LOGO

How to teach interspecies design? Formal education in biodesign

Como ensinar design interespécies? O ensino formal em biodesign

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ABSTRACT

The community of biodesign (interspecies design collaborations) seems to be heading toward solid self-organization and formalization. Some authors speculate that the approximation to biology could mark the design practice of the 21st century. It seems relevant to understand how teaching and learning are happening in biodesign to develop how it could be further introduced in design curricula. It doesn't seem that an analysis of formal education was made yet. To address this research gap, this paper aims to understand the formal education scene in biodesign through an analysis of some of the main biodesign courses and programs. The methodological strategy is a systematic and a narrative review through a popular search engine. 16 results were analyzed: 1 Masterclass for Professionals, 8 courses, 1 undergraduate course (Major), 4 master's, and 2 Ph.D. programs.

KEYWORDS

Biodesign; Interspecies Design; Formal Education

RESUMO

A comunidade de biodesign (colaborações interespécies em design) parece estar caminhando para uma sólida auto-organização e formalização. Alguns autores especulam que a aproximação com a biologia poderia marcar a prática do design do século 21. Parece relevante entender como o ensino e a aprendizagem acontecem no biodesign para desenvolver como poderiam ser melhor introduzidos nos currículos de design. Parece que ainda não foi feita uma análise da educação formal em biodesign. Para atender a esta lacuna de pesquisa, este trabalho visa compreender o cenário da educação formal em biodesign através de uma análise de alguns dos principais cursos e programas. A estratégia metodológica é uma revisão sistemática e narrativa por meio de um buscador popular. Foram analisados 16 resultados: 1 masterclass para

PALAVRAS-CHAVE

Biodesign; Design Interespécies; Educação Formal

1 INTRODUCTION

The community of biodesign seems to be heading toward solid self-organization and formalization. The consistency of specific competitions suggests that biodesign is not an ephemeral trend: like the "Bio Art & Design Award" (BAD, 2021), since 2011, and the "Biodesign Challenge" itself, since 2016. The subject also features events, like the annual Biofabricate summits (BIOFABRICATE, 2021), the "Design with the Living" annual Symposium (DESIGN MUSEUM, 2020), and "Still Alive" (STILL ALIVE, 2020). These events bring together researchers from around the world.

The term biodesign has many interpretations, in this paper, Dade-Robertson's definition is the reference: "[...] design and design research which use living systems as part of their production and operation" (2021, series introduction note) – in other words, biodesign implies in interspecies design collaborations. Examples of the biodesign practice include works with different species, from bacteria to animals. For instance, the company Fullgrown shapes living trees into furniture through horticultural techniques (FULLGROWN, 2021); Modern Synthesis weaves bacteria into shoes (MODERN SYNTHESIS, 2020); the Blast Studio develops 3D printed mycelium modules to compose objects such as lamps and columns (BLAST STUDIO, 2020); The Reef Design Lab develops 3D printed calcium carbonate structures to be collaboratively fulfilled with corals (REEF DESIGN LAB, 2021). Some of these examples are illustrated in Figure 1.

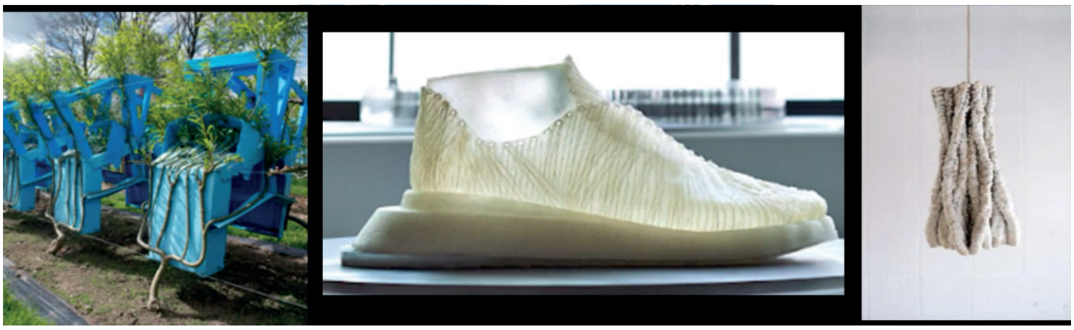

Figure 1 - Biodesign examples.

