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An Engineering Multidisciplinary Undergraduate Specialty with Emphasis in Society 5.0*

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A substantial reform of undergraduate engineering education is necessary due to the increasingly complex and technologically driven workplace, political, and social arenas of the 21st century. Apart from technical skills, engineering students should acquire a broader set of essential skills through different student-centred learning approaches where engineering disciplines should be integrated with ethics and sustainability approaches in a more multidisciplinary environment. In response to these challenges, in this article we present a proposal for an undergraduate specialty in Society 5.0 for the School of Engineering at the University of Los Andes (Bogotá, Colombia). The specialty introduces students to the concept of Society 5.0 and provides essential and technical skills concerning selected technologies of the digital transformation age. The acquired knowledge is further applied to build prototypes for facing societal problems, and the proposed solutions are validated with respect to technical, ethical, and sustainability requirements. Given the deep social inequalities present in Colombia, and the increased ecological footprint in the country, we expect that the specialty increases the interest in the topic of Society 5.0, applies it in practice, and therefore contributes to the sustainable development of the country.

Keywords: engineering education; Society 5.0; ethics; sustainability; multidisciplinary education

1. Introduction

Education plays a central social role, in so far as its effectiveness is directly proportional to society's strength both nationally and internationally [1]. Furthermore, education is fundamental for making a society succeed in the competing global market, being conditional to a variety of interconnected factors such as economics and sustainable development as well as advances in scientific technology and knowledge, among others. In this context, education has evolved over the industrial revolution as explained in the next paragraph [2, 3].

The 4th industrial revolution or *Industry 4.0* (i4.0) refers to the current transformation of the ways human function and is the result of the industrial application of disruptive technologies of the digital transformation age, such as Internet of Things, Virtual Reality, Cloud Computing, and Artificial Intelligence, among others [4, 5]. The aforementioned technologies have blurred the borders among the physical, digital, and biological

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domains, and are introducing substantial changes to industry and society [6, 7].

In accordance with these global trends, the concept of *Society 5.0* (s5.0) was introduced in January 2016 in the 5th Science and Technology Basic Plan, adopted by the Japanese Cabinet [8, 9]. s5.0 is "a human-centred society that balances economic advancement with the resolution of societal problems by a system that highly integrates cyber and physical space" [10]. In other words, s5.0 can be defined as the application of the i4.0 technologies for the resolution of societal problems. The implementation of the s5.0 paradigm would enable society to reach economic development while solving key societal problems. It would also contribute to meeting the United Nation's *Sustainable Development Goals* (SDGs), and in particular the three dimensions of sustainability: social, economic, and environmental [11]. Since societies are being reshaped by the disruptive i4.0 technologies, it is vital for engineers to be properly qualified for fulfilling the new requirements that the changing global ecosystem is asking from them [12, 13].

The planet we live in today is very different from the one we had in the preindustrial era. Human activities have affected most parts of the world. For instance, only 23% of the earth's surface [14] and 16% of the oceans [15] are still unaltered. *Global environmental change* is much more than greenhouse gases emissions and climate change, and includes animal and plant species extinction, degradation of marine ecosystems, groundwater depletion, air pollution and land overexploitation, among others [16]. By 2030, the SDG agenda aims to tackle the global environmental change and improve *human wellbeing*. To do so it includes 17 goals and 169 targets that must be met across the globe. Despite the progress towards addressing social and economic issues, humanity continues to face an unprecedented environmental and biodiversity crisis [17]. Society 5.0 must not remain unresponsive to this challenge that threatens humanity. On the contrary, s5.0 must be an active part of the solution. In the past, ingenuity, science, and technology contributed to earth's degradation. Today they are called to drive changes to increase human well-being and respect the limits imposed by nature. To address sustainable development challenges in the following decades, s5.0 must concentrate its efforts on training agents of change with the necessary skills [18] to tackle SDGs unsolved conflicts [19].

Along with the technical skills currently fostered in engineering education, Ahmad [20] indicates that a broader set of skills must be acquired to cover the above new requirements. This broader set of skills are generally known as *21st century skills*. 21st Century skills comprise essential and technical skills that have been identified as crucial for success in the 21st century society and workplaces by educators, business leaders, academics, and governmental agencies [21–23]. Many of these skills are also associated with deeper learning, which is based on mastering skills such as analytic reasoning, complex problem solving, and teamwork. These skills differ from traditional academic skills in that they are not primarily content knowledge-based [24]. Along with 21st century skills, we believe that a multidisciplinary education including ethical and sustainability concerns should also be provided for training engineers for the fulfilment of s5.0.

The application of i4.0 technologies for the resolution of societal problems has complex *ethical* and *sustainability* dimensions. As an example, the continuous automation of manufacturing processes will take over many of the current jobs. How can a socially responsible engineer respond to this challenge? An understanding of the broad social conditions tied to automation processes – economic interests, the social background of workers who are thought as "replaceable," the social and environmental inequalities possibly embedded in the technologies, etc. – is urgently needed for engineering students to understand their professional and ethical responsibilities, and to consider the economic, environmental, and societal impact of their contributions. Consequently, a substantial reform of undergraduate engineering education is necessary [25].

In response to these needs, in this article we present a multidisciplinary *undergraduate specialty* in Society 5.0 for the School of Engineering at the University of los Andes (Bogotá, Colombia). In the University of los Andes (Uniandes), an undergraduate specialty is the opportunity for an undergraduate student to develop competencies in a complementary training area, in addition to his/her major. These competencies are based on a specific group of subjects in a certain area of knowledge, or in an interdisciplinary field of study. The specialty may be offered by the same faculty or department in which the student is enrolled or by one or more other units. We designed the specialty following a twofold methodology: a theoretical and an empirical component. Concerning the former, we reviewed the literature looking for educational programs relevant to the i4.0 and s5.0 themes. Regarding the latter, we applied two surveys to different stakeholders (i.e., students, faculty members, practitioners, and public officers) aiming at validating the essential skills and technologies to be considered within the specialty.

Given the above, the article is structured as follows. Section 2 describes the state of the art in i4.0 and s5.0 with respect to education. Section 3 shows the methodology adopted for the specialty design, and section 4 illustrates the proposed specialty in Society 5.0. Finally, section 5 presents the conclusions and sets the directions for future work.

2. Literature Review

The need for engineering curricula redesigning in line with *Industry 4.0* technologies is indicated in different works [26–28, 7]. The latest technologies of the digital transformation age, such as Big Data, Artificial Intelligence, Augmented Reality, Internet of Things, Cloud Computing, and other advancements should be introduced in curricula so that students learn their aggregate value and applications. Different efforts can be found in the literature concerning this 'actualization' of engineering educational programs. For instance, a MSIS (Master of Science in Information Systems) curriculum with a modular structure is proposed in [29]. The development of Master Engineering Programs with a focus on i4.0 and Smart Systems is shown in [30]. A Lean 4.0 curriculum based on the integration of Lean Manufacturing and i4.0 is introduced in [31]. However, the reviewed programs only deal with the acquisition of technical and technological competencies.

