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Neuro-Competence Approach for Sustainable Engineering

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Abstract: Manufacturing systems under Industry 4.0, and their transition towards Industry 5.0, take into account the Quintuple Helix innovation model, associated with the sustainable development goals (SDGs) set by the UN and Horizon 2030, in which companies focus on operational efficiency in terms of the use and minimisation of resources for the protection of the environment. In this respect, the implementation of the circular economy model, which requires engineers to acquire appropriate competencies, enabling companies to establish this model at the manufacturing level. Moreover, competence has always been a priority for both the professional and the company. In this sense, connectivism has been called a learning theory for the digital era; this is the reason why a review of the state-of-the-art developments of this paradigm focused on engineering has been carried out. In this sense, the potential of the digital transformation in instruction to formulate an engineering model based on neuro-competences is of great interest, taking the connectivist paradigm as a methodological axis. To this end, a first bibliometric analysis has been carried out to identify the drivers on which to base the design of the neuro-competencies of the instructional engineering environment and the trend towards curriculum development under dual training models. The bibliographical research carried out on the connectivist paradigm has served to identify the trends followed to date in education within the subject area of engineering. These trends have not fully taken into account the leading role of the human factor within the socio-technical cyber-physical systems of sustainable manufacturing (SCSSM). The focus was more on the technology than on the adaptation of the uniqueness of the human factor and the tasks entrusted to him, which entails an additional complexity that needs to be addressed in both academic and professional contexts. In light of the foregoing, an improvement to the acquisition and management of competencies has been proposed to the academic, professional and dual engineering contexts. It is based on the transversal inclusion of the concept of neuro-competence applied to the competence engineering (CE) model, transforming it into the neuro-competence engineering (NCE) model. The foregoing provides a better match between the characteristics of the human factor and the uniqueness of the tasks performed by the engineer, incorporating activity theory (AT), the law of variety required (LVR), the connectivist paradigm and neuroscience as a transversal driver of innovation through fractality. This proposal enables a ubiquitous and sustainable learning model throughout the entire academic and professional life cycle of the engineer, placing it sustainably at the heart of the instructional and professional cyber-physical socio-technical system, thus complying with the SDGs set by the UN and Horizon 2030.

Keywords: sustainable engineering; circular economy; SDG; industry 5.0; cyber-physical systems; manufacturing; neuro-competence

1. Introduction

The contribution to the development of the SDGs set by the UN and the 2030 Horizon under Industry 5.0 is not exclusive to a single industrial sector, although this work focuses on smart manufacturing, which is made up of a broad set of competencies in engineering, giving it a fundamental role [1].

Manufacturing systems take into account the Quintuple Helix model of innovation as a consequence of the SDGs set by the UN [2]. The Triple Helix model was focused on the relationships between academia, industry and government; the Quadruple Helix incorporates media, culture, and through the Quintuple Helix, the natural environments of society are added [3], as companies focus on operational efficiency in terms of resource utilisation and minimisation for the protection of the environment.

Advanced and sustainable manufacturing enables the improvement of productive capacity; this is possible by taking into account increased efficiency in the use of energy and materials, reducing emissions through process control technologies, efficient engine systems and product life cycle management, integrating digital technologies, local, people-oriented and ultimately socially sustainable methods.

Associated with the increase in consumer demand for product customisation is social and environmental awareness, which is influencing the manufacturing sector to lead an industry-wide sustainable paradigm, affecting all stages of the product life cycle. This trend has been generated both by the evidence that natural resources are finite [4] and by the consequences of pollution and greenhouse gases associated with climate change [5]. This is giving way to the implementation of the circular economy model that emerged in the mid-1970s [6], as opposed to the linear economy, which translates, among other things, into longer product life cycles through the after-sales service, repair, reuse and recycling of products and their components. This production and consumption model involves sharing resources, reusing, repairing, refurbishing and recycling existing materials and products for as long as possible. There are several frameworks and methodologies focused on this concept [7], including RESOLVE, an acronym for regenerate, share, optimise, loop, virtualise and exchange, which is used by companies to identify a set of actions to facilitate the transition towards this circular economy [8]. The basic principles on which the circular economy is based are also involved in methodologies and approaches such as cradle-to-cradle, natural symbiosis, ecosystem services, biomimicry, collaborative consumption and others.

Industry 5.0 emphasises the role of the engineer in reconfigurable and adaptive cyber-physical socio-technical manufacturing systems (CSMS), where the human and technological factors work collaboratively, stimulated by the contributions of Industry 4.0 at the technological level (digital twins, cobots, etc.). This is in addition to a marked sense of sustainability through circular economy models, which determines the interest in improving the degree of incorporation of the human factor in different areas of digital and technological transformation of smart manufacturing, as well as the way in which its incorporation is managed, evaluated and optimised.

This change in managing the manufacturing process and the relationship with customers requires professionals capable of facing new operational and educational challenges, based on updating skills that make it possible to adapt to this new industrial paradigm [9]. The human and technological factors are co-evolving together, developing work more oriented towards sustainable engineering, linked to decision-making, associated with specialisation and high educational competencies acquired in the educational field for the engineer, and of a more automated and repetitive nature for the machine [10], Figure 1.

The aforementioned implies changes in educational and instructional models in both academic and business environments to address the acquisition of competencies associated with these new approaches. In this sense, the sharing of resources and structures between universities and companies facilitates the acquisition of the necessary competencies that engineers and technicians need to acquire in order to take on the technological change produced in the manufacturing sector, with new educational paradigms emerging that enable this cooperation between the academic and professional field.