Source: From left to right: Fullgrown's chair production (MATERIAL DISTRICT, 2018). Modern Synthesis' microbial woven shoe (MODERN SYNTHESIS, 2020) and Blast Studio's 3D printed mycelium lamp shade (BLAST STUDIO, 2020)

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Some authors speculate that the approximation to biology could mark the design practice of the 21st century: "Building with bacteria and other organisms is simultaneously becoming a technological possibility and a necessity" (MYERS, 2018, p.16). Collet writes that "the beginning of the twenty-first century marks a strong shift towards the amalgamation of the binary code (1s and 0s) with biological systems" (2020, p.1). She sees a shift in the role of design "from working with inanimate matter such as plastic and metals to making with animate living entities such as mycelium, yeast, and bacteria" (COLLET, 2020, p.1).

Designing with the living is reportedly different from what designers are used to. Antonelli writes that "It goes without saying that when the materials are not plastics, wood, ceramics, or glass, but rather living beings or living tissues, the implications of every project reach far beyond the form/function equation and any idea of comfort, modernity or progress" (2018, p.7). Dade-Robertson says that "You can't master life in the way a painter masters oils or a joiner masters wood" (2021a, p. 95). To Collet (2020), growing would now be part of the design process, which impacts form, structure, aesthetics, and material specification. The creating and controlling, she argues, brings to light new competencies to the designer besides the traditional methods they would be used to. Camere and Karana (2018) refer to these new skills and competencies as the "new designerly sensibilities".

It seems relevant to understand how teaching and learning are happening in biodesign to develop how it could be further introduced in design curricula. It doesn't seem that an analysis of formal education was made yet. To address this research gap, this paper aims to understand the traditional education scene in biodesign through an analysis of some of the main biodesign courses and programs. In the following sections, the methodological strategy for finding and analyzing the courses and programs is presented; following the results and discussion; finally, conclusions are drawn with recommendations for future studies.

One last consideration to be acknowledged before beginning is that this research intention still lies in an anthropocentric perspective of science because it still thinks in means to operationalize collaboration with living organisms in terms of a useful resource. But the hope is that it leads to a respectful conscience and way of treating living organisms, and towards a more ecocentric attitude of design (MELKOZERNOV; SORENSEN, 2020). This is also why the term collaboration is used to describe the relationship of the designer with other living organisms.

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1.1 Teaching and Learning Biodesign

Prof. Dr. Anke Pasold, Associate Professor at Copenhagen-based Material Design Lab, makes a literature review on "Advanced Growing Materials", and draws an overview of the teaching and learning scenario for biodesign (PASOLD, 2020).

According to her: "designing with living matter is, by its very nature, designing with complex, open systems" (PASOLD, 2020, p. 135) – hence, learning approaches from systems design seems a logical connection to be made. Pasold (2020) cites Chen and Crilly's 2016 "Describing complex design practices with a crossdomain framework: learning from Synthetic Biology and Swarm Robotics" to list the established characteristics of complexity that designers will have to work with: (1) the system's unpredictability, (2) context dependency, (3) noise, (4) emergence, (5) stochasticity, (6) non-linearity, (7) crosstalk, (8) open systems, (9) overlapping hierarchies, (10) incomplete understanding, and (11) possible multiple characterizations.

To tackle complex systems designers would have to (1) map the systems correlations and find out patterns that might be interesting for the design process; and try to find (2) boundaries, to define a design space – understanding, for instance, how the material behaves biologically – and sometimes this can be only achieved through experimentation (PASOLD, 2020). Pasold (2020) cites Chen and Crilly's once again to explain the two approaches that establish "a sense of control to effectively design within the network of parameters at hand" (PASOLD, 2020, p.138). These would be (a) Rational design approaches and (b) Black box design approaches (PASOLD, 2020). Rational design approaches include (a1) the reduction to a number of conditions to be explored individually to establish patterns; (a2) the learning through designing and making experimentation as part of the whole design process; and (a3) the integration of multiple characterizations from different sources (from different disciplines) (PASOLD, 2020). In addition, Black box design approaches aim at making things more concrete – one strategy would be to clearly define requirements (PASOLD, 2020). These principles seem to align with educational contexts to "prevent students from stranding in the pool of sheer endless possibilities" (PASOLD, 2020, p.138). Continuing to cite Chen and Crilly's work, Pasold (2020) explains that: "the most important conclusion from the working with complexity, however, is the recorded manifestation that only by working and therefore designing with the system, at whatever level of complexity or isolation, will we gain a better

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understanding of the very same" (PASOLD, 2020, pp. 139-140). This would be aligned with the more hands-on approaches to design with. Finally, simulation would be an important resource to tackle complex, open systems (PASOLD, 2020).

