enfoque y cada una tiene un color, si no estoy mal, los blancos son los de industria"

Darcy Rincón

**¿Cómo se evalúa la clase? (Principales criterios)**

- Trabajo en grupo (roles y liderazgo, actitud, uso del tiempo)
- Comprensión de conceptos básicos de biología sintética
- Contexto empresarial e interacción de diseño
- Explicación de la metodología empleada a lo largo del proceso de diseño, desde la formulación de insights hasta el proceso de prototipado
- Presentación de información en diagramas que demuestren el uso de herramientas de diseño de forma clara y precisa
- Justificación selección de insights
- Informes de práctica
- Da solución al menos parcial a la problemática identificada a partir de la funcionalidad del circuito y la experiencia de usuario

### Caso: Microbio

Estudiantes:

- Mónica Mares (Microbiología y Física)
- Valeria Castel (Diseño)
- Juan Pineda Nilo (Microbiología e Ingeniería Biomédica)
- Sofía Castellanos (Diseño)

Microbio aborda una posibilidad de innovación en el área de tratamiento de residuos de la Universidad de los Andes, problematizando la segregación de residuos orgánicos y ordinarios y cuestionando distintas soluciones desde la microbiología. Mediante el diseño estratégico, plantean alianzas colaborativas entre agentes de escalas micro (microorganismos) y macro (seres humanos), promoviendo así nuevas respuestas para la cultura ambiental en los espacios de diseño primario de residuos de la universidad. La propuesta atiende específicamente a la oportunidad de cómo producir residuos en los procesos de separación primaria del manejo de residuos desde la microbiología? La propuesta final, plantea la intervención de botas de basura mediante tapas "vivas", una forma de hiperdimensionar el contenido microbiológico dentro del contenedor para impulsar dinámicas de cuidado entre sistemas micro y usuarios de separación primaria. Con dispositivos diseñados para la biodegradación y expresión enzimática, se propuso la creación de color sistemas vivos a través de la separación de residuos orgánicos, botas de basura cuya tapas están hechas para ser vivas, reconocidas y nutridas con los residuos de la alimentación propia.



FIGURE 8. Technical details of the class Designing biological systems/Synthetic biology: designing the future. Prepared by the author based on the class syllabus.

## Valoración de herramientas

Nombre de la herramienta:

Taller de Prototipado: Makenspace

¿Qué hice con esta herramienta? ¿Para qué me sirvió?

En el taller llevamos los hallazgos de la ecografía de la planta (cáscara mano, medio y micro) y buscamos materiales y herramientas para replicarlos. Usamos los materiales para imitar la movilidad, propiedades y dimensiones de la planta para entender su comportamiento y describir la planta.  
Fue sirvió para comenzar a delimitar el principio activo y buscar las propiedades más relevantes que queríamos estudiar y aplicar en otros contextos.

Describe en 3 palabras su relación con la herramienta en la clase. Piense en los atributos y defectos que consideró de la herramienta cuando la usó

- Experimentación
- Aplicación (de los hallazgos a un contexto tangible)
- Versatilidad (posibilidad de explorar según cada proyecto)

¿Cuál es su fuente?

1. Hallazgos propios de la ecografía de la planta
2. Referencias de fuentes relacionadas con la planta
3. Información de profesores y monitores sobre construcción de prototipos

En escala de 1-10 ¿qué tanto me sirvió esta herramienta en la clase?



En función de la metodología de la clase ¿en cuál de estas categorías clasificaría esta herramienta? Encierrela en un círculo. (puede elegir varias)

Comunicación Categorización **Probar/testear algo** **Explorar las posibilidades** Síntesis

Comprensión/Entendimiento **Construcción de conceptos** Tomar decisiones Otra:

En función de la innovación ¿en cuál de estas categorías clasificaría esta herramienta? Encierrela en un círculo. (puede elegir varias)

Favorece la generación de nuevas ideas que contemplan diversidad de enfoques y perspectivas **Aprendizaje colectivo** **Flexibilidad/adaptabilidad** Colaboración transdisciplinaria

Beneficio colectivo Otra:



FIGURE 9. Maria's tool evaluation matrix 1. Created by Maria using her own template.

## Valoración de herramientas

Nombre de la herramienta: Bibliografía Anotada

¿Qué hice con esta herramienta? ¿Para qué me sirvió?

