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Collaborative Networks and Sustainability in Education 4.0: An Approach to Achieve Complex Thinking Competencies in Higher Education

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Abstract. Today, collaborative networks are considered one of the critical elements that shape Education 4.0 in higher education. They are necessary to connect, cooperate, and collaborate with key external stakeholders during training and co-creation processes. Students use them to be immersed in real-world scenarios with complex environments. Consequently, Higher Education Institutions are relevant and critical in promoting and designing these collaborations where students can train and acquire desirable competencies. In this work, the competencies for complex thinking have been adopted in students' training to include specific transversal and disciplinary competencies and encourage the development of sustainable systems. Therefore, key stakeholders must foster sustainability in design processes through collaborative networks. We present two case studies involving collaborative networks and sustainability in this work.

Keywords: Collaborative Networks, Sustainability, Education 4.0, Complex Thinking, Higher Education, Educational Innovation

1 Introduction

Collaborative Networks (CNs) are a strategic driver for confronting current challenges in higher education because they stimulate collective actions to leverage operational advantages, sharing or using complementary human, technological, and knowledge resources. Currently, collaborative activities between internal and external actors are critical to performing training and co-creations that are necessary within the framework of Education 4.0, which seeks to implement Industry 4.0 technologies to improve or create systems in education [1]. Therefore, through new active teaching-learning methods, cutting-edge infrastructure incorporating physical, virtual, and cyber-physical systems, and the participation of key internal and external stakeholders, the students

can be trained in the current-profile competencies required for the 21st-century student [1].

In this sense, Higher Education Institutions (HEIs) are challenged to play a relevant role in preparing the new generation of professionals to be highly competitive in their professional lives. Therefore, in this work, complex thinking has been adopted as a meta-competency for students. Complex thinking comprises a set of transversal and disciplinary competencies such as critical, systemic, creative, innovative, and scientific thinking that improve students' decision-making processes and competitive performance in their professions [2]. Also, these competencies allow students to carry out research, design, and creation activities and develop sustainable solutions.

Consequently, new teaching-learning activities, resources, and dynamics have emerged to guide teachers and academicians in resolving current challenges in higher education. Then, students must get involved in real-world problems to train desirable competencies. In this context, there is evidence that universities are one of the main promoters of the development of sustainable solutions and through active teaching-learning techniques, it is possible to integrate external stakeholders to strengthen co-creation processes through CNs [3].

In this work, we seek to provide a new reference framework for the design of teaching-learning systems that is based on the components of Education 4.0, with a special emphasis on the components of sustainability and stakeholders. With this reference framework, it is sought to answer if with the resulted education systems (product, process, and infrastructure) it is possible to scale in the training of the complex thinking competencies. For this reason, this work presents CNs and sustainability as critical elements to consider in emerging teaching-learning systems designed within the Framework of Education 4.0.

The rest of this paper is structured as follows: In Section 2, the current challenges in higher education and the core components of Education 4.0 are presented. Section 3 shows the relevance of CNs and sustainability in the framework of Education 4.0 today. Section 4 presents the conceptual framework of this work applied in higher education. In Section 5, two case studies illustrate how the presented concepts can be practiced. Finally, conclusions are presented in Section 6.

2 Education 4.0: Challenges and Core Components

Challenges in higher education continuously emerge in various ways at different moments because educational processes are dynamic and multidimensional (cognitive, emotional, technological, and social) [4]. Thus, social phenomena, technological advances, and megatrends affect current processes and set the agenda for a specific and crucial discussion in the next few years. However, significant challenges have been identified as higher education priorities, highlighting the need to provide quality and accessible education for all. Several authors have presented education challenges on the agenda of many institutions and organisations worldwide today [5], [6].

Additionally, the disruption caused by the COVID-19 pandemic has led to considerable adverse effects that have caused the gap to become even more prominent

in several dimensions. Consequently, the challenges are more complex due to the immediate attention they demand [7].

The pandemic triggered the urgency to improve processes, models, infrastructure, and accessibility to carry out the desired operations to achieve quality education for all. The challenges described in this work are framed within Education 4.0. According to Miranda et al. (2021), "*Education 4.0 is the current period in which higher education institutions apply new learning methods, innovative didactic, management tools innovative didactic and sustainable infrastructures complemented mainly by new and emerging ICT, to enhance the processes of knowledge generation and information transfer. The combination of these resources during the teaching-learning processes will support the formation and development of critical competencies desirable in today's students.*" [8].

