25TH INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
7-8 SEPTEMBER 2023, ELISAVA UNIVERSITY SCHOOL OF DESIGN AND ENGINEERING, BARCELONA, SPAIN

DESIGN AND ENGINEERING IN ACADEMIA: LEARNING FROM PRACTICE

Ana Filomena CURRALO[1,2], António CURADO[1,3], Leonel NUNES[3] and Sérgio Ivan LOPES[1,4]
[1]Instituto Politécnico de Viana do Castelo, Portugal
[2]ID+ Instituto de Investigação em Design, Media e Cultura, 3810-193 Aveiro, Portugal
[3]ProMetheus, Instituto Politécnico de Viana do Castelo, Portugal
[4]ADiT-LAB, Instituto Politécnico de Viana do Castelo, Portugal

ABSTRACT
Design is a creative and innovative process that takes advantage of engineering's technical knowledge to develop products, services, and benefits for a consumption-driven society. This article highlights the importance of a coordinated approach between design and engineering education as a driver for innovation. To validate this concept, we analyzed several use cases undertaken at a higher education institution that resulted in the systematization of the adopted methodology. Then, a case study, the RnHealth TECH project, has been used to validate the proposed methodology. This project, aims to design and develop new technologies and products, and create interactive materials to prevent and promote awareness regarding the risk of exposure to indoor radon gas, a radioactive gas that tends to accumulate in indoor environments with a known relation to lung cancer. In this context, design and engineering students are collaborating on the design and development of a set of Internet-of-Things (IoT) devices for Indoor Air Quality (IAQ) management and thus promote awareness-raising. Although engineering methodologies have tasks that overlap with the design process, with a focus on functionalities, they may face technical implementation constraints. Product design, on the other hand, must respond to user requirements, user interface, market needs, and product manufacturing requirements, with a focus on satisfying consumers. These two areas complement each other, resulting in a continuous improvement process of product design, particularly in the innovation process development. This multidisciplinary synergy between students and researchers works both ways, with each functional area contributing to the work according to its specificity and influencing the final product. This approach not only develops students' specific technical knowledge but also provides them with new skills that can be applied to improve their technological literacy.

Keywords: IoT, smart technologies, design, engineering

1 INTRODUCTION
Design is a process that involves creative thinking and innovation to develop new products and services that enhance people's lives and contribute to the society's well-being. To create successful products, designers rely on the technical knowledge and expertise of engineering. The collaboration between design and engineering helps designers understand the functional and technical aspects of their creations, allowing them to develop products and services that are both practical and visually appealing. By providing engineering's technical knowledge, designers ensure that their designs are reliable, safe and meet consumers' needs. As a result, designers must consider not only the functional and technical aspects of their designs, but also their impact on society and the environment.
This article proposes a methodology for integrating engineering practices into Design development for new products creation. The methodology is demonstrated through the implementation of projects within the Master in Integrated Design course at the Polytechnic Institute Viana do Castelo, Portugal. These projects showcase the benefits of interdisciplinary collaboration between design and engineering in product development [1-3]. As a result, the systematization of the adopted methodology has been presented with a case study, the RnHealth TECH project, which has been used to validate the proposed methodology. This RnHealth TECH project, aims to design new products, develop new technologies,

and create interactive materials, to promote awareness regarding the risk of exposure to indoor radon gas, a radioactive gas that tends to accumulate in indoor environments with a known relation to lung cancer. In this context, design and engineering students are collaborating on the design and development of a set of Internet-of-Things (IoT) devices for Indoor Air Quality (IAQ) management and thus promote awareness-raising. Design is a practice-based discipline that emphasizes design development, as well as areas such as design history, theory, and criticism [4]. However, designers often think and work primarily through visual means, making it challenging to articulate their ideas using more traditional forms of knowledge [5]. The use cases introduced in this article demonstrate the value of interdisciplinary collaboration in the creation of new products. The methodology used in the development of these use cases involves stages or cycles that consider the risks inherent in the design process, focusing on problem-solving and the needs of the end-user. This holistic approach emphasizes the importance of integrating engineering considerations into the design process. The results of these projects can be verified in the respective publications, where data and findings are presented in the form of tables.