The author explains that part of the strategy used in education in design with living materials is the use of very hands-on – experimental and experiential approaches - and do-it-yourself open resources (2020). Formal input "in form of lectures and tutorials is not excluded from the syllabus and is seen as a way of building a base level of understanding, subject placement, general introduction and introduction of the respective other [...]" (PASOLD, 2022 p. 141). To gain an in-depth understanding of the material consumes a good part of the projects and is considered an indispensable foundation (PASOLD, 2020). Pasold (2020) summarizes the general design phases in designing with living materials: (1) a first phase of understanding the material, for defining aesthetics and understanding time; a (2) second phase for experimentation in a goal-oriented manner; a (3) third phase to close the ends of what needs further elaboration and a (4) fourth phase to create the outcome (PASOLD, 2020). Educational biodesign practices usually combine lab and studio activities. Process documentation is detailed and illustrated, often in the form of a project journal, or a design catalog (PASOLD, 2020). The continuous inclusion of interdisciplinary expert assistance and feedback is common to all phases (PASOLD, 2020).

To enable design with living materials, Pasold writes that "It has been established that there is an inherent need for cross-disciplinary knowledge, communication and engagement [...]" (2020, p.147). Enabling design with living materials would concern: (1) new ways of thinking, which refer to a (1.1) new mindset and a (1.2) new role; and (2) new ways of working, which comprise the dimensions of (2.1) frame, (2.2) collaborative learning, (2.3) communication, and (2.4) coordination (PASOLD, 2020).

Concerning the (1.1) new mindset, it would be "the basis for learning and effectively working and creating within this new frame" (PASOLD, 2020, p.148). It relates to an understanding of the interdisciplinary, open, complex nature of the projects. This mindset includes appreciating to enter "a new way of designing; material first, product synchronously after" (PASOLD, 2020, p.148), which deals with time issues, lack of control, experimentation, working with professionals from other disciplines, learning new language and vocabulary (PASOLD 2020). With this different mindset, designers would assume a (1.2) new role, really connected to the "making" of the material, a co-creation with the other organism, different

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from the one from the "learned fashion" (PASOLD, 2020, p.149).

Regarding the (2.1) frame: there would be a higher demand for what would be a "proper setup" (PASOLD, 2020, p.149). The setup would refer to physical spaces for designing, such as labs and resources, and the establishment and facilitation of expert network(s), like advisors, and/or open-source materials (PASOLD, 2020). About (2.2) collaborative learning: "part of the systemic didactic approach is that complex and new knowledge is learnt in collaboration and co-teaching sessions that enable peer review as well as external analysis and criticism" (PASOLD, 2020, pp.149-150). Expert feedbacks also help the project to develop faster, and more effectively, and might be useful to validate results (PASOLD, 2020). Pasold gives some ideas on how to facilitate collaborative learning: cross-disciplinary project setups, exchange periods, and the integration of teaching staff from other disciplines (PASOLD, 2020). In this context of collaboration, an appropriate glossary is crucial for (2.3) communication. An agreement on terms and definitions would be an interesting proposition (PASOLD 2020). Finally, (2.4) coordination, which would refer to checking in and following along a plan (PASOLD, 2020).

2 Methodological

The systematic review is adapted from Conforto, Amaral, and Silva's (2011) roadmap. The selected search engine is Google, using the search strings: "biodesign" AND "course"; "biodesign" AND "master's" OR "Ph.D." OR "graduation"; "biodesign" AND "program" OR "programme".

The filter application follows an open reading strategy, exclusion criteria are:

(1) courses/programs that are not provided by universities

(2) courses/programs in which the scope are not designers

(3) term disambiguation – when the term biodesign is not related to design and only related to medical and health sciences. When it refers only to biomimicry, not to biodesign as described by Dade-Robertson (2021);

To prevent some biases, such as search strings, a narrative review was also necessary (FERRARI, 2015) and references found in the literature were added.

e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
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In the analysis process, available data were organized into three categories when the information was available: (1) Title, University, Course Load; (2) Infrastructure; (3) Course overview. The process involved reading each course material and summarizing it.