2.1 Challenges in Higher Education

In this work, six critical challenges are linked to the concept of Education 4.0. It is sought through Education 4.0 to reduce and mitigate challenges and provide pending solutions to them. Below are these six challenges:

(i) Train the new generation of professionals to acquire complex thinking competencies. Complex thinking has been identified as a core competency because it comprises desired transversal and disciplinary competencies to be trained in today's students [2]. These competencies encourage students to react highly competitively to complex events, make better decisions, and participate in collaborative environments.

(ii) Engage students through active teaching-learning methods. The lack of students' attention during their training sessions and intrinsic motivation to participate actively in the teaching-learning processes of formal courses has been a challenging issue that institutions seek to mitigate.

(iii) Strengthen the digital transformation in higher education. The step towards digital transformation in the era of Technologies 4.0 entails significant challenges requiring the attention and collaboration of various actors. These include participants from government, companies, academia and society because solving digital education challenges demands incorporating technological infrastructure, trained personnel, and appropriate dynamics to efficiently carry out the teaching-learning processes. But digital transformation is not only an issue at the institutional level but also at the level where individuals, teachers, students, and collaborators closely connect due to the need to have, operate, and implement technologies

(iv) Provide access to adequate infrastructure and initiatives that reduce or eliminate the digital divide. Access to good infrastructure during teaching-learning processes is a significant challenge addressed in different dimensions, by different actors, and in various social and demographic contexts. However, It is reported today that many institutions lack adequate facilities and have limited services. Also, facilities that promote collaborative work must have innovative furniture, connected tools, and other educational and didactic resources. The pandemic led to remote activities in asynchronous and synchronous formats and included technologies such as hologram-teacher, remote laboratories, virtual classrooms, cyber-physical classrooms, and hybrid

classrooms. However, access to infrastructure must also be considered at the individual level because remote work tools are necessary to access essential services that allow computer and mobile device connectivity. Many problems involve families' low income, geographical areas, and digital lag.

(v) Encourage collaborative networking and partnership. CNs with leading stakeholders are strategic for cooperation and collaboration on projects. Also, they are excellent platforms to immerse the students into real-life problems in teaching-learning and co-creation processes. Strategies such as Open Innovation and Triple/Quadruple Helix have been widely used to promote and facilitate co-design and co-creation processes [9]. In addition, thanks to the incorporation of 4.0 Technologies, it has been possible to improve communication and remote collaborative work. The external actors specialising in specific themes complement the most active teaching-learning processes and are more immersive to real-world environments.

(vi) Promote sustainable development to achieve quality education, equity, inclusion, and attention. The path toward a sustainable society is part of the 2030 plan of various institutions, organisations, and governments. They look to the UN Sustainable Development Goals (SDGs) to achieve this [10]. In addition, the dynamic world in which we live demands incorporating creative and innovative solutions and immediate reactions. Therefore, the new generation of professionals trained in HEIs must promote affordable, replicable, and sustainable solutions that positively impact society. For this, HEIs are challenged to provide a universal education of quality, equity, and inclusion. Efforts must be focused here.

2.2 Core Components of Education 4.0

To provide creative, innovative, and sustainable solutions that help close the digital gap and address the priority challenges outlined in this work, it is propose using the Education Framework 4.0 to provide a plurality of solutions [1]. It will allow us to evaluate that the designed and implemented programs contain desirable components in current training programs. Miranda et al. (2021) determined four core components to consider in implementing and designing teaching-learning systems within Education 4.0 [8]. In this work, six core components are considered, and they are described below:

(i) Competencies: train critical competencies for the 21st-century challenges, (ii) Teaching-learning processes: apply active teaching-learning methods and formats in different delivery modalities, (iii) 4.0 Technologies: Use emerging technologies to enable teaching-learning processes (iv) Infrastructure: provide adequate infrastructures such as innovative facilities, services, and systems to improve training processes, (v) Stakeholders: due to the relevance of using CN within the student training processes and the participation of leading actors from government, companies, academia, and society, and (vi) Sustainability: one of the purposes of Education 4.0 is to provide access to quality, affordable, sustainable education with high social impact. To achieve this, collaborators must design ad-hoc teaching-learning systems characterised by social, economic, and environmental sustainability.