One of the main arguments behind modern engineering education is that in order to succeed in the increasingly complex and technologically driven workplace, political, and social arenas of the 21st century, a person needs to acquire a unique set of knowledges, skills, and abilities defined as *21st century skills* [32, 22]. However, universities are generally unsuccessful in establishing a bridge between higher education and the labour market, focusing on conceptual issues, rather than on experiential learning and 21st century skills [33].

Many observers currently discuss the 21st century skills within the context of technology. These skills constitute the main difference between jobs that will be taken over by robots or artificial intelligence, and those that will require direct human interaction [34]. The required 21st century skills can be found in the insights of key academic and industrial organizations. For example, the ABET (Accreditation Board for Engineering and Technology) Criteria for Accrediting Engineering Programs [35], the Future of Jobs report from the World Economic Forum [36], and the set of skills identified from the Partnership for 21st Century skills [37], among others. For instance, apart from technological competencies, *ABET* indicates that engineers should acquire [38]: (outcome 2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors; (outcome 3) an ability to communicate effectively with a range of audiences; (outcome 4) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts; (outcome 5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. It is thus clear that an engineering curriculum concerning the application of i4.0 technologies for the resolution of societal problems should deal with a broader set of skills beyond the technical and technological ones, such as ethics, sustainability, communication, and teamwork, among others. Moreover, *personalized paths* should be available in order to provide personal learning trajectories and professional competences fulfilling the 21st century need of lifelong education within the modern technological and rapidly changing work environment [39].

The tendency of integrating technology, ethics, and sustainability can also be found within the CDIO INITIATIVE. The CDIO consists in an educational framework that stresses the set of engineering fundamentals in the context of conceiving, designing, implementing, and operating real-world systems and products [40]. In the third version of the 'CDIO Standards', authors included the topics of sustainability, digitalization, services, and faculty competences [41]. Furthermore, several curricula applied the CDIO approach as a mean to develop skills in sustainability [42, 43]. Given the above, it can be noticed that the engineering specialty proposed in this paper is aligned with the current view of integrating technology, ethics, and sustainability, and may inspire or be adopted also by other educational institutions.

3. Methodology for the Society 5.0 Specialty Design

The methodology adopted for the design of the specialty is shown in Fig. 1. We began by applying an interest survey to evaluate the interest of students at Uniandes in the topic of i4.0. Then, we analysed engineering curricula in i4.0, and we decided to move towards the paradigm of s5.0, since it provides a broader view than i4.0 by considering the ethical and sustainability implications of technological solutions. Thus, we reviewed educational programs in s5.0 and we organized a workshop to: (i) clarify the paradigm of s5.0; (ii)

Fig. 1. Methodology for the design of the Society 5.0 specialty.

analyse the interest in the topic from members of the academic, industry, and government sectors. From the insights obtained in the workshop, we proceeded to the design of the specialty. These activities are next illustrated.

We came across the idea of a specialty when a group of mechanical and electronics students expressed their desire to deepen their knowledge in *mechatronics and industrial automation*. After some discussions, we concluded that a specialty related to i4.0 would better prepare students for facing the challenging 21st century workplace, since it would also integrate computer science and industrial engineering contributions. Therefore, we designed a survey to verify the interest of students at Uniandes in a specialty in Industry 4.0. The positive results of this *interest survey* motivated us to proceed with the design of the specialty.

After the survey, we started analysing national and international university curricula in i4.0. Once the selected curricula were examined, it was clear that most of them focused on the acquisition of technical and technological competencies without considering the societal and environmental aspects of such technologies. However, we believe that a curriculum based on i4.0 should also include the discussion concerning the sustainability and ethical dimensions of i4.0-based solutions. Therefore, we decided to move towards a *Society 5.0* specialty, since this paradigm explicitly includes ethical concerns, and the evaluation of the economic, societal, and environmental factors related to i4.0-based solutions.

Additionally, we organized a *workshop* to clarify the paradigm of s5.0 and to analyse the interest in the topic from academic, industry and government. Thus, the final version of the specialty reflects the insights from the workshop, the literature review, and a close collaboration with academic experts in ethics and sustainability studies. This process was also followed to obtain the approval of the relevant department chairs, achieving support, and confirming the need for a more multidisciplinary education that could make an innovative change in preparing the next generation of engineers.

The rest of this section is organized as follows: section 3.1 illustrates the results of the specialty interest survey, while section 3.2 describes the organization and results of the workshop. These two sections motivate most of the choices made in the design of the s5.0 specialty presented in section 4.

3.1 Specialty Interest Survey

The survey was taken by students at Uniandes in May 2019. It consisted of three sections. The first one included demographic questions such as gender, age, background, and educational level (undergraduate or graduate). The second section had the goal of identifying students' knowledge about the i4.0 paradigm and technologies. Finally, the third section asked about their interest in the topic.

The number of students that responded to the survey was 336. Participants were both male (77%) and female (23%), with an undergraduate (86%) and graduate (14%) educational level. Their background distribution is illustrated in Fig. 2. The

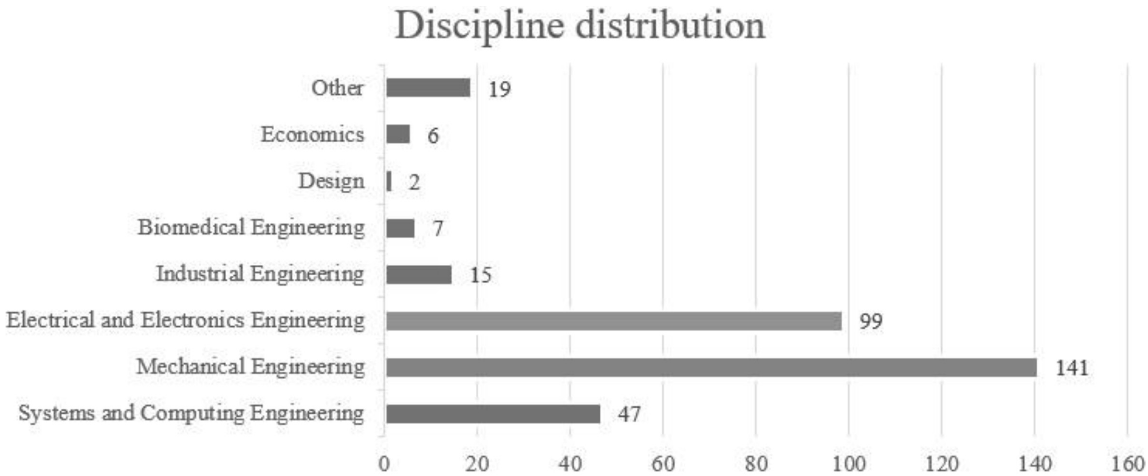

Fig. 2. Distribution of students' majors from responses of the specialty interest survey.

figure indicates that most of the students belonged to the School of Engineering. However, the presence of students from the Schools of Design and Economics shows how the topic can be of interest also to students from other backgrounds. Concerning their knowledge in the topic, 35% of the participants did not know about i4.0 or the related terms (e.g., Smart Manufacturing, etc.), 41% reported that they had heard of them but did not know their meaning, whereas only 24% of the participants knew about them.