Con esta herramienta investigo y recopilo información que considero que es relevante para realizar el proyecto. A medida que avanza el proceso buscamos información que me distingan en el momento, pero nunca dejamos la de la bibliografía anotada. Algunas fuentes nos sirven para tener proyectos como referentes en metodología, pero no llegan a ser la referencia o utilidad de la herramienta.

Describe en 3 palabras su relación con la herramienta en la clase. Piense en los atributos y defectos que consideró de la herramienta cuando la usó

- No relevante
- Investigación
- Recopilar info

¿Cuál es su fuente? Clase

En escala de 1-10 ¿qué tanto me sirvió esta herramienta en la clase?



En función de la metodología de la clase ¿en cuál de estas categorías clasificaría esta herramienta? Encierrela en un círculo. (puede elegir varias)

Comunicación Categorización **Probar/testear algo** Explorar las posibilidades Síntesis

Comprensión/Entendimiento **Construcción de conceptos** Tomar decisiones Otra: **Investigación**

En función de la innovación ¿en cuál de estas categorías clasificaría esta herramienta? Encierrela en un círculo. (puede elegir varias)

**Favorece la generación de nuevas ideas que contemplan diversidad de enfoques y perspectivas** Aprendizaje colectivo Flexibilidad/adaptabilidad Colaboración transdisciplinaria

Beneficio colectivo Otra:



FIGURE 10. Sara's tool evaluation matrix 2. Created by Sara using her own template.

## Valoración de herramientas

Nombre de la herramienta:

Pirámide

¿Qué hice con esta herramienta? ¿Para qué me sirvió?

**Me sirvió para descubrir cuál era la problemática y por que era importante.**

Describe en 3 palabras su relación con la herramienta en la clase. Piense en los atributos y defectos que consideró de la herramienta cuando la usó

- Útil
- Compleja
- Estética

¿Cuál es su fuente?

**Hacia parte de los recursos de la clase**

En escala de 1-10 ¿qué tanto me sirvió esta herramienta en la clase?



En función de la metodología de la clase ¿en cuál de estas categorías clasificaría esta herramienta? Encierrela en un círculo. (puede elegir varias)

Comunicación **Categorización** **Probar/testear algo** **Explorar las posibilidades** Síntesis

**Comprensión/Entendimiento** Construcción de conceptos Tomar decisiones Otra:

En función de la innovación ¿en cuál de estas categorías clasificaría esta herramienta? Encierrela en un círculo. (puede elegir varias)

**Favorece la generación de nuevas ideas que contemplan diversidad de enfoques y perspectivas** **Aprendizaje colectivo** Flexibilidad/adaptabilidad **Colaboración transdisciplinaria**

Beneficio colectivo Otra:



FIGURE 11. Juana's tool evaluation matrix 2. Prepared by Juana using her own template.

#### CATEGORÍAS DE POTENTIAL PARADIGMS

The conditions and dilemmas that influenced the success or failure of interdisciplinary collaborations in the cases studied were termed paradigms, in reference to the concept proposed by Kuhn in *The Structure of Scientific Revolutions* (1962). Although not all of them can be considered definitive paradigms of biodesign at this point, they mark the starting point for possible paradigms.

They were categorized as follows: participants (students, teachers, and advisors).

1. Experience
2. Discipline of origin
3. Stereotypes and invalidation
4. Group trajectory
5. Teaching and learning dynamics
6. Moment of connection

Conditions of the discipline

7. Scientific validation
8. Differences in purposes and starting points
9. Dealing with uncertainty

Conditions of the class

10. Tools and exercises
11. Challenging monodisciplinary logic
12. Learning from scratch
13. Negotiated meaning
14. Translations of meaning
15. Vote of confidence
16. Learning imbalance
17. Disparity between disciplines
18. Time

#### METHODOLOGY FOR OUTLINING THE MODEL APPLIED TO THE CASES STUDIED

The information gathered from the class program and student testimonials made it possible to identify the paradigms described, as well as the moments, tools, and stages of the project in which participants felt more or less comfortable, and those phases that presented the greatest difficulties in terms of progress and teamwork. These findings were represented using a spiral model (Figures 16 to 18) to analyze the project's development in relation to the three dimensions of innovation. Symbols indicating paradigms were used for interpretation:



favorable.



unfavorable or difficult moments during the project.



inconclusive.

In addition, an emotional journey was integrated with emojis to represent the emotions of the participants, and each student's name was placed in the spiral corresponding to their discipline of origin.