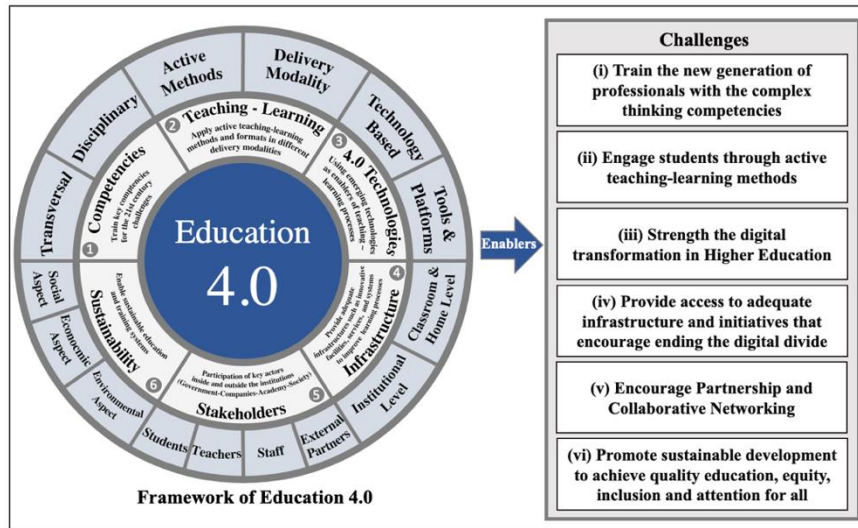


Fig. 1. Education 4.0 as enablers to provide solutions to the challenges facing Higher Education today

3 Collaborative Networks and Sustainability in Education 4.0

Since the participation of key stakeholders is considered a core component of Education 4.0, CNs are necessary today in the training processes of students since they stimulate the co-creation of solutions with strategies and actors and promote the students' immersion in real-world settings. These interactions, complemented with tools and teaching-learning processes, are necessary for training the competencies that shape complex thinking. These dynamics will be positively reflected in the analysis, research, and design techniques and the development of solutions for societal demands. Therefore, this section addresses the CN as a strategy to be implemented in today's higher education and the ad hoc designs for sustainable solutions.

3.1 Collaborative Networks in Education 4.0

Because Education 4.0 relies on the strategic participation of internal and external stakeholders, training programs and projects must be designed that stimulate their collaboration, resulting in collaborative projects that resolve real-world problems. Various partnerships and CNs can be accommodated as part of the teaching-learning dynamics in the student's training that involves them in complex environments. These also place them in scenarios to apply their learning in practice, using emerging technology tools to participate in co-creation activities. That is why today's CNs are considered a strategy in emerging teaching-learning programs.

Collaborative Networks (CNs) "consist of a variety of entities that are autonomous, geographically distributed, and heterogeneous in their operating environment, culture, social capital and goals that have come together to collaborate to achieve better, common, or compatible goals" [9]. Thanks to 4.0 Technologies, today's CN interactions are supported mainly by ICTs, allowing close, flexible collaborations without geographical restrictions. Consequently, CN strategies have high potential as drivers of value co-creation, sharing resources and knowledge, combining complementary skills and capacities, and even sharing responsibilities and risks [11]. Thus, academic projects involving CNs generate disruptive teaching-learning processes and leverage the resources and infrastructure of strategic stakeholders.

Historically, collaborations between university-university, university-government, university-company, and university-society have been practices that have brought great benefits and results to the academic community. With Education 4.0, these practices take on even greater relevance and benefit from the new dynamics in active learning and technologies as all these collaborators participate in joint projects.

It is necessary to promote complex thinking competencies so that students can make decisions to apply the best physical/digital resources and create innovative and sustainable solutions to current and future problems. Therefore, higher education has the challenge of enabling spaces where students have direct contact with complex scenarios of the real world, either through emulating those scenarios or becoming involved in real situations where the participation of external stakeholders is relevant to achieving solutions.

That is why CNs have been considered a pivotal strategy to accompany the core processes in Higher Education: (i) knowledge generation, (ii) information and knowledge transfer, and (iii) managerial processes.

Therefore, the different types of CNs have been considered and are in force today in the teaching-learning processes. They should be used within the framework of Education 4.0: (i) Goal-Oriented CNs, (ii) CN Breeding Environments, (iii) Interplay of multiple CNs, and (iv) Hybridisation of cognition and resilience.