Then, we explicitly asked whether they supported the introduction of a specialty in i4.0, and 89% of the participants agreed. Finally, we explored the extent to which they were interested in enrolling in an i4.0 specialty in comparison to other existent specialties offered by the School of Engineering (Fig. 3). 54% of the participants confirmed their preference for enrolling in the i4.0 specialty, if they had to enrol mandatorily in one engineering specialty.

The results of this specialty interest survey motivated us to start the design of an i4.0 specialty, given that very few students had knowledge of the topic and most of them showed interest.

3.2 Workshop on 'People and Industry in the age of Society 5.0'

The workshop was held at Uniandes in February 2020. Around 335 people from academia, industry, and other interested areas participated in the event. Keynote talks were given by national and international experts from the academic, industrial, and governmental sectors. Moreover, keynote speakers belonged to different areas of knowledge covering various technical and social science backgrounds. This multidisciplinary and intercultural 'mix' aimed to generate a complete vision of s5.0 that would support the subsequent design of the specialty. Next, a short description of the keynote talks is provided:

- *Prof. Harumi Watanabe* (Department of Embedded Technology, Tokai University, Japan): introduced the paradigm of s5.0 and the challenges of building this society. It is worth noting that Japan was the country where the term was coined.
- *Prof. David Romero* (Department of Industrial Engineering, Tecnólogico de Monterrey, Mexico): discussed the role of technology in relation to humans for the implementation of s5.0.
- *Prof. Don Howard* (Department of Philosophy, University of Notre Dame, United States): clarified why the possession of technical knowledge implies an ethical and political responsibility.
- *Prof. Carlos Eduardo Pereira* (Director of Operations at EMBRAPII, Brazil): illustrated a business model adopted in Brazil for funding and promoting technological innovations.
- *PhD Maria del Pilar Noriega* (Member of the 'Misión de Sabios', an initiative from the Colombian Government to define a research and innovation agenda for the coming years [44]): showed the challenges of building the s5.0 in Colombia, and the actions that the government is implementing to move forward.
- *Diego Tovar* (CEO of the Everis company, Colombia): explained how technologies of the digital transformation age can support the resolution of societal problems, based on his experience as CEO of a multinational company.

The discussion that took place in the workshop helped us better understand the s5.0 paradigm, affirming the need to include ethical and sustainability concerns within the development of i4.0-based solutions. Moreover, the speakers highlighted the importance for students to acquire essential skills for succeeding within the modern technological and rapidly changing work environment.

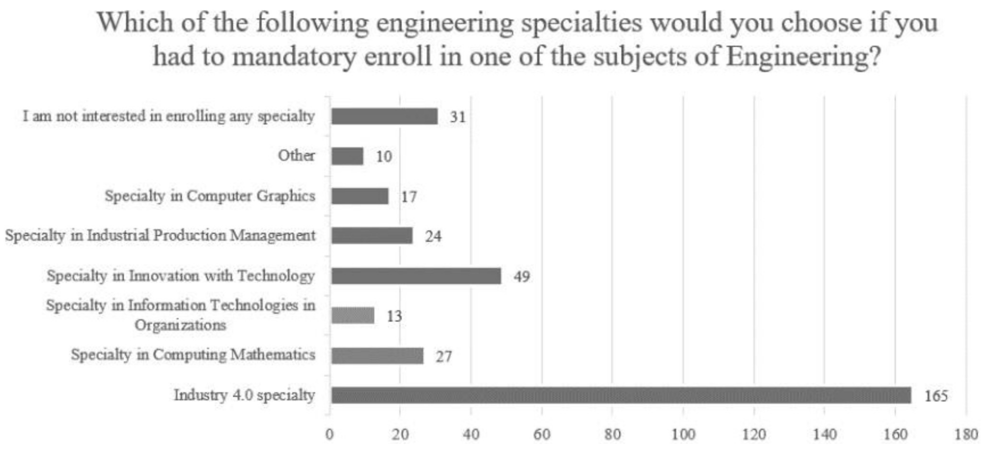

Fig. 3. Interest in enrolling in a specialty of the engineering school.

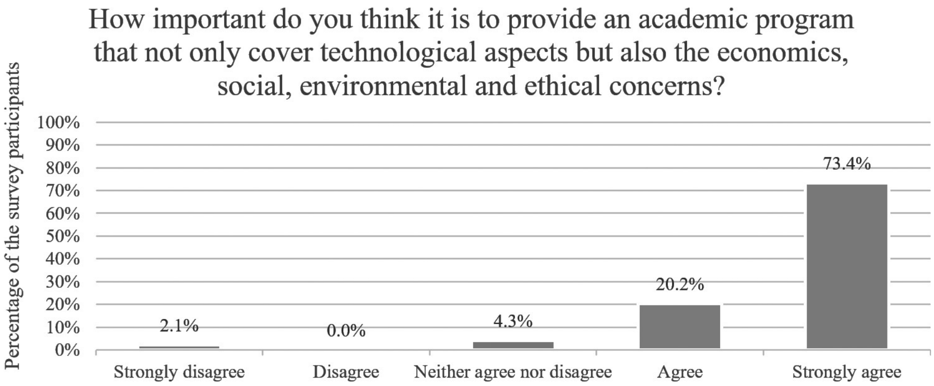

Fig. 4. Importance of the existence of an academic program that includes ethical and sustainability concerns in combination with i4.0 technologies.

To analyse the emerging interest in the s5.0 paradigm from academic, industrial, and governmental actors, another survey was carried out. The survey was sent after the workshop both to the participants and to those who were registered but did not attend the event. We received 94 responses, 73 of workshop attendees and 21 of non-attendees. 94% of the population indicated the importance of the existence of an academic program that merges technology with ethical and sustainability concerns, showing the need to design a curriculum tackling these topics; see Fig. 4.

Another goal of the survey was to explore the role of technology with respect to the three dimensions of sustainability. We started analysing the *social sustainability* concerns. We asked whether the use of technology will generate a social problem by taking over most of the current jobs. As shown in Fig. 5, 42% of the population thinks that technology will take over more jobs than the new ones that it is going to generate. However, the workshop showed that technology will determine a change in the type of jobs rather than a job reduction. This tendency will determine a change in the competencies required from future engineers. To properly identify which competencies should be acquired in a s5.0 curriculum, it is important to understand what the role of the technology with respect to humans will be. Consequently, the survey asked a question on this controversial issue (Fig. 6). Most attendees (62%) indicated that technology will support humans in performing their tasks. Therefore, their vision is to reach a human-technology collaboration and symbiosis. People that did not attend the workshop were less strong with their opinion but still the human-technology symbiosis resulted as the most chosen one (38%) from this part of the sample. Furthermore, people think that technology has the potential to generate new business models and opportunities; see Fig. 6. These responses brought us to the following conclusions: (i) the workshop showed that a collaboration between humans and technology is possible, probably influencing a shift in the opinions of the participants concerning the role of technology in the jobs of the future. Accordingly, we consider the time ripe for developing an academic curriculum for students to critically address such topics; (ii) the academic curriculum should contextualize the technology with respect to its *economic sustainability* in order to boost its potential to generate new business models and opportunities.