Although the innovation model considers the analysis of cases from three dimensions (market, technology, and social appropriation), the academic nature of the projects limited the possibility of exploring them in a balanced manner. Therefore, this exercise should be understood as a starting point for identifying the degree of development of each dimension and guiding future research.

#### PROTOTYPES

The identified paradigms, together with emotions, testimonies, and interactions, constitute an analytical tool for understanding transdisciplinary collaborations in biodesign. Based on these inputs, socialization sessions were held with teachers (Figures 19 to 21) in which cases constructed based on student accounts were presented in order to reflect on and identify opportunities for improvement that would strengthen specific aspects of interdisciplinary collaboration. The main results obtained in these sessions are described below.

#### CLASSIFICATION OF THE RESULTS

The analysis of the three cases allowed us to identify common lessons learned and specific challenges in transdisciplinary collaborations in biodesign (Table 3). In case 1, the need to strengthen the market dimension and the application context was highlighted, incorporating real industry references, the circular economy to connect biological exploration with sustainable scenarios, and methodological adjustments that favor group cohesion and experimentation. In case 2, methodological and language tensions arose between design and science, especially when demanding scientific justification behind aesthetic or material decisions. These were addressed through changes in the course structure, such as the fragmentation of the fashion system and the use of the problem tree to improve methodological clarity aimed at improving methodological clarity and critical appropriation of knowledge.

In case 3, the main challenge was scientific validation: students had difficulty understanding and applying rigorous scientific processes, which led to the proposal of intermediate exercises that balance theory and practice, promoting a more active role for designers concerning scientific knowledge. Across the board, the three cases highlighted the importance of extending experiences beyond the classroom to strengthen the continuity, scalability, and impact of collaborations.



FIGURE 12. Teacher 1 and guest assistant in the class during the prototyping session, interacting with the socialization tool. Own elaboration.

Diseño inspirado en la naturaleza		
<p><b>Etapa 1: seleccionar</b></p> <p>Objetivos/Propósitos</p> <ul style="list-style-type: none"> <li>- Sensibilizar a los estudiantes</li> <li>- Despertar interés y curiosidad</li> <li>- Alinear a los estudiantes a la naturaleza.</li> </ul> <p>Herramientas/Ejercicios</p> <ul style="list-style-type: none"> <li>- Salidas de campo</li> <li>- Exploración sensorial</li> <li>- Dibujo botánico</li> <li>- Universos estéticos</li> <li>- Investigación de segunda mano</li> </ul> <p>Indicadores de éxito</p> <ul style="list-style-type: none"> <li>- Actitud de los estudiantes</li> <li>- Comentarios y emoción a lo largo de esta etapa</li> </ul>	<p><b>Etapa 2: ecografía</b></p> <p>Objetivos/Propósitos</p> <ul style="list-style-type: none"> <li>- Profundizar en una especie mentora</li> <li>- "Ser expertos" en la especie mentora</li> <li>- Cuestionar la investigación</li> </ul> <p>Herramientas/Ejercicios</p> <ul style="list-style-type: none"> <li>- Aproximación geométrica</li> <li>- Experiencia en laboratorio con microscopía</li> <li>- Revisión bibliográfica</li> <li>- Identificación de principio activo</li> </ul> <p>Indicadores de éxito</p> <ul style="list-style-type: none"> <li>- Profundidad de la investigación</li> <li>- Apropiación del conocimiento de la especie mentora.</li> </ul>	<p><b>Etapa 3: protodiseño</b></p> <p>Objetivos/Propósitos</p> <ul style="list-style-type: none"> <li>- Explorar el principio activo</li> <li>- Definir aplicación y contexto</li> </ul> <p>Herramientas/Ejercicios</p> <ul style="list-style-type: none"> <li>- Sesiones de prototipado individual y grupal</li> <li>- Taller de estructura</li> <li>- Taller de movimiento</li> <li>- Prototipado digital</li> </ul> <p>Indicadores de éxito</p> <ul style="list-style-type: none"> <li>- Prototipos de mayor resolución y contextos acotados.</li> </ul>



FIGURE 13. Matrix of objectives, tools, and indicators of success for Teacher 1. Own elaboration.



FIGURE 14. Matrix of paradigms and ideation of teacher 3. Own elaboration.

TABLE 3: SUMMARY OF CASE COMPARISONS.