Today, some activities are powered by 4.0 Technologies, allowing collaborations to be increasingly close, accessible, and without geographical restrictions. In addition, other approaches include citizen science, which encourages society's participation in academic programs and projects. Another trending example is CNs with Open Education strategies. All of which are excellent instruments in university programs and lifelong learning programs.

3.2 Sustainability in Education 4.0

The literature has documented that the teaching-learning systems based on Education 4.0 have provided significant benefits to society and allow us to obtain systems that are increasingly efficient, agile, personalised, and affordable [12]. Moreover, sustainability is a relevant domain in educational systems design. Sustainability in education seeks not only to generate a positive social effect but also to improve profitability and be eco-friendly. This has allowed sustainability's impact to be positive and scalable to reach larger audiences and produce even more positive effects. For this, Technologies 4.0 in education have played a critical role in developing new products, services, and

platforms. Therefore it is a desirable component with two primary purposes (i) to promote collaboration through online real-time cloud platforms and (ii) to promote the co-creation of new products and services. Therefore, today, 4.0 Technologies in education can be considered enablers of sustainability.

Sustainability is closely related to new product development processes that are ethical as well as operationally robust. It is conceived multidimensionally in environmental, social and economic aspects, also known as the triple bottom line of sustainability [13].

In this context arises the term "sustainable development." It can be understood under the umbrella of the three aspects (social, economic, and environmental). In 1987, sustainable development was defined for the first time as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [14]. In this sense, there are initiatives promulgated by the UN as Sustainable Development Goals (SDGs).

4 Conceptual Framework Applied in Higher Education

In the context presented, the concepts and components are then integrated into a conceptual framework that incorporates sustainability and value that seeks new solutions with positive social, economic, and environmental effects. The conceptual framework proposed in this document is oriented around research in the design of new products and the known concepts of Education 4.0, so the constructions that support the development of this framework are identified from the existing literature. The proposed framework has the purpose of guiding designers during the design and development of new didactic products, teaching-learning processes, and educational infrastructure through the generation of generic, partial, and particular models. The framework is further developed in iterations based on known tools and techniques that foster sustainability and collaborative networks.

Therefore, it is desirable to consider practices that stimulate the development of sustainable products-services in co-creation processes. This signifies ad-hoc designs for sustainability and applied tools such as DfX (Sustainability and Environment), Life Cycle Assessment, eco-design, and sustainability taxonomy.

Once the contextual problem/challenge/opportunity has been identified and addressed, it is necessary to build a teaching-learning process using CNs with the components of Education 4.0 as the primary enablers.

Finally, the expected result is to yield (i) knowledge generation and information transfer, (ii) co-design and co-creation, (iii) new products and services, (iv) technology transfer, and (v) entrepreneurship and enterprise creation. Figure 2 shows the Conceptual Framework of CNs and Sustainability applied in higher education (See Fig. 2).

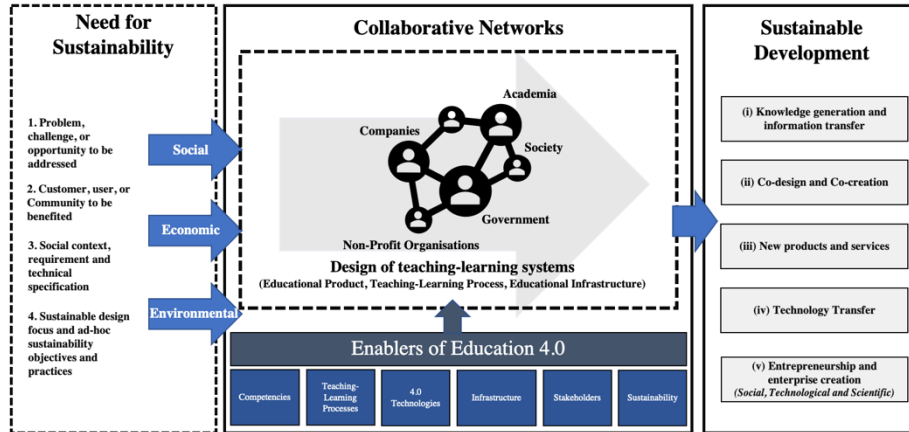


Fig. 2. Conceptual Framework of Collaborative Networks and Sustainability applied in Higher Education

5 Two Case Studies

Historically, the collaboration among academicians from different universities has led to the development of internships and exchanges in academic and industrial fields. However, today relevant efforts to promote shared value, risk, and responsibility, co-creation through multi-disciplinary and interdisciplinary projects, and shared goals and purposes. These are powered by current technologies that make communication, relationship, and process control even closer; they are considered different from before. In this work, two cases are presented where CNs and Sustainability are implemented in the framework of complex thinking. This section offers one case for sharing knowledge and product design and a second for designing training programs, both considering Education 4.0.