3 Results and Discussion

After the filter application, the systematic review retrieved 14 results. The Biostudio project summarized some of the opportunities to study biodesign (BIOSTUDIO, 2021) – through this reference, one more result was added. Finally, a paper was found about a biodesign course at the Faculty of Fine Arts and Design of the University of Economics of Izmir. The analysis comprised 1 Masterclass for Professionals, 8 courses, 1 undergraduate course (Major), 4 master's, and 2 Ph.D. programs. Table 1 presents information for each of these initiatives:

Table 1: Masterclasses, courses, undergraduate courses, masters and Ph.D. programs

1	**Title:** Biological Design (course) - University of Pennsylvania **Course load:** not informed **Infrastructure:** not informed **Course overview:** The course assumes the dynamics of a studio. According to Upenn (2023), it is a research-based course that "introduces new materials, fabrication, and prototyping techniques to develop a series of design proposals in response to the theme: Biological Design". Life sciences and biotechnologies are introduced to designers, artists, and non-specialists. (UPENN, 2023)

e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
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2	**Title: Biomaterials:** Designing with Living Systems (course) - Faculty of Fine Arts and Design of the University of Economics of Izmir **Course load:** not informed **Infrastructure:** not informed **Course overview:** [...] Pedagogical objectives are: "to reinforce basic design principles through a new media and to broaden the students' understanding of design as a cross-disciplinary problem-solving process" (PINTO; PUGLIESE, 2017, p.1). Activities of the course comprise: "observation, tinkering, playing, gathering, sketching, experimenting and predicting" (PINTO; PUGLIESE, 2017, p.2). Students work together on projects around a specified organism, like silkworms. The course is organized into two main modules: one theoretical and one "application unit". The theoretical module presents a case study analysis and introduces to the basics of "morphological, physiological, anatomic, behavioral, origin, and distributional, aspects of many biological actuators and in particular silkworms" (PINTO; PUGLIESE, 2017, p.4-5). In the applied module students developed their own projects around a design hypothesis and scenario simulation. Students were asked to make records of their progress and the development of the other organism in the project (PINTO; PUGLIESE, 2017).
3	Title: BioDesign Fundamentals course – The University of Sidney Course load: 6 credit points Infrastructure: not informed Course overview: According to the course description, it presents basic concepts of designing with science and reinforces the participant's own domain expertise, augmenting the participant's existing skills with new approaches to problem-solving. The unit introduces "prototyping for science and biology, evaluating ethical implications of designing with life, communicating scientific processes to justify biodesign choices" (THE UNIVERSITY OF SIDNEY, 2023), and shows the participant to support peers with their own expertise. Learning objectives are related to: ethical concerns; prototyping in a biodesign context; interdisciplinary thinking; developing the ability to explain scientific concepts "using abstracted models to a broad audience";

e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
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	supporting peers in the development of new skills; and "understand the theory, methods, and technology that underpin key approaches to biodesign" (THE UNIVERSITY OF SIDNEY, 2023).
4	**Title:** IDE Design Master Class for Professionals – Biodesign - TUDelft- **Course load:** 2 days, paid course **Infrastructure:** not informed **Course overview:** The course introduces the participants to the "world of living organisms, to fundamental biodesign theories, tools, and methods to understand and design with living organisms" (TUDELFT, 2023) – it is oriented to a "cleaner production and unique experiences in everyday products" (TUDELFT, 2023). Learning objectives concern: theory and principles of biodesign; "get a feeling for bio lab tools and machines, basic bio lab technical and research skills to grow, maintain, and observe living organisms"; hands-on experiences; and "gain competence in envisioning future applications for living materials" (TUDELFT, 2023).
5	**Title:** (1) Biodesign theory and practice: biodesign challenge part I (course) and (2) biodesign experimentation and prototyping: biodesign challenge part II (course) - University of California, Davis **Course load:** 3 hours (part I) +3 hours (part II) **Infrastructure:** not informed **Course overview:** These courses prepare the participants to take part in the Biodesign Challenge (BIODESIGN CHALLENGE, 2023). Students must enroll separately in each part. Part I gives the participants an overview of biodesign foundational principles, presenting biodesign examples in many segments. Later on, it develops participants' "team-based experience in biodesign intervention; first steps in a mini-entrepreneurial start-up experience" (UNIVERSITY OF CALIFORNIA, DAVIS, 2023). Part II is the continuation of the team's work, focusing on prototyping.