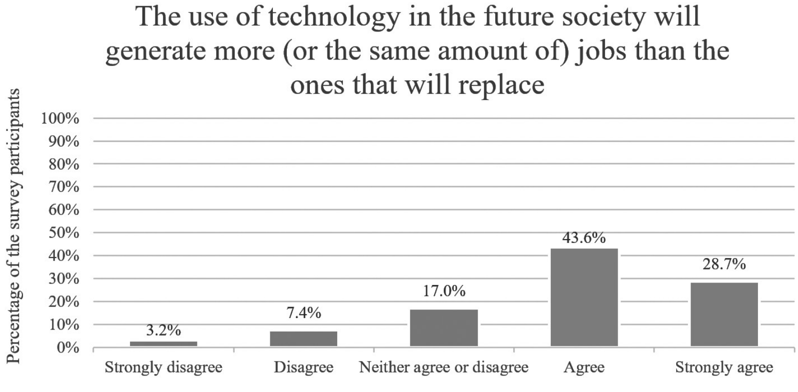

Fig. 5. Future employability scenario due to the technology involvement.

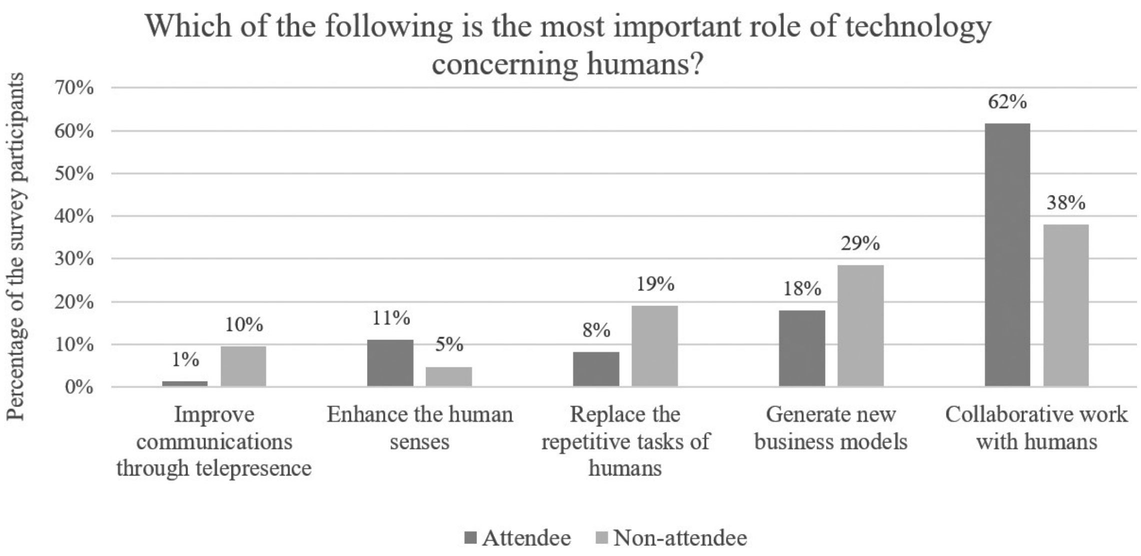

Fig. 6. The importance in the role of the technology with respect to the human.

Concerning *environmental sustainability*, we asked whether the use of the technology will reduce energy consumption and material waste of industrial applications. 72.3% agreed with this, 17% did not agree or disagree, while 10.6% did not agree. Notice that most of the population thinks that technology will generate a positive environmental impact. Therefore, it is fundamental to include environmental concerns within a specialty in *Society 5.0*. Especially those related to: (i) understanding the magnitude and nature of the global crisis, which has brought humanity in a state of global insecurity and risks, and stresses the need to consider a global ethical agenda; (ii) be able to discern the relevance of technology based solutions, in accordance to the complexity of the issues and stake; (iii) apply nature-based solutions as appropriate to social and ecological contexts.

Finally, the survey asked a question concerning the most important *i4.0 technology* in the future society, in order to identify which ones should be the centre points tackled in the specialty (Fig. 7). Data Analytics, Cyber-Physical Systems, and Internet of Things resulted as the most important ones. When validating this response with the literature, we found out that these technologies constitute the three fundamental functional layers of i4.0 applications [45]; i.e., Cyber-Physical Systems (physical layer), Internet of Things (interconnectivity layer), and Data analytics (application layer). Therefore, these technologies constitute the basis for understanding and implementing i4.0 and s5.0 solutions.

4. Society 5.0 Specialty

4.1 Vision, Pillars and Learning Objectives

An overview of the proposed *Society 5.0 specialty* is shown in Fig. 8 and will be described in what follows. The specialty has been designed by an interdisciplinary team with members from four

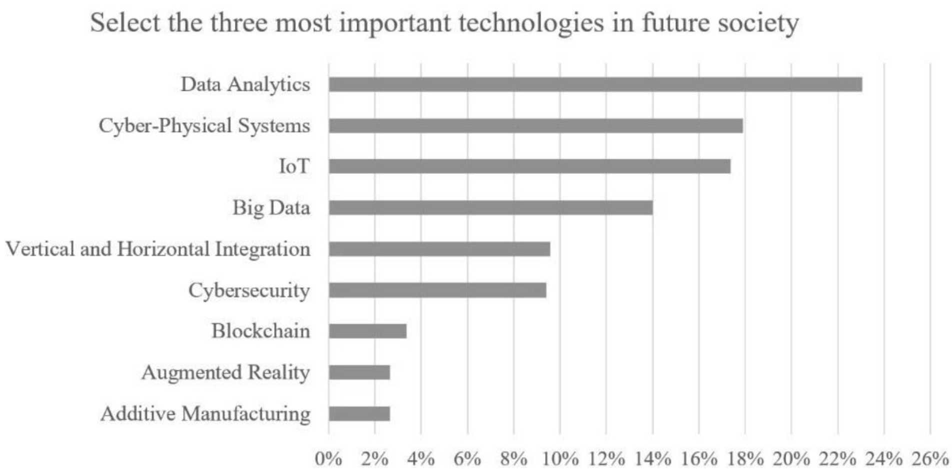

Fig. 7. People perception concerning the most important i4.0 technologies in the future society.