Case / Subject	Disciplines involved	Participating	Type of collaboration	Tools and methodologies	Level of innovation	Key findings	Conditions and dilemmas that influenced the success or failure of the collaboration
<b>CASE 1.</b> Design inspired by nature – GreenGuajira	Design, biology, microbiology, and biomedical engineering.	Teachers of architecture, biomedical engineering, design, and science; students of design and biomedical engineering.	Interdisciplinary collaboration with the intention of migrating to transdisciplinarity.	Observation of nature and direct contact with biological systems. Selection of a mentor species. Identification of a relevant active principle. Development of experimental models for simulation and understanding. Formulation of design proposals with potential for application in a specific context and need.	It covers the technological and social appropriation dimensions of innovation, although the latter is not explored in great depth. The market dimension is not explored.	Product: a kit of spheres designed to counteract salinity and nourish the soil, which could be used to transform arid land into fertile soil. Through their proposal, the team sought to promote small-scale agriculture so that families in the department of La Guajira could access food grown in their homes. Through their proposal, the team sought to promote small-scale agriculture so that families in the department of La Guajira could have access to food grown in their own homes.	Conditions for participants (students, teachers, and advisors) Group trajectory Teaching and learning dynamics Moment of the discipline Differences in purposes and starting points Dealing with uncertainty Conditions of the class Negotiated meaning Vote of confidence Learning imbalance Time.

\*The numbering in the last column corresponds to the paradigm named in the section “Categories of potential paradigms”.

TABLE 3: SUMMARY OF CASE COMPARISONS.

Case / Subject	Disciplines involved	Participating	Type of collaboration	Tools and methodologies	Level of innovation	Key findings	Conditions and dilemmas that influenced the success or failure of the collaboration
<b>CASE 2.</b> Biomoda – Penumbra	Microbiology and design.	Design and microbiology teachers; design students.	Limited interdisciplinary work.	Laboratory practices focused on exploring materials. Technical experimentation with materials and processes applicable to the fashion system. Practical design exercises to integrate the knowledge acquired. Development of proposals aimed at responding to the needs of the fashion ecosystem.	It focuses primarily on the dimension of social appropriation, with a great effort to justify the technological dimension, and does not explore the market dimension.	Product: biomaterial made from gelatin, water, eggshell powder, graphite, and glycerin. It arises from the problems caused by the mass production of traditional buttons, zippers, and Velcro, which are usually made from polluting materials such as PET plastic, resins, nylon, and acrylic. Learning: Theoretical and practical knowledge to explore new ways of creating fashion through a proposal that solves an identified challenge.	Conditions for participants (students, teachers, and advisors) Group trajectory Conditions of the discipline Scientific validation Differences in purposes and starting points Class conditions Tools and exercises Learning from scratch Translations of meaning Disparity between disciplines.
<b>CASE 3.</b> Biological systems – Microbe	Design, microbiology, and biology.	Teachers and students of biological sciences and design.	Interdisciplinary collaboration with initial approaches to transdisciplinarity.	Progressive approach to the study context. Theoretical classes focused on understanding the fundamentals of synthetic biology. Guided experimentation in the laboratory. Use of design tools to prototype and communicate results. Integration of scientific concepts into innovative proposals focused on local challenges (Figure 12).	It moves along a very even path in terms of technology and the social adoption of innovation. It does not explore the market dimension.	Product: Intervention in university trash cans using "living" lids to produce microbiological assistance in the primary separation processes of waste management, promoting care dynamics between micro systems and the users responsible for primary separation. Learning: Introduction to scientific processes and basic understanding of biological systems to apply them in a design proposal based on the identified problem(s).	Conditions of participants (students, teachers, and advisors) Experience Teaching and learning dynamics Moment of connection Conditions of the discipline Differences in purposes and starting points Conditions of the class Tools and exercises Challenging monodisciplinary logic Learning from scratch Negotiated meaning Translations of meaning Vote of confidence Learning imbalance Disparity between disciplines Time

\*The numbering in the last column corresponds to the paradigm named in the section "Categories of potential paradigms".

## CONCLUSIONS AND PROSPECTS

This study analyzed transdisciplinary collaborations in biodesign from the three dimensions of innovation (market, technology, and social appropriation), developing tools to collect and analyze the experiences of students and teachers. The paradigms identified allowed for reflection on pedagogical practices that strengthen collaboration, highlighting the role of language, alliances, connection with the context of application, and the link between academia and industry. The dimensions model was validated with teachers as a frontier object that facilitates communication and interdisciplinary learning, although it requires iterations and greater articulation with existing programs and methodologies. More than a prescriptive guide, the methodology promotes critical reflection on the values of biodesign and its contributions to innovation.