2 DESIGN AND ENGINEERING IN ACADEMIA

Product and design development teams today require seamless collaboration between designers and engineers who possess multidisciplinary skills [6]. Such integration leads to innovative design and engineering methodologies and new synergies, broadening the scope of service delivery. The focus of product design and development has also evolved, with a greater emphasis on sustainable and socially responsible design that meets user needs, creating opportunities for designers to make a positive impact on global communities while advancing technologies that support sustainable development [7]. To succeed in this new paradigm, designers and engineers must adapt and embrace new responsibilities to ensure the successful realization of products. To be effective, they must possess new skills, including creative design abilities and a user-centered perspective. In recent years, there has been a convergence between design and engineering in academia, characterized by interdisciplinary and integrated approaches [8]. Some educational institutions have transformed the teaching of design and project engineering to encompass human, social, collaborative, and sustainable aspects [9, 10].

In academia, the integration of design and engineering has been a growing trend in recent years. Institutions like Finland's Aalto University, which is defined as a multidisciplinary community focused on engineering sciences, design, art, and economics, have embraced this approach [11]. Similarly, other universities have also started integrating design and engineering into their curricula. These institutions are shaping the future of design and engineering by creating knowledge through multidisciplinary courses that incorporate design concepts and methods throughout the program. For example, at Stanford University in the United States, the Masters of Science in Design program requires candidates to have a background in science or engineering [12]. The curriculum of this program encompasses three key areas: the Design Core, Methods Focus Area, and Domain Focus Area. This approach highlights the importance of cross-disciplinary education in the field of design and engineering. Polytechnic Institute Viana do Castelo (IPVC), Portugal, was established in 1985 in response to the demands of the labor market in the Alto-Minho region of northern Portugal. This institution serves as both a higher-level training center and a scientific and technological training center that trains qualified professionals in technology and management and the relevant sciences and techniques. During the academic year 2021/2022, 13 vacancies were opened for undergraduate students and 8 for master's students, with a total of 1900 students enrolled in degree courses and 315 students enrolled in master's courses. Of the courses offered at IPVC, eight belong to the field of engineering (including food engineering, civil and environmental engineering, graphics and multimedia computing, networks and computer systems, information technology, mechanics, and mechatronics), two to design courses (product and environment design), and the remaining courses belong to the areas of management and tourism. Although IPVC is recognized for its expertise in engineering, the design field is also growing, with around 60 students enrolled in the product design course and 40 in the environment design course in 2021/2022, and approximately 30 students enrolling annually in the master's course.

The increasing competition in consumer markets and growing recognition of the importance of design in the market have reinforced the belief that design success can only be achieved through the integration of both engineering and design skills [13]. The division between these distinct disciplines is eroding, particularly in the realm of product design and development, where designers and engineers work together to expand their range of services [14]. The convergence of design and engineering brings

together the human aspects and aesthetic-formal elements of design while emphasizing the technical skills of engineering and the human skills of design [15]. This integration gives rise to the concept of "creative engineering" or "creative engineering design," which envisions the "redesign of the engineering mind" through a creative process [16].
Despite the differing curricula between the fields of design and engineering, IPVC fosters collaboration between these two areas within the Master of Integrated Design students and research and development (R&D) activities carried out at existing reseach units in IPVC. These opportunities allow students to apply their knowledge through project-based learning, which is a more effective means of assessment compared to traditional problem-solving activities that do not result in a tangible outcome. Project-based learning is a crucial aspect of design education, as it instills the tools and techniques of design practice early in the curriculum and provides ample opportunities for skill, knowledge, and confidence development. Table 1 presents some examples of product design achieved through interdisciplinary pedagogy that integrates engineering science and design. To facilitate the convergence of these two distinct worlds - technical and creative - the application of tools and techniques to support the design process was emphasized from the outset, particularly those that promote the principles of sustainability in the current discourse on the future of humanity.