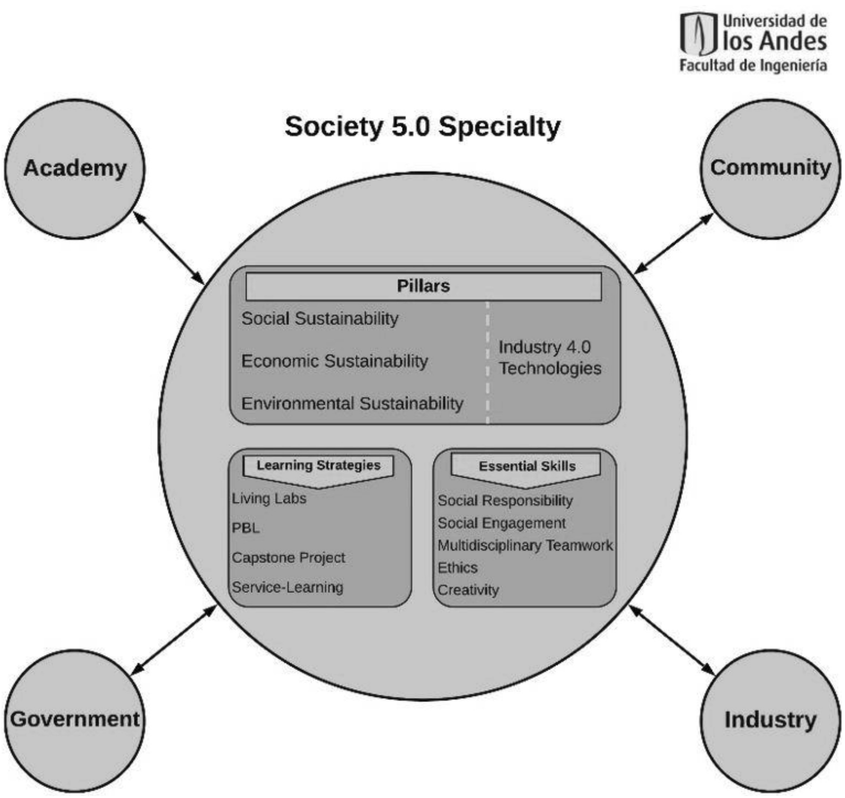

Fig. 8. Society 5.0 specialty overview. The PBL acronym indicates both Problem-based Learning and Project-based Learning.

departments of the School of Engineering (Mechanical, Electrical and Electronics, Systems and Computing, and Industrial) and two university centres, i.e., the Centre for Applied Ethics (CEA) and the Centre of the Sustainable Development Goals for Latin America and the Caribbean (CODS). The specialty vision is defined as:

> *"To equip engineering students with technical and sustainability skills allowing them to propose and prototype Industry 4.0-based solutions built within multidisciplinary teams and targeted to fulfil societal needs"*

By analysing the presented vision, it can be noticed that the specialty is based on two *pillars*:

1. *i4.0 technologies*. A basic knowledge about the technologies, their aggregate value, and their implementation challenges is important for the adoption of technologies. Local industrial partners showed us that different projects failed due to the implementation of 'technology push' strategies rather than 'process pull' ones. In other words, companies bought expensive technologies misaligned with their daily needs and unknown to their employees. The technologies brought additional work without the short-term benefits that they expected. Consequently, the technology was never integrated within the industrial process. These testimonies showed us the importance for students to acquire knowledge concerning the pros and cons of the different i4.0 technologies to properly select them.
2. *Sustainability*. Recently, our global society has reached a crucial agreement regarding sustainable development goals. Accordingly, governments and private companies have become increasingly concerned with the social and environmental impacts of technological development. Therefore, students need to learn how to include ethical, social, and environmental implications within their decision process. Finally, students will build business models to evaluate the economic sustainability of the proposed solutions. In this way, all the dimensions of sustainability (i.e., social, environmental, and economic) will be considered within the decision process.

To fulfil the presented vision, we have defined the following *learning objectives*:

LO1: Identify and formulate requirements that a viable solution to a given societal problem should fulfil considering ethical and sustainability concerns.

LO2: Select i4.0 technologies suitable to solve societal needs, understanding their scope and limitations as well as their ethical and sustainability implications.

LO3: Implement prototypes that integrate the selected technologies and test their fulfilment with respect to previously identified requirements and constraints.

LO4: Work in interdisciplinary teams.

4.2 Curriculum

The specialty consists of 14–15 *credits* in addition to the ones necessary for obtaining the bachelor's degree. In Uniandes, one credit corresponds to 48 working hours during the duration of the course. At most 40% of the credits of the specialty can be transferred from already approved courses of the student curriculum, given that these courses are part of the specialty curriculum.

Students applying to the specialty must fulfil the following *prerequisites*:

- Be enrolled in at least one program of the School of Engineering.
- Have reached the first layer of training of any of the school programs. This first layer covers introductory courses related to the student's major and basic science courses.
- Have completed the course of 'Introduction to Programming'.

To achieve a straightforward integration of the specialty to the curriculum, the specialty relies on the following *strategies*:

- Shared vision among the departments and the centres coordinating the specialty.
- Use of existing courses on i4.0 technologies, ethics, and sustainability.
- Co-creation of capstone projects with stakeholder organizations.
- Strong collaboration with industry/academic partners and government from local and regional spheres to build a 'data-base' of problems that students can address during the specialty. When comparing the main cities of Colombia with countryside regions, big gaps can be found in terms of resources, infrastructure, and services. Thus, it is necessary to contribute through cooperation strategies with the goal of promoting exchanges that lead to a sustainable development throughout the country [44].
- Flexible structure where students can configure their pathways with core and elective courses considering their background and career interests.

The planned s5.0 specialty *curriculum* is shown in Fig. 9. In the figure, the core courses are represented with squares and the elective ones with ovals. On the right-hand side of the figure, it is indicated which courses are designed from scratch, which ones are obtained from adaptations of pre-existing courses, and which ones can be reused since they are already available in the curriculum of other programs. Notice that the design of new courses or the adaptation of pre-existing ones are led by at least two departments or centres as indicated by the colours. Moreover, the colours also represent the teaching responsibilities for each course. The courses will provide the following essential skills: social responsibility, social engagement, creativity, multidisciplinary teamwork, and ethics; see Fig. 8. Finally, the courses can be divided into four categories: introductory course, industry 4.0 principles, specialization courses, and capstone design project; see the details in what follows.