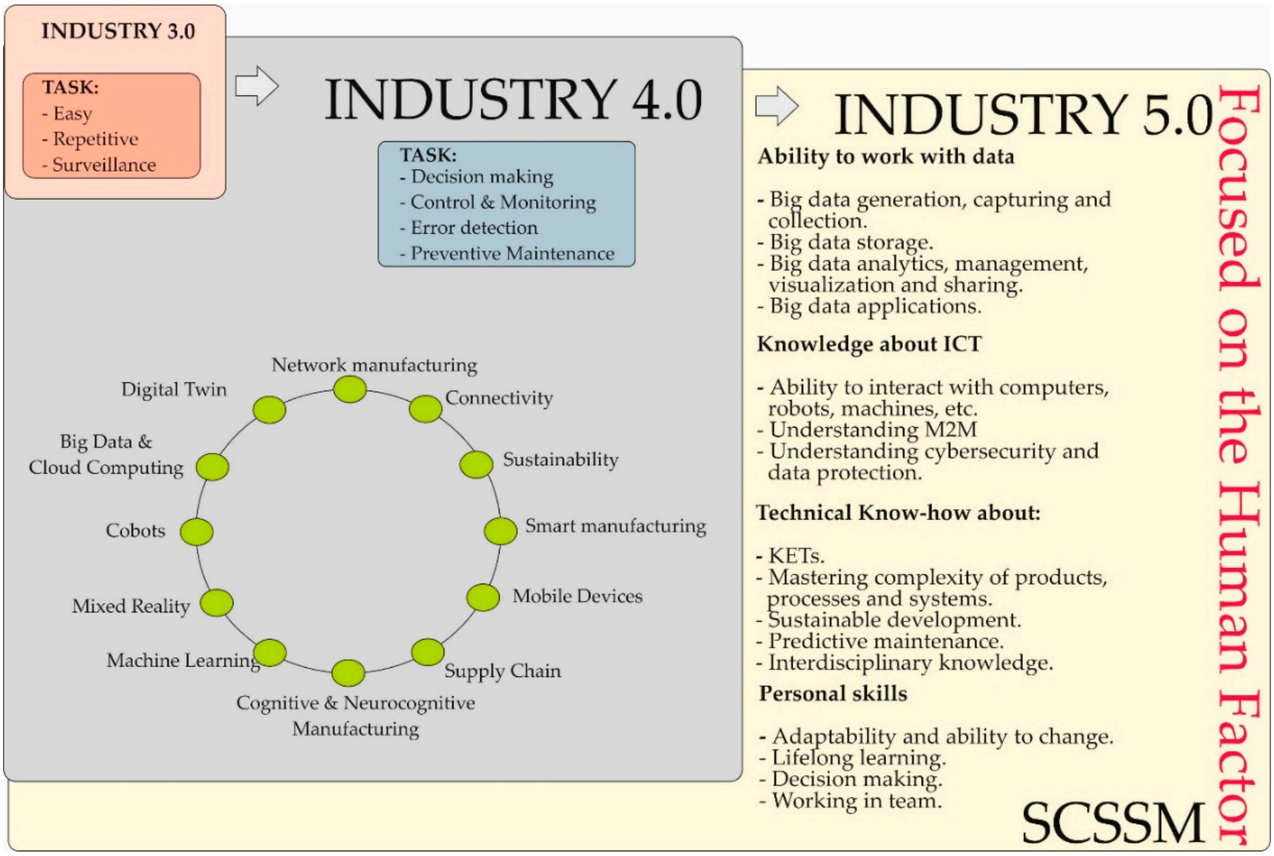

Figure 1. Alignment between the human and technological factor.

The engineering lifecycle of manufacturing systems, within the framework of Industry 4.0, includes, together with the concept of a cyber-physical system of technical equipment, the concept of Operator 4.0 [11], with the latter's differential characteristics being creative intelligence and the fact of being an expert in the domain of knowledge that constitutes their area of responsibility. Their modes of operation in Industry 4.0 environments are carried out cooperatively with robots, machines and other cyber-physical means, using advanced technologies of human–machine interaction and adaptive automation to achieve an appropriate degree of symbiosis [12,13]. Among the characteristics of these systems, visualisation technologies such as augmented, virtual and mixed reality are incorporated into production processes and skills training, as they are considered useful for Industry 5.0 [14]. The immersive technologies named above [15], brain–computer and brain–machine interfaces thus improve manufacturing and instructional systems [16] and the performance of Operator 4.0 towards the transition to Operator 5.0 [12].

The new circular economy approach requires specific skills to enable companies to cope with this new model on the manufacturing level [17]. Digital technologies, in addition to enabling the monitoring and control of products, components and materials through intelligent product passport, resource mapping and consumer information, can facilitate the acquisition and specialisation of the necessary skills depending on the characteristics of the engineer and the task required [18], together with the connectivist paradigm.

In this sense, the trends to be taken into account in Horizon 2030 can be found framed at the social, environmental, technological and economic levels [19]—see Figure 2.

Figure 2. Manufacturing trends for Horizon 2030.

In order to achieve the objectives proposed for Horizon 2030, the European Union has established three basic pillars on which to state all the work to be done [20]:

- Science and Technology.
- Innovation and Entrepreneurship.
- Education and Training