5.1 Didactic Product Development: Multifunctional Machine-Tool

This case study presents the co-design and co-creation of a didactic product developed between researchers and students from various disciplines of Tecnológico de Monterrey and UNAM. In addition, key stakeholders such as technological partners and primary and secondary users of various public and private institutions participated in the co-creation dynamics. The main objective of this CN was to scale the level of maturity of a new product and bring it to market through technology transfer or a venture. This project was within the framework of a collaboration called a "research, technology transfer, and entrepreneurship consortium," through which both institutions shared responsibilities and commitments. Figure 3 summarises the process carried out among the actors involved (See Fig. 3).

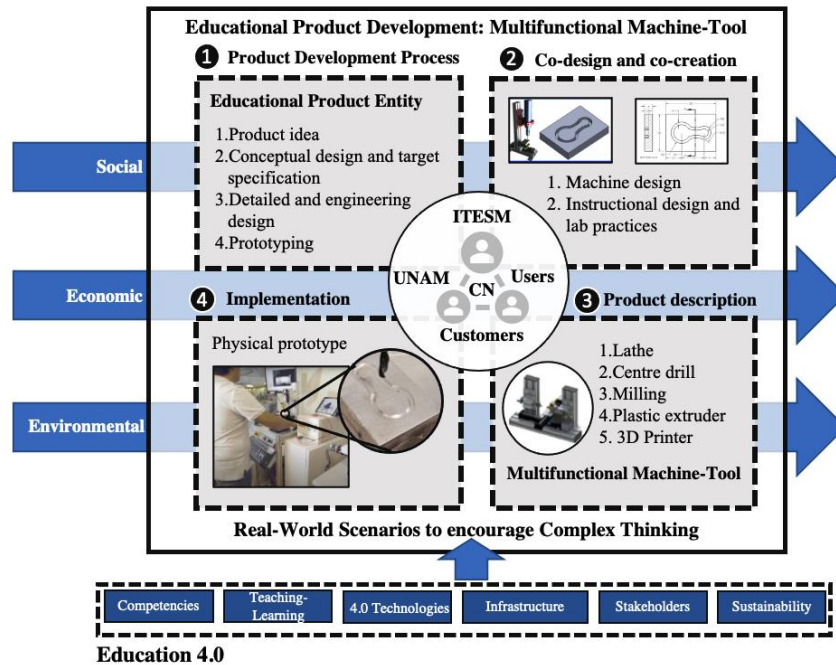


Fig. 3. Summary of the process carried out among the actors involved in the didactic product development: Multifunctional Machine-Tool

The developed product was didactic and aimed to pursue the desirable dynamics of Education 4.0 and include training complex thinking competencies in Industry 4.0. The system designed was a numerical control multifunctional machine tool with three main characteristics: (i) it is *small*; its dimensions were reduced for easy transport, and it did not require secondary installations; (ii) it is *reconfigurable*; its physical and software parts can be reconfigured to offer different manufacturing processes (milling, turning, 3D-printing, and laser cutting); (iii) it is *low-cost*; it was designed ad-hoc for sustainability and pursuing best practices for its manufacturing and assembly; and (iv) its design was based on *user experience*, which allows incorporating active dynamics in the teaching-learning processes. In this case, the complex thinking active competencies are included in two moments, the first during the design process of the machine, and the second through the training of the competencies in the implementation of the machine. To achieve the latter, a laboratory practice book was designed.

5.2 Teaching-Learning Process Development: The Scientific and Technological Entrepreneurship Bootcamp

This second case study presents the co-design and co-creation of a teaching-learning process developed by researchers from Tecnológico de Monterrey and partners from the government of Mexico City and Durango State. This teaching-learning process

sought to train researchers in trasversal competencies (complex thinking) and disciplinary competencies (entrepreneurship, marketing, and business models, emphasising technological and scientific developments) . The program was taught in a remote-modality-bootcamp format with synchronous sessions. This type of program seeks to stimulate development and promote technology from the laboratory to the market. Figure 4 summaries the design process and resulting content (See Fig. 4).