The study was limited to three courses and a single institution, which restricts the generalizability of the results. The sample prioritized successful experiences and students with high academic continuity, excluding perspectives that could complicate the analysis. Future studies should incorporate failed projects, students who dropped out, and teams with no connection to the author, in order to identify tensions, obstacles, and structural barriers to transdisciplinary collaboration.

Furthermore, although the approach was transdisciplinary, the analysis focused on internal academic disciplines and did not include external actors or knowledge, which are fundamental to a broad conception of transdisciplinarity. Including communities, citizen laboratories, industry, artistic collectives, non-academic experts, and local knowledge would allow for an analysis of the negotiation of epistemic and ethical boundaries in biodesign.

These considerations have curricular implications: biodesign requires pedagogical structures that recognize its hybrid nature, with spaces for interdisciplinary encounters, mechanisms for conceptual translation, time for experimentation, evaluation criteria that are sensitive to methodological diversity, and sustained links with external actors, strengthening the coherence of courses and their alignment with the innovation ecosystem.

Finally, avenues for future research are opened up: applying the methodology to other courses and institutions; creating repositories of good practices and frontier objects; exploring the role of emerging technologies (generative AI, advanced biofabrication, accessible biological analysis tools); and incorporating external actors to understand how transdisciplinarity redefines the relationships between universities, society, and innovation ecosystems. Taken together, the study provides a conceptual and methodological framework for analyzing transdisciplinary collaborations in biodesign and their contribution to debates on innovation, sustainability, and scientific-creative training. Far from closing the discussion, the research invites further exploration of new lines of research on training in transdisciplinary contexts.

## ETHICAL CONSIDERATIONS

The study was conducted in accordance with ethical principles of informed consent, confidentiality, transparency, and risk minimization. Although initial consent from teachers and students was obtained as part of a degree project, the evolution of the project into an academic publication has required obtaining additional specific consent for dissemination in a journal, informing them about the nature of the publication, the materials included, and their right to approve, modify, or withdraw their participation. In the absence of authorization, photographs, descriptions, contextual data, or fragments that allow direct or indirect identification will be removed.

Since the study uses information from real classes (course names and photographs with teachers), there is a potential risk of identification. To mitigate this, pseudonymization was used (fictitious names and generic designations such as teacher 1, 2, 3), personal references were avoided, and images were carefully reviewed. Photographs will only be included with written authorization; otherwise, they will be replaced by diagrams, anonymized versions, or textual descriptions.

The data will not be used for academic evaluation, nor will it be shared with teaching teams responsible for grading students, ensuring the separation between pedagogical and research roles, and minimizing risk to participants.

A minor conflict of interest is acknowledged, given the researcher's prior knowledge of some participants, which could have influenced case selection or interpretation of results. To manage this, predefined selection criteria, transparency in the declaration of roles, and anonymization processes were adopted. In future research, it is recommended that data collection be carried out by an independent third party or that impartiality protocols be strengthened.

Finally, intellectual property considerations were respected: prototypes, deliverables, and visual or textual materials produced by students and teachers will only be used with explicit authorization, respecting the moral and economic rights of their authors.

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DESIGNER WITH A MINOR IN BIOLOGY INTERESTED IN BIODESIGN, SOCIAL INNOVATION PROCESS DESIGN, CO-CREATION METHODOLOGIES, AND SCIENTIFIC DISSEMINATION. FOCUSED ON WORKING WITH COMMUNITIES, PEDAGOGY, RESEARCH, AND FIELDWORK. EXPERIENCED IN THE DESIGN AND MANAGEMENT OF EDUCATIONAL RESOURCES AND PLAYFUL STRATEGIES FOR TEACHING BIOMIMICRY TO CHILDREN AND BIODESIGN, AS WELL AS IN THE APPROPRIATION OF INNOVATIVE EDUCATIONAL TOOLS.