e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
DOI:10.26771/e-Revista.LOGO/2023.01

6	**Title:** The Biodesign Challenge (course) – University of Cincinnati **Course load:** not informed **Infrastructure:** not informed **Course overview:** The course aims to prepare students to participate in the Biodesign Challenge. Participants work in interdisciplinary teams, with advice from experts to solve a specific problem. Focus lies on ideation and prototyping (UNIVERSITY OF CINCINNATI, 2023).
7	**Title:** Aesthetic Crossovers of Art and Science and Art and Life Manipulation (courses) – The University of Western Australia **Course load:** not informed **Infrastructure:** not informed **Course overview:** There are two elective courses, the first one, called Aesthetic Crossovers of Art and Science, focuses on "A practical and theoretical investigation, through critical engagement of the nexus and differences of the art and science cultures through the use of the technologies of life science/biotechnology as an art-form" (UWA, 2022). The second course, called Art and Life Manipulation, aims at introducing biological lab "practices and techniques dealing with the manipulation of living biological systems within the context of contemporary arts practices" (UWA, 2022).
8	**Title:** Biological Design Major – The University of Sidney **Course load:** not informed **Infrastructure:** not informed **Course overview:** This program brings together design principles, along with biomedical science and engineering to create innovative solutions for human and planet health (THE UNIVERSITY OF SIDNEY, 2022). Students learn about ethical implications, prototyping for Science and biology, communicating scientific processes, and supporting peers with their own expertise. There are also interdisciplinary projects with industry partners including one aiming at the Biodesign Challenge (THE UNIVERSITY OF SIDNEY, 2022). The courses in the program are (some of them have an advanced version):

e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
DOI:10.26771/e-Revista.LOGO/2023.01

	- Animal behavior; BioDesign Fundamentals; BioDesign Studio; Biology of Insects; Biomedical Design and Technology; Biomedical Engineering 1B; Botany; Cell Biology; Co-Design and Participatory Approaches; Design Thinking; Design for Wellbeing; From Molecules to Ecosystems; Fundamentals of Human Anatomy; Fundamentals of Visual Design; Global Challenges: Food, Water; Human Biology; Industry and Community; Introduction to Interface Design; Key Concepts in Physiology; Life and Evolution; Principles of Design; Reproduction, Development, and Disease; Responsible Design for Innovation; Science Interdisciplinary Project; Systems Physiology; Terrestrial Plant Ecosystem Management; Zoology (THE UNIVERSITY OF SIDNEY, 2022).
9	**Title:** Master of Biological Arts – The University of Western Australia **Course load:** not informed **Course overview:** The program emphasizes on developing “critical thought, discussing ethical and cultural issues, and encouraging cross-disciplinary experimentation in art and science” (UWA, 2022). The target audience of the master’s is art practitioners, scientists, and humanities scholars who wish to engage with creative bioresearch. Students must take art and science credits – with a balance of disciplines (UWA, 2022).
10	**Title:** Master of Arts Biodesign - University of the Arts London **Course load:** 2 years, 30 hours per week (180 credits) **Infrastructure:** Grow-Lab (Containment Level 1 biology laboratory); Biologist in the teaching team; International network of the Design & Living Systems Lab; Knowledge exchange with industry partners. (UAL, 2022). **Course overview:** The curriculum is research-driven, with an emphasis on ethical concerns and learning by making – students develop a personal research agenda. Learning objectives concern: understanding critical context challenges for design in the 21st century “social, political, economic, ethical and sustainable issues” (UAL, 2022); bio-informed design strategies and whole system thinking; biomimicry principles in design; biological sciences and biofabrication tools and methods; sophisticated lab-based biodesign practice; “to explore and integrate biocomputation tools into design practice” (UAL, 2022, p.5); to develop biodesign portfolio of work.