4.2.1 Introductory Course

Its goal is to introduce students to the concept of Society 5.0 and to the challenges of building this society. We will adopt a 'black-box' approach to describe the *i4.0 technologies* available for the resolution of societal problems. We will explain their basic characteristics, aggregate value, and implementation challenges to enable students to compare and select them to be integrated in a unified solution. Since any student at the university can be enrolled in this introductory course, the level of explanation of the i4.0 technical aspects will be quite basic, while the details of a specific technology will be provided in the industry 4.0 principles and specialization courses. By making this course available to all students, we aim to acknowledge the interest that the topic generates independently from the student's background, and the fundamental roles that different disciplines play in accomplishing the principles of the s5.0. In addition, at the end of the course, students will be able to recognize that i4.0-based solutions have ethical and sustainability dimensions. With respect to the *ethical dimensions*, students will be able to: (i) identify the ethical dilemmas the emerge during the development and the later adoption of certain technological solutions; and (ii) through a process of ethical deliberation, present solutions to such dilemmas. For example, in the domain of e-Health – where patients afflicted with chronic diseases are remotely monitored through smart devices – an ethical dilemma arises when deciding whether to minimize the privacy risk of patients or to collect as much data as possible to advance medical research. Possible alternatives to manage this trade-off include data anonymization or 'Habeas data' agreements. With respect to *social and environmental sustainability*, this course will introduce the foundations that will be applied in the subsequent courses of the specialty. In particular, concerning sustainability stu-

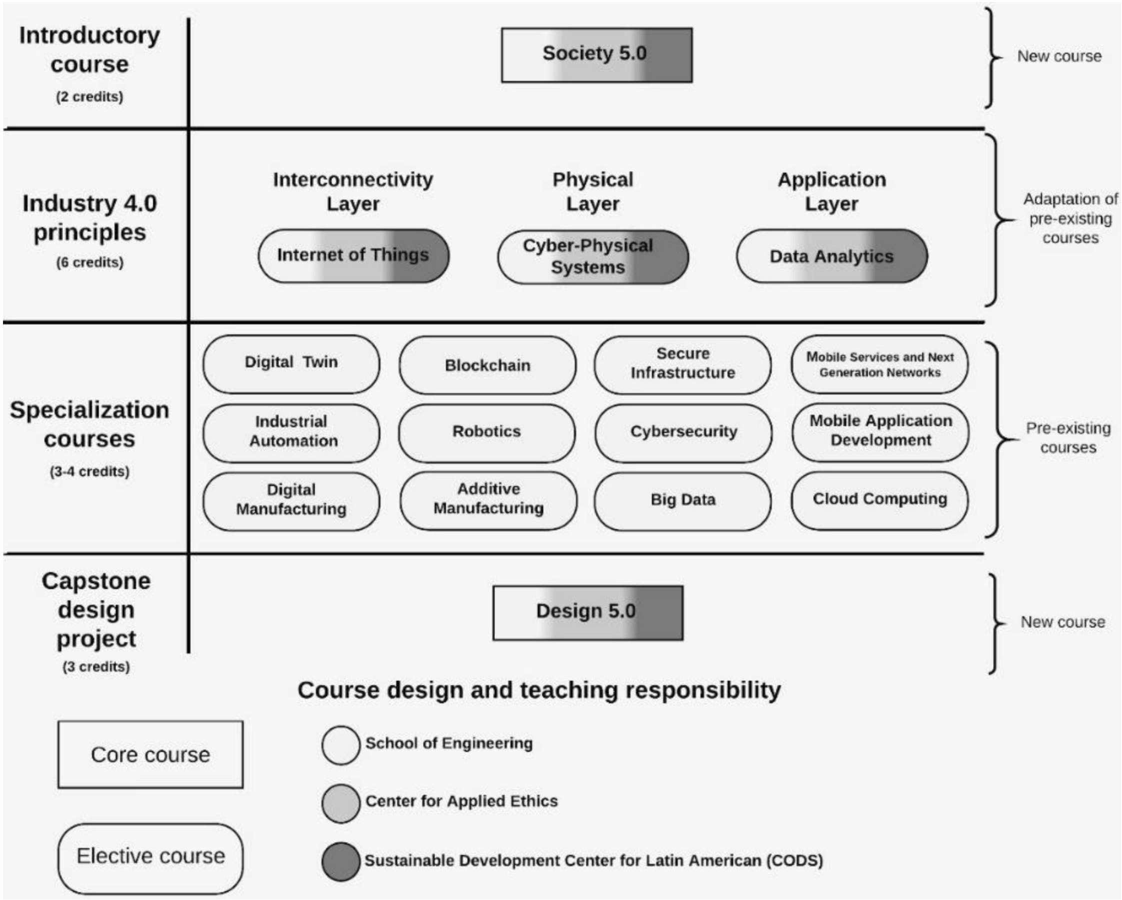

Fig. 9. Structure of the Society 5.0 specialty.

dents will be able to: (i) recognize the SDGs impacted from a specific s5.0 solution; (ii) identify possible conflicts that a technological solution may generate with respect to the SDGs; (iii) recognize the existence of synergies, trade-offs, and unsolvable contradiction among social, economic, and environmental goals; (iv) Understand the scope of current sustainability crisis, and its critical challenges to command and control approaches, and the need to embrace a new environmental ethic based upon prudence and solidarity.

4.2.2 Industry 4.0 Principles

Students must choose two courses from this category. As indicated in Section 3.2, these courses provide the fundamental functional layers for understanding and implementing i4.0 and s5.0 solutions, i.e., Cyber-Physical Systems (physical layer), Internet of Things (interconnectivity layer), and Data Analytics (application layer). *Cyber-Physical Systems* (CPSs) consist in the integration of computation with physical processes. In CPSs, embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice-versa [46]. In turn, *Internet of Things* (IoT) allows CPSs to transfer data both vertically (machine to data storage communication) and horizontally (machine to machine communication). Finally, *Data Analytics* enables to represent and synthesize the collected data to support the decision making. The objective of these courses is to provide the principles and technologies of the three i4.0 functional layers. With respect to the Introductory course, a 'white-box' approach is adopted since the technical aspects will be illustrated. Students will explore: (i) the challenges faced in building a CPS, IoT or Data Analytics solution; (ii) the alternatives available to deal with these challenges; (iii) the open-source and commercial technologies that can be adopted for prototyping a solution. In addition, students will prototype the solution to evaluate its technical viability. For example, in the IoT course, students will explore distributed queuing management to guarantee message delivering from sensors to the application. In this context, decisions must be taken about the messages ordering or federated/centralized queuing. Students will need to choose which protocol is most suitable to implement the design decision (e.g., HTTP, MQTT, COAP, etc.) and the technology supporting that protocol, e.g., Apache Tomcat, Mosquitto, OM2M, etc.

4.2.3 Specialization Courses

Students must choose one course from this category. This course can also count as one of the courses from the Industry 4.0 principles category. In this way, the student would have a view of the three i4.0 functional layers without specializing in one specific field. Fig. 9 represents the courses currently available within the curriculum of the School of Engineering. In the future, new courses may be created or some of the existing ones may be replaced. These courses will allow students to deepen their knowledge on a specific i4.0 technology and/or application area.

4.2.4 Capstone Design Project

In this course, professors will provide *real-world societal challenges* coming from projects developed in the Society 5.0 laboratory; see Section 4.4. Students will form interdisciplinary teams, choose a challenge of their interest, and fully develop an i4.0-based solution to solve the selected challenge. The development of the solution will include the: (i) identification of technical requirements, ethical dilemmas, and sustainability criteria within the challenge; (ii) design of a solution that targets the identified specifications by integrating i4.0 technologies; (iii) verification of the technical viability of the solution through a prototype; and (iv) evaluation of the *business viability* of the solution through economic analysis and validation with stakeholders. At least one technical advisor and one stakeholder will be assigned to each team.