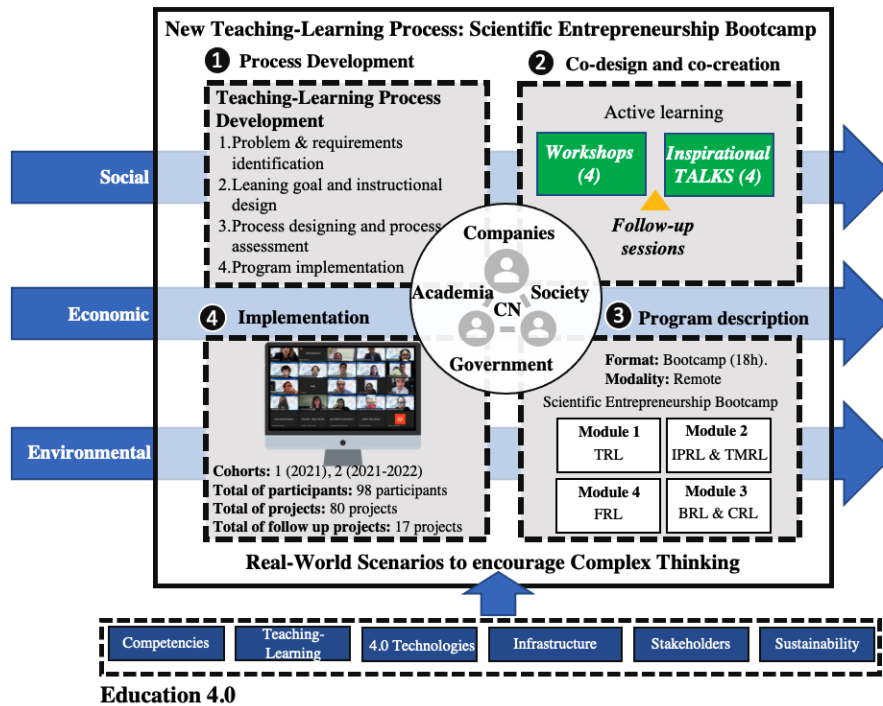


Fig. 4. Summary of the process carried out among the actors involved in the teaching-learning processes development: Entrepreneurship Bootcamp

Thirty-eight scientific projects in Mexico City were involved in public and private HEIs; 5 projects had special follow-up sessions during the 2021 cohort. Sixty projects were in public and private HEIs in Durango state; 12 of these projects had special follow-up sessions during the 2022 cohort. A general result shows that 85% of the projects will pursue a technology transfer strategy, and the other 15% will pursue the creation of an enterprise. Also, it was observed that the most relevant pain was the decision-making process of choosing the pathway to the different alternatives for bringing the product to the market. Finally, it was observed that the topics of creating technology packages, intellectual property strategy, and funding and finance around entrepreneurship processes must be strengthened and fostered.

6 Conclusions

In this work, we presented an approach to CNs and Sustainability within the framework of Education 4.0, showing the relevance of strategic participation by various actors during the co-design, co-creation, and teaching-learning processes. Since this type of collaboration involves design and development processes, the concept of sustainability was pursued to focus efforts on obtaining new products and services with positive social, economic and environmental effects. These topics are relevant for learners' responsiveness and engagement in real-world scenarios. This project promoted complex thinking competencies, and two case studies were analysed.

We sustain that through Education 4.0, it is possible to reduce, mitigate, or provide adequate solutions to current challenges in Higher Education. In addition, we observed that in the design processes of either products or functions within the framework of Education 4.0, it is possible to achieve didactic systems that develop desirable competencies in the current student profile. It can also be mentioned that by following the Reference Framework for Education 4.0, it is possible to be guided throughout the design and creation processes to have the desirable components.

With the dynamics carried out in the case studies, it was possible to verify that the design of new systems in education can have two main effects (i) it encourages the co-creation of sustainable solutions among the members of the CN, (ii) in Within the framework of Education 4.0, it is possible to design teaching-learning dynamics that allow stimulating complex thinking competencies.

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