Table 1. Projects where an interdisciplinary pedagogy was used, integrating engineering and design

Project name and date	**Involved areas**	**Publications**
Design as an Enhancer in Stimulating Individuals with Dementia (2016)	- Product Design; - Computer Graphics and Multimedia Engineering; - Psychology.	- Master thesis project in Integrated Design
UX design in the mobile application of accessible routes to the city center of Viana do Castelo (2019)	- Communication design; - User Experience Design; - Computer Science and engineering.	- Master thesis project in Integrated Design. Published Articles: [17]
Design and Sustainability at Academia: the practical case of reducing the consumption of plastic bottles in the IPVC community (2021)	- Product Design and Communication; - Network and Computer Systems Engineering.	- Master's Project in Integrated Design; - Refill_H2O, an EEA Grants Portugal Environmental Project. Published Articles: [18-20]
Design applied to the development of IoT products for intelligent environments (ongoing)	- Product Design and Communication; - Network and Computer Systems Engineering.	- Master's Project in Integrated Design; - Part of RnHealth Project

The projects presented in Table 1 demonstrate the belief that project-based learning is a productive, collaborative and highly effective method for educating designers and engineers in the field of product design and development. As such, new innovations have emerged, such as Co-Creation and Design Thinking [21], which serve as methodologies for addressing the uncertainty inherent in the conceptual phase of any innovation project. These approaches have been widely recognized and documented in the literature [22, 23].

3 FOSTERING DESIGN AND ENGINNERING: A METHODOLOGY

We have previously analyzed several use cases undertaken at IPVC that resulted in the systematization of the adopted methodology. In this section, a case study, the RnHealth TECH project, will be used as an use case for the proposed methodology. The RnHealth TECH project, an initiative of IPVC, aims to prevent and promote health through innovative technologies by examining the presence of radon gas in buildings and evaluating its potential impact on pulmonary health in Alto Minho, Northern Portugal. To achieve this, a project was initiated to develop mobile devices for air monitoring. This resulted in the creation of four devices, including a radon gas analysis sensor, sensors for monitoring CO_2, temperature, relative humidity, and VOCs gases, an infrared camera for analyzing the number of people in a room, and a fan and a differential pressure sensor for mitigating negative air quality factors.
A multidisciplinary team of students and researchers from areas such as Civil Engineering, Biomedical, Electronics, Telecommunications and Informatics, and Arts and Design, collaborated to design and develop a new IoT-based product for IAQ management. The composition of the team was governed by

a multidisciplinarity of areas, as well as students aged between 22-28 years who are finishing their courses and have shown interest in participating in the project. The team was led by three senior researchers and included a student from the Master's in Integrated Design program and two Bachelor students of Networks and Computer Systems Engineering. In the initial phase, the team employed the Design Thinking approach, which utilizes design tools and methods to explore solutions and ideas and validate them through fast and iterative prototyping. This human-centered practice is recognized for its integrative thinking, exploration, and visualization.

The study is based on data, information, knowledge, and research to acquire design knowledge applied to product design. The analysis is based on a cross-methodology, as illustrated in Figure 1.

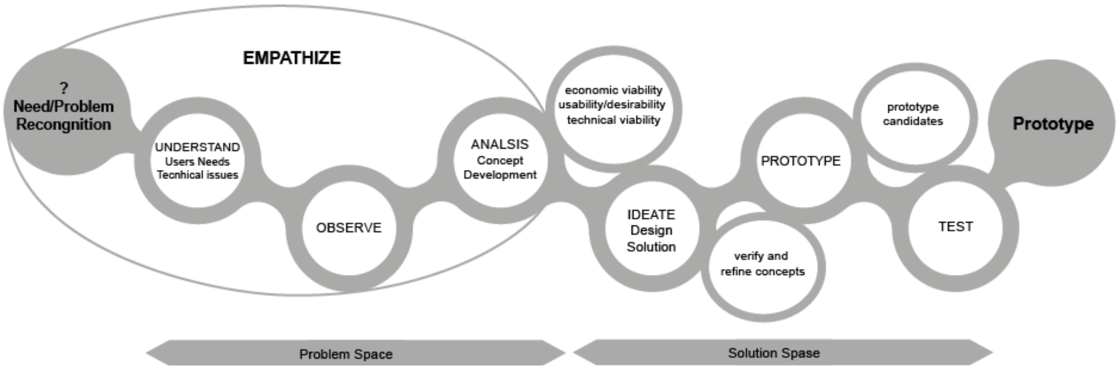

Figure 1. (adapted fromRattcliffe [24])

According to Rattcliffe [24], the Design Thinking process can be separated into two clear "spaces": the problem and solution spaces. From a cognitive point of view, it is a combined divergent and convergent process, where a set of alternatives is created, and only then are choices made based on the different options [21]. The problem spaces is considered an empathy phase. Empathy is the centerpiece of a human-centered design wich is a process of creating things deeply based on general natural characteristics and peculiarities of human psychology and perception. Empathize mode is the work done to understand people within the context of your design challenge. It is their effort to understand the way they do things and why, their physical and emotional needs, how they think about the world, and what is meaningful to them.