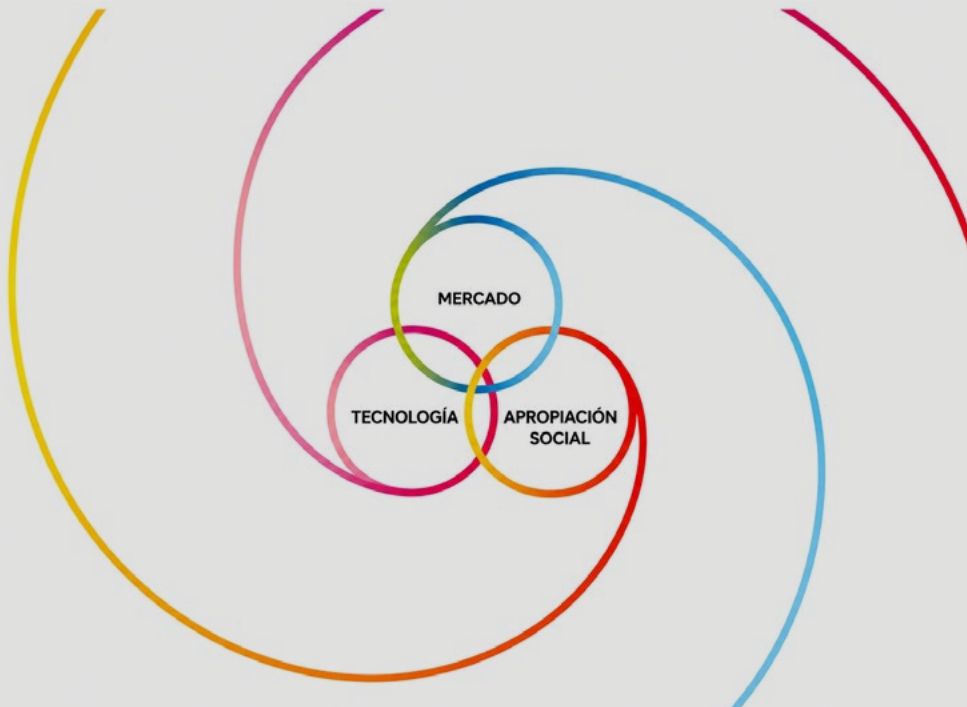


FIGURE 7. Innovation dimensions in a triple helix system. Adapted from Chanal et al. (2011).



- Ocurre en el laboratorio.
- Control total respecto a la acreditación y uso del conocimiento.
- Recursos internos generalmente.
- Protección de la propiedad intelectual.
- La regulan instituciones como colciencias, MINTIC, universidades, entidades internacionales, centros de innovación, entre otras.
- Está mediada por el descubrimiento o invención.
- Investigación aplicada en universidades y centros de conocimiento.
- Se reconoce la importancia de esta para el progreso y crecimiento económico y la mejora de la productividad.



FIGURE 8. Technology-centered innovation: science as a guide. Adapted from Chanal et al. (2011), including concepts described by Arocena and Sutz (2003).



- Está mediada por la metodología de investigación-acción participativa y la co-creación entre diversos actores que incluyen gobiernos, empresas, organizaciones sin fines de lucro y comunidades.

- Ocurre y se mide a través de su impacto en las comunidades.

- Aún no tiene tanto equipamiento institucional, la respaldan sobretodo ONG, grupos de base, organismos de cooperación internacional y entidades como Prosperidad Social.

- Involucra colaboraciones transdisciplinarias.



FIGURE 9. Business- and enterprise-centered innovation: market success as a guide. Adapted from Chanal et al. (2011), including concepts described by Arocena and Sutz (2003).

- Ocurre a través del mercado (oferta y demanda).
- No controla las preferencias o valoraciones de la innovación.
- Incorpora características de la innovación tecnológica y social.
- La respaldan, entre otros, financiadores de STARTUPS.
- Mediado por el I+D y el I+D+I con el fin de crear nuevos conocimientos y aplicarlos de manera efectiva en el mercado. Requiere de la colaboración de diversas disciplinas y actores.