4.2.5 Courses – Learning Objectives Mapping

Fig. 10 shows how each course contributes to the development of the learning objectives. Notice that each learning objective is addressed in at least two courses, given that acquiring a competency requires multiple applications.

4.3 Learning Strategy

The specialty will consist of online, blended, and face-to-face courses, and will implement the following student-centred learning approaches:

- *Living lab innovation process*: a living lab is an open innovation ecosystem focused on the user, which often operates in a particular context (e.g., neighbourhood, region, etc.) integrating research and innovation processes within a government-business-academy-society partnership [47]. A living lab is not a simple testbed since its philosophy is to transform users, from being traditionally considered observed subjects for testing modules against requirements, into users who contribute to the co-creation and exploration of emerging ideas, breakthrough scenarios, innovative concepts, and related artefacts. The living lab innovation process involves users throughout the whole innovation process by means of the following activities [48]: (i) co-creation; (ii) exploration; (iii) experimentation; (iv) evaluation. The living lab innovation process will be adopted in the Capstone design project and will develop students' creativity through the co-creation and exploration stages of the innovation process.
- *Project-Based Learning*: through this strategy, students develop viable solutions to 'unstructured problems' [49]. The process starts with the selection of a project among a list of real-world societal challenges provided by the professors. Next, students interact with the stakeholders to identify and formulate a list of requirements and constraints that a viable solution should fulfil. Then, students and stakeholders design a possible conceptual solution through the living lab innovation approach. After that, students select a list of competencies necessary for its implementation and conduct a self-directed study of the identified learning needs. Eventually, a prototype of the solution is built and validated with the stakeholders. This learning strategy will be adopted in the Capstone design project.
- *Service-learning*: through this strategy, students learn from connections made between their community experiences and the themes studied in their courses. Through their community service, students become active learners, bringing skills and information from community work, and integrating them with the course theory and their curriculum background to produce new knowledge. This strategy develops more tolerant, altruistic, and culturally aware students. Moreover, it contributes to the acquisition of the following essential skills: social responsibility and social engagement, along with stronger leadership and communication skills [50]. This learning strategy will be adopted in the Introductory and Industry 4.0 principle courses.

Course / Objective	LO1	LO2	LO3	LO4
Introductory Course	X	X		X
Industry 4.0 Principles		X	X	
Specialization Courses		X	X	
Capstone Design Project	X	X	X	X

Fig. 10. Contribution of each course category to the specialty's learning objectives.

With respect to the other complementary practices, all the courses will incorporate flipped classroom and teamwork learning strategies. With the flipped class strategy, students will review short conceptual videos or selected readings before the class. During the synchronous meetings with professors and classmates, questions will be clarified, and new concepts will be applied through interactive activities. With respect to teamwork strategies, the courses will illustrate standard practices to guarantee a shared vision of projects/activities and to ensure the equity among the contributions of each member. For instance, some of these practices include: (i) definition of contracts, responsibilities, communication plans, and safe environment expectations when the team is constituted; (ii) regular meetings for progress evaluation; (iii) post-mortem meetings when a milestone is reached to analyse team strengths and weaknesses; iv) peer assessments.

4.4 Facilities

The specialty will be supported by the Society 5.0 laboratory. This laboratory has been proposed to the University's board and its implementation is expected in the near future. The *Society 5.0 laboratory* will integrate the concepts of s5.0 and living labs into a space in which different i4.0 technologies will be explored to solve societal challenges. The laboratory will consist of: (i) work-stations to process and analyse the data coming from different case studies; (ii) demonstrators to show the results of the application of the proposed innovations; (iii) flexible meeting rooms to support the living lab process of co-creation and exploration with stakeholders.

The laboratory will mainly deal with the 'cyber' aspect of the i4.0 technologies focusing on data analysis and exploitation. To integrate the 'physical' aspect, synergies with other Uniandes laboratories have been generated and will be explored in accordance with emerging needs and case studies. Examples of such laboratories are the Manufacturing Laboratory, the Advanced Electronics Laboratory, the Interaction-Visualization-Robotics-Autonomous Systems Laboratory, and the Biological Science Laboratories, among others. In addition, case studies coming from two university living labs will also be researched within the Society 5.0 laboratory:

- *Smart City Fenicia*: living lab born to prototype and evaluate different technological solutions and innovations for Smart Cities. It operates in the territorial context of Fenicia, a neighbourhood in the historic centre of Bogotá. The living lab is part of Bogotá's plan of urban renovation. Uniandes constitutes the main promoter and seeks to contribute to the well-being of the community, and to create innovation in close collaboration with industry and government exploiting the technologies of the digital transformation age.
- *AgroLab Uniandes* [51]: living lab born for comparing and investigating different urban food production technologies and strategies spacing from robotics agriculture to hydroponics and aquaponics.

4.5 Organization and Management

From a financial point of view, the incomes for tuition fees associated to a given course will be proportionally divided considering the efforts devoted by each department/centre involved in the deployment of the course. From an administrative point of view, the specialty will be organized into the following strategic and functional committees (see Fig. 11):

Executive committee: This committee will be coordinated by a chair and will include one representative from each of the other committees, i.e., students, curriculum, and counsellors' committees. The selection of the chair will occur annually, and the role will rotate among the departments that designed the specialty. This committee will be in charge of establishing the vision, implementation, and reporting of the specialty. The chair selection also determines which of the engineering departments will bear the management of the Society 5.0 laboratory during that year.

Students committee: This committee will consist of maximum eight scholars that should advocate for students' interests and concerns and provide feedback for the improvement of the specialty. At least one scholar from each engineering department – with students enrolled in the specialty – should be present in the committee.

Curriculum committee: This committee groups representatives of each department and centre that designed the specialty. It will be in charge of the enhancement of the curriculum and of making the necessary agreements among the engineering faculty.

Counsellor committee: This committee is composed by the counsellors of each engineering department. It will be in charge of recruitment and mentoring efforts. For example, it will validate that students satisfy the prerequisites of the 'specialization course' (Fig. 9) they are going to attend.