Observing users, behaviours, relevant contexts, and interviews are key aspects of this first phase. Perceiving people makes it possible to capture physical manifestations of their experiences - what they do and speak. This will allow you to infer the intangible meaning of these experiences to unlock insights. These insights guide you to create innovative solutions. The best solutions result from the best insights into human behavior. Direct involvement with people reveals a tremendous amount about the way they think and the values they defend [24]. The solution scape is the oriented phase, starting with Ideate, in which the team will delve into the existing problem and solutions, looking to understand the "big picture" and needs. Iteration is critical to good design. It iterates by cycling through the process several times or iterating within a step - for example, creating multiple prototypes or trying variations of brainstorming topics with multiple groups. In general, as you make multiple cycles through the design process, its scope narrows, and you move from working on the broad concept to subtle details, but the process still supports this development. For simplicity, the process is articulated here as a linear progression, but design challenges can be met using design modes in various orders. In addition, there are an unlimited number of design frameworks to work with.The phase evolves with a clear exposition and specific problem to be addressed within the scope of the challenge. This is followed by prototype and testing, where the team creates rapid, close prototypes of solutions to the needs they've discovered and then tests them with users to get feedback. Testing is another opportunity to understand the user, but unlike the initial empathy mode, now have more problem-framing and creating prototypes to test.

Several proposals are presented, a final solution is chosen, and, in the test phase, the selected solution is developed, including a working prototype. Thus, a learning experience based on challenges is proposed, in which learning is carried out through the identification, analysis and design of a solution to a sociotechnical problem [25]. The search for new ideas and innovative solutions to complex problems is inherently uncertain and has fewer specific results than improving existing solutions.

4 FINAL CONSIDERATIONS

In today's world, transdisciplinarity is of utmost importance to bring together competencies that are disseminated through disciplines that act alone. This research plays an important role to promote the interplay between Product Design, Electronics, and Materials Science to create insightful deliverables that may lead to the development of innovative product solutions. The Internet of Things (IoT) involves the integration of everyday objects with the vast network of data and information available on the internet, enabling their operation and functionality through a computer, smartphone, or other internet-connected devices. This world opens up new avenues for human-object and object-object interactions, as well as real-time monitoring of physical changes. Therefore, the methodology plays a crucial role in the entire project monitoring process, contributing to the identification and resolution of research questions that may arise during the design process and enriching the conclusions of the research.

The proposed methodology is, promoting not only the knowledge transfer and teaching of the Design process but also facilitating teamwork in the development of effective methodologies. Design creation prioritizes stages that focus on the user and their needs, as well as the final construction of the project, while engineers, with a more practical and results-oriented background, aim to solve problems, optimize results and efficiency, and construct prototypes with a focus on the planned design, adopting a different approach within the various phases. The investment in initial research is immediately advantageous as it defines the systematic framework for a project.

Funding: This work is a result of the project TECH - Technology, Environment, Creativity and Health, Norte-01-0145-FEDER-000043, supported by Norte Portugal Regional Operational Program (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF).