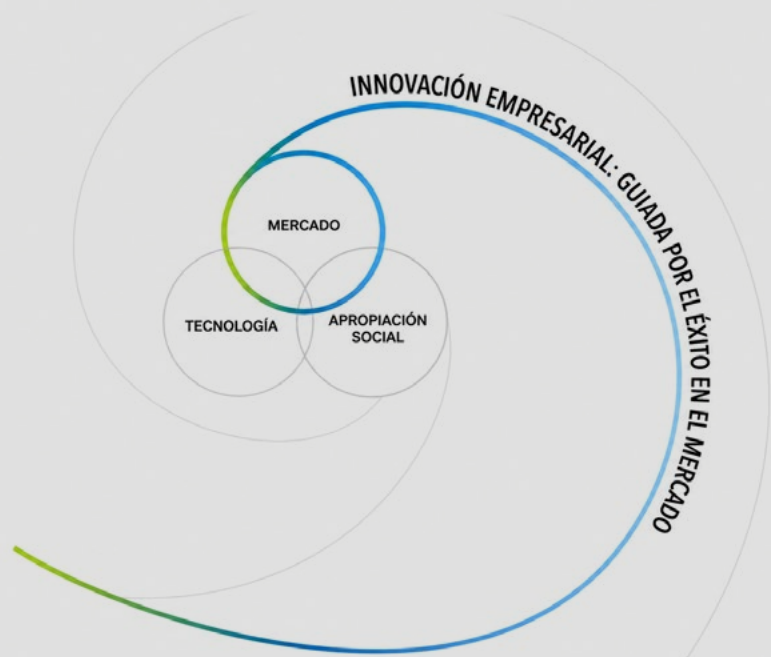
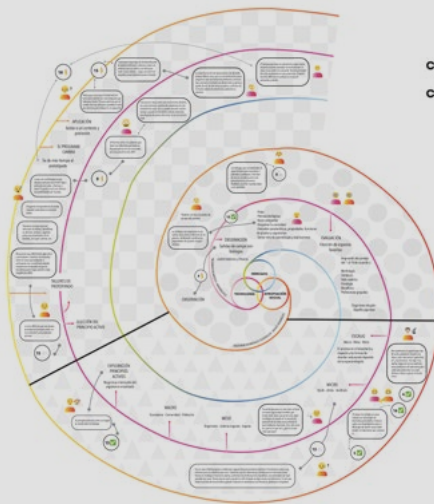


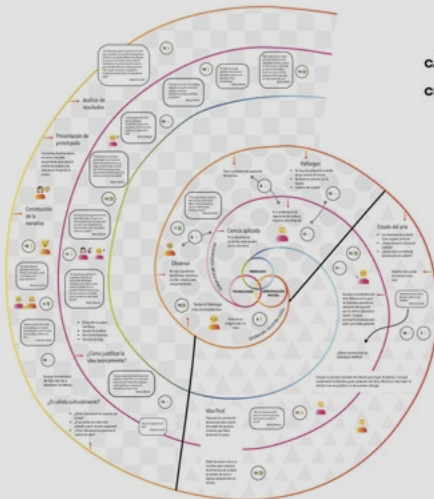
FIGURE 10. Human-centered innovation: behavior and social appropriation as a guide. Adapted from Chanal et al. (2011), including concepts described by Arocena and Sutz (2003).



**CASO DE ESTUDIO: PROYECTO GREENQUAJIRA**  
**CLASE: DISEÑO INSPIRADO EN LA NATURALEZA**



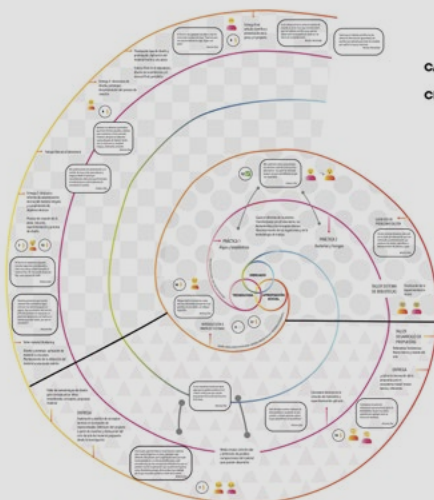
*FIGURE 16. Innovation model with the Greenquajira project from the nature-inspired design class. Created by the author based on testimonials from students who carried out the project.*



**CASO DE ESTUDIO: PROYECTO MICROBIO**  
**CLASE: SISTEMAS BIOLÓGICOS**



*FIGURE 17. Innovation model with the Microbio project from the Biological Systems class. Created by the author based on testimonials from students who carried out the project.*



**CASO DE ESTUDIO: PROYECTO PENUMBRA**  
**CLASE: BIODISEÑO**



*FIGURE 18. Innovation model with the Penumbra project from the Biomoda class. Created by the author based on testimonials from students who carried out the project.*