4.6 Implications of the Specialty

In a nutshell, the expected impacts from the proposed specialty are to: (i) generate competences in i4.0, including its ethical and sustainability dimen-

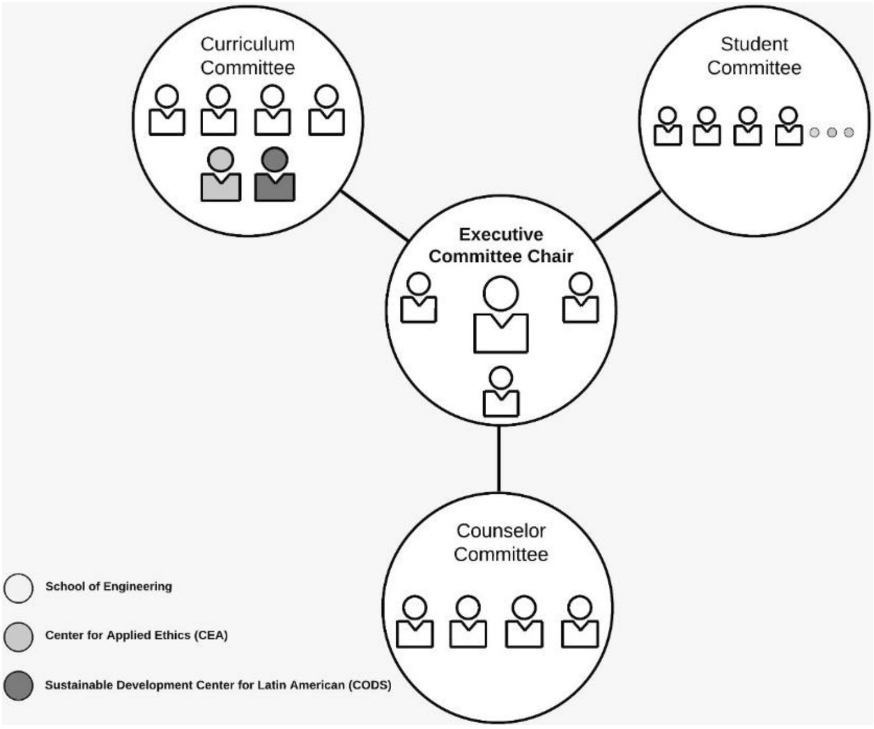

Fig. 11. Specialty committee organization.

sions. These elements are part of the Colombian governmental strategy to move towards a more equitable country [29]; (ii) engage students with the community in the resolution of societal problems; and (iii) generate awareness on the effects that i4.0 technologies have on sustainability and ethical concerns.

Given these broad impacts, the motivation for offering the specialty can be organized into impacts/implications for four groups of stakeholders: students, faculty members, society, and the School of Engineering. The next sections illustrate the impacts/implications for each one of these stakeholders.

4.6.1 Students

Students who enrol in the specialty will obtain a specialty certificate – along with the undergraduate degree – that includes highly demanded technical and essential skills. They will also acquire a unique 'lens' for the consideration of societal and environmental aspects in technical solutions, as well as strengthening critical view of their own practice. Additionally, they will have a pathway for graduate studies, which can be streamlined by the 'Specialization' courses, since these credits can be transferred to master's engineering programs. Students will also have the opportunity to connect with other undergraduate and graduate students within the specialization courses. This offers the potential for mentoring, and even possible collaboration on entrepreneurial projects. Finally, students will have the opportunity to network with different partners (academy-government-industry-community) engaged in the Society 5.0 laboratory, which might result in future opportunities for students, such as co-operative placement.

4.6.2 Faculty Members

Faculty members will have the chance of conducting interdisciplinary, collaborative, and applied research, as well as learning new pedagogical strategies. The interaction with faculty from other programmes will also encourage the development of synergies with other professors with common interests. The specialty also offers faculty members the opportunity to expand the current offer with new courses on i4.0 technologies and sustainability. These courses can be designed in collaboration among the different engineering departments, generating a more effective use of human resources and developing more interdisciplinary courses. Finally, the specialty will also encourage the sharing of facilities, such as labs.

4.6.3 Community, Government, and Industry

The specialty presents a unique opportunity for developing collaborative projects with the community, the government, and the private industry. These stakeholders will also have the possibility of improving their knowledge and competencies associated to i4.0 and sustainability. Furthermore, the specialty will bring them access to prototype ideas that may be subsequently converted into products. Teams conformed by students and partners may generate entrepreneurship initiatives (e.g., start-ups) by taking advantage of the following university facilities: (i) Office of Technology and Knowledge Transfer: in charge of managing the university's intellectual property and relationships with the external sector for the commercialization of research results; (ii) Innovandes: university's initiative that articulates different actors from inside/outside the university to develop projects with high innovation components; and (iii) Entrepreneurship Centre: in charge of supporting the university's community members in the construction of projects that generate positive impacts in society. Finally, the specialty will also encourage these stakeholders to work with a broader spectrum of potential co-operative or full-time employees pre-screened through the Society 5.0 laboratory.

4.6.4 The School of Engineering

The School of Engineering will benefit from the specialty in different ways. First, the specialty will contribute to closing the gap of competences generated from the i4.0 paradigm. Second, it will expand the current offer of educational programmes committed to serving societal needs, developing a more critical view of engineers' own practice. Third, the specialty will likely contribute to the growth in the enrolment of undergraduate and even graduate students, and to enhancing the School's recognition and reputation. Finally, it will generate a controlled environment to test and prototype innovative teaching approaches, as well as fostering 21st century skills, ethics, and sustainability before their 'transfer' into undergraduate and master's curricula.

5. Conclusions and Future Work

This article proposes an engineering undergraduate specialty in *Society 5.0* in the School of Engineering at the University of Los Andes (Bogotá, Colombia). The specialty introduces students to the concept of s5.0 and teaches them how to identify and formulate requirements and constraints that a viable solution to a given societal problem should fulfil. Technical competencies concerning selected i4.0 technologies and applications are provided, and then applied for the resolution of a societal challenge within a capstone design project. The role of *ethics* and *sustainability* within the application of i4.0-based solutions will be fundamental throughout the whole specialty. The core courses of the specialty will foster essential skills and multidisciplinary teamwork since students from all engineering programs can enrol in the specialty. Finally, student-centred learning approaches will be applied in most of the courses such as the living lab innovation and service-learning approaches, and project- and problem-based learning.

Given the deep social inequalities present in Colombia, we hope that the proposed specialty increases the interest in the topic of s5.0 and contributes to the sustainable development of the country. Furthermore, we believe that the specialty may become a controlled environment to test and prototype innovative teaching approaches, and the fostering of 21st century skills – in particular, ethics and sustainability – before their 'transfer' into undergraduate and master's curricula.

Next, some *future works* are identified:

- *Society 5.0 introductory course*: this course will be designed and prototyped as a continuing educational course before the launching of the s5.0 specialty. This type of course is opened to people from inside/outside the university, not necessarily enrolled in a formal program.
- *Society 5.0 laboratory*: the laboratory has already been pro-posed to the University's board and will be implemented following the guidelines provided in the article.
- *Society 5.0 specialty*: after prototyping the Society 5.0 introductory course, the Industry 4.0 principle courses will be designed starting from the adaption of already existing courses. Then, the specialty will be launched.
- *Fully multidisciplinary specialty*: given the interest that the topic generates among students, independently from their background, either engineering, design, health, business, social science, etc. and the contributions that other disciplines can provide for the realization of the s5.0, we will investigate how to generate additional pathways for students coming from none-engineering backgrounds to enrol in the specialty.

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