REFERENCES

[1] Cross N. *Designerly ways of knowing.* Design studies, 1982. 3(4): p. 221-227.
[2] Schön D. A. *The reflective practitioner: How professionals think in action*. 2017: Routledge.
[3] Lawson B. *21. How designers think*. 2005, Oxford: Architectural Press.
[4] Johansson-Sköldberg, U., J. Woodilla, and M. Çetinkaya, *Design thinking: past, present and possible futures.* Creativity and innovation management, 2013. 22(2): p. 121-146.
[5] Allen S. *Designs for learning: Studying science museum exhibits that do more than entertain.* Science education, 2004. 88(S1): p. S17-S33.
[6] Chandrasegaran S. K. et al. *The evolution, challenges, and future of knowledge representation in product design systems.* Computer-aided design, 2013. 45(2): p. 204-228.
[7] Howard T., Culley S. J. and Dekoninck E.. *Creativity in the engineering design process*. in *DS 42: Proceedings of ICED 2007, the 16th International Conference on Engineering Design, Paris, France, 28.-31.07. 2007*. 2007.
[8] Richter D. M. and Paretti M.C. *Identifying barriers to and outcomes of interdisciplinarity in the engineering classroom.* European Journal of Engineering Education, 2009. 34(1): p. 29-45.
[9] Yarime M. et al. *Establishing sustainability science in higher education institutions: towards an integration of academic development, institutionalization, and stakeholder collaborations.* Sustainability Science, 2012. 7: p. 101-113.
[10] Miller T. R., Muñoz-Erickson T. and Redman C. L. *Transforming knowledge for sustainability: towards adaptive academic institutions.* International Journal of Sustainability in Higher Education, 2011. 12(2): p. 177-192.
[11] Tavin K., Tervo J. and Löytönen T. *Developing a transdisciplinary university in Finland through arts-based practices.* Arts-based Methods and Organizational Learning: Higher Education Around the World, 2018: p. 241-263.
[12] Epstein D. and Miller R. T. *Slow off the Mark: Elementary School Teachers and the Crisis in Science, Technology, Engineering, and Math Education.* Center for American Progress, 2011.
[13] Walsh V., Roy R. and Bruce M. *Competitive by design.* Journal of Marketing Management, 1988. 4(2): p. 201-216.

[14] Rosenberg N. and Nelson R. R. *American universities and technical advance in industry.* Research policy, 1994. 23(3): p. 323-348.

[15] Erlhoff M. and Marshall T. *Design dictionary: perspectives on design terminology*. 2007: Walter de Gruyter.

[16] Barcellos E. E. I. and Botura Jr G. *Design e Engenharia: Integração como Estratégia de Inovação nos Parques Tecnológicos.* Interação: panorama das pesquisas em Design, Arquitetura e Urbanismo, 2015.

[17] Paiva S. et al. *A mobile application to enhance mobility of people with permanent or temporary mobility disability–a case study in Portugal.* Procedia Computer Science, 2021. 181: p. 34-41.

[18] Mendes J. et al. *Fostering Sustainability on Campus: Design of an IoT-Enabled Smartbottle for Plastic Reduction in the Academic Environment*. in *Advances in Human Dynamics for the Development of Contemporary Societies: Proceedings of the AHFE 2021 Virtual Conference on Human Dynamics for the Development of Contemporary Societies, July 25-29, 2021, USA*. 2021. Springer.

[19] Mendes J. et al. *The sustainable smartbottle: a proposed design methodology to minimize plastic pollution*. in *Advances in Design and Digital Communication: Proceedings of the 4th International Conference on Design and Digital Communication, Digicom 2020, November 5–7, 2020, Barcelos, Portugal*. 2021. Springer.

[20] Curralo A. F. et al. *Joining sustainable design and internet of things technologies on campus: the IPVC smartbottle practical case.* Sustainability, 2022. 14(10): p. 5922.

[21] Brown T. *Design thinking.* Harvard business review, 2008. 86(6): p. 84.

[22] Yang K. Y. E. and Cheach M. *Chemical product design as foundation for education as sustainable development*. in *Proceedings of the 10th International CDIO Conference*. 2014.

[23] Ping C. S., Chow P. and Teoh C. *The use of design thinking in CDIO projects*. in *Proceedings of the 7th International CDIO Conference, Technical University of Denmark, Copenhagen*. 2011.

[24] Ratcliffe J. *Steps in a design thinking process.* The K-12 Lab Wiki. Retrieved November, 2009. 19: p. 2013.

[25] Malmqvist J., Rådberg K. K. and Lundqvist U. *Comparative analysis of challenge-based learning experiences*. in *Proceedings of the 11th International CDIO Conference, Chengdu University of Information Technology, Chengdu, Sichuan, PR China*. 2015.