e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
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	The program is divided into three units: (1) Seed; (2) Grow; (3) Harvest. The first unit forms the theoretical basis and students develop a series of small projects, it concludes with the submission of a biodesign portfolio [... and an] oral and visual presentation" (UAL, 2022, p. 8). The second unit focuses on a personal project to apply the different biodesign competencies. The third unit is dedicated to "creative production and communication of the final MA project" (UAL, 2022).
11	**Title:** Master of Architecture Bio-Integrated Design (Bio-ID) – University College London **Course load:** 2 years (300 credits) **Infrastructure:** BiotA Lab (Biotechnology and Architecture Lab). Taught jointly by UCL's "The Bartlett School of Architecture" and "Biochemical Engineering Department". **Course overview:** The course aims to "[...] integrate biotechnology, advanced computation, and fabrication to create a radically new and sustainable built environment" (UCL, 2022). Students work simultaneously in a scientific laboratory, in a design studio, and at a fabrication workshop. Participants engage in short projects in teams and also in a speculative design project (thesis). The final module aims at research career preparation. Course modules consist of: - Introduction to Scientific Methods, Laboratory and Environmental Practices; Computational Skills; Literature Review; Preliminary Design; Year 1 Design Project and Fabrication; Year 1 Thesis Report; Design Specialisation and Interdisciplinary Context; Comprehensive Project Thesis.
12	**Title: Biological** Design, MS – Arizona State University **Course load:** 30 credit hours and a thesis, or 30 credit hours including the required applied project course **Infrastructure:** not informed

e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
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	Course overview: The program emphasizes a continuum between technology and biology. Students have to "take one program core course (Principles of Biological Design), one course from a suite of biotechnology courses, and one from a suite of statistics courses" (ASU, 2022). In this program "students read literature; identify critical problems related to energy, environment, human health, sustainability, and security; and develop solutions to these problems using a synergy of technological and biological solutions, either in teams (course projects) or individually (thesis or applied project)" (ASU, 2022). Courses are: - Research Methods in Biological Design (mandatory); Topic: Six Sigma Methodology/Engineering Experimentation (statistics); Design Engineering Experiments (statistics); Regression Analysis (statistics); Mathematical Statistics (statistics); Topic: Bioenergy and Microbial Biotechnology (biotechnology); Topic: Cellular and System Modeling (biotechnology); Topic: Chimeras and Recombinant Organisms in Medicine (biotechnology); Advanced Environmental Biotechnology (biotechnology); Environmental Microbiology (biotechnology); Topic: Bio-inspired Design (biotechnology); Microbial Bioprocess Engineering (biotechnology); Topic: Nanobiotechnology (biotechnology); Topic: Synthetic Biology and Metabolic Engineering (biotechnology); Seminar; Applied Project; Thesis.
13	**Title:** Biological Design Ph.D. – Arizona State University **Course load:** 84 credit hours **Infrastructure:** not informed **Course overview:** "The program is a joint effort by the College of Liberal Arts and Sciences, The Biodesign Institute, and the Ira A. Fulton Schools of Engineering" (ASU, 2022). Besides the credits, a qualifying exam, a comprehensive exam/proposal prospectus, and a dissertation are required. There is a system of research rotations, where students rotate between laboratories in order to define a potential advisor and research topic. After the first year, students decide on one of the three labs for their Ph.D. studies. Besides the credits of specialized coursework, "there is a recommendation to include courses with components in bioethics and grant writing" (ASU, 2022). Some of the courses offered:

e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
DOI:10.26771/e-Revista.LOGO/2023.01

	-Biological Design II (required); Biological Design Proseminar; Biological Design Seminar; Research; Lab Rotations; Dissertation; Patterns in Nature; Materials Synthesis; Structure and Properties of Materials; Materials and Civilization; Sensing the World (ASU, 2022).
14	**Title:** Biological Arts and Ph.D. – The University of Western Australia **Course load:** not informed **Infrastructure:** not informed **Course overview:** Not informed, a general statement is given: "Emphasis is placed on developing critical thought, discussing ethical and cultural issues, and encouraging cross-disciplinary experimentation in art and science" (UWA, 2022).

Source: Authors.

It is important to note that biodesign education happens in other educational constellations, such as the "Cluster of Excellence Matters of Activity" (MoA, 2023) and the "Hub for Biotechnology in the Built Environment" (HBBE, 2023). The cluster and the hub gather funding around common projects – where Ph.D. students and other researchers develop their projects associated with these initiatives. The cluster even has a Ph.D. program, but it is not exclusive to biodesign projects.

Course load varies between institutions. For example, the Master's in Biological Design, from Arizona State University requires 30 credit hours and a thesis, while the Master of Architecture in Bio-Integrated Design (Bio-ID), from the University College London, requires the completion of 300 credits.

Infrastructure is not always informed, a highlight is the University of the Arts London, which offers a containment level 1 biology laboratory, a biologist in the teaching team, an international network, and knowledge exchange with industry partners. (UAL, 2022).

Regarding the course overview, five results emphasize (1) laboratory work or introductions (TUDELFT, 2023; UWA, 2022; UAL, 2022; UCL, 2022; ASU, 2022). A highlight of this approach is given by Arizona State University (ASU, 2022), where students rotate between laboratories to define a research interest and an advisor. (2) Ethical implications are a main topic in five of the results (THE UNIVERSITY OF SIDNEY, 2023; THE UNIVERSITY OF SIDNEY, 2022; UWA, 2022; ASU, 2022; UWA, 2022). (3) Project/studio structures are adopted by 7 of the initiatives (UPENN, 2023, PINTO; PUGLIESE, 2017; ASU, 2022; THE UNIVERSITY OF SIDNEY, 2022;

e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
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UNIVERSITY OF CINCINNATI, 2023; UNIVERSITY OF CALIFORNIA, DAVIS, 2023; ASU, 2022). (4) Interdisciplinary experience is promised by 6 of the results (THE UNIVERSITY OF SIDNEY, 2023; THE UNIVERSITY OF SIDNEY, 2022; UWA, 2022; UCL, 2022; ASU, 2022; UAL, 2022). (5) Prototyping is the focus of five of the courses/programs (UPENN, 2023; THE UNIVERSITY OF SIDNEY, 2023; UNIVERSITY OF CALIFORNIA, DAVIS, 2023; UNIVERSITY OF CINCINNATI, 2023; THE UNIVERSITY OF SIDNEY, 2022). (6) Market-driven/application-driven solutions are the goal of TUDelft (2023) and the University of California, Davis (2023). The University of Sidney (2023) and the University of the Arts London (UAL, 2022) emphasize on the ability of the students to (7) communicate their projects. Four of the initiatives were oriented or had activities oriented to the participation in the (8) Biodesign Challenge (2023) (UNIVERSITY OF CALIFORNIA, DAVIS, 2023; UNIVERSITY OF CINCINNATI, 2023; THE UNIVERSITY OF SIDNEY, 2022). The Biodesign Challenge is an international competition sponsored by companies like Google, Science Sand Box, Ginkgo Bioworks, and others. It introduces students to the intersections of biotechnology, art, and design. Universities and high schools may register, gaining access to pedagogical resources and a mentor network.

The study's findings converge with the overview provided by Pasold (2020), which also described laboratory and studio work, interdisciplinary experiences, experiential (hands-on) approaches, and the importance of communication in collaborative settings.

In the next section, the final considerations are outlined, along with the recommendations for future research.

4 FINAL CONSIDERATIONS

The biodesign community, which collaborates in interspecies designs, seems to be reaching a solid development. It seems relevant to understand how teaching and learning are happening in biodesign to develop how it could be further introduced in design curricula. It didn't seem that an analysis of formal biodesign education had been made yet. To address this research gap, this paper aimed to understand the formal education scene in biodesign through an analysis of some of the main biodesign courses and programs. The methodological strategy was a systematic and a narrative review through a popular search engine, Google. 16 results were analyzed: 1 Masterclass for Professionals, 8 courses, 1 undergraduate course (Major), 4 master's, and 2 Ph.D. programs.

It was found that biodesign education doesn`t happen only in

e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
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biodesign formal programs – but also happens in other constellations, like the "Cluster of Excellence Matters of Activity" and the "Hub for Biotechnology in the Built Environment". The course load varies greatly between institutions. Infrastructure and resources are not widely informed, but some initiatives state that they offer laboratories. Course overview highlights are: laboratory work or introductions; ethical implications; project/studio structures; interdisciplinary experience; prototyping; focus on market-driven/application-driven solutions; the development of the ability of the students to communicate their projects; and activities oriented to the participation in the Biodesign Challenge.

For future studies, it seems interesting to interview the teachers and professors in these institutions and to look into other educational constellations, such as Matters of Activity, the Hub for Biotechnology in the Built Environment, and others. Furthermore, courses and programs could look into complex design and systems design strategies to address biodesign, as suggested by Pasold (2020).

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e-Revista LOGO - v. 12, n.1, 2023 - ISSN 2238-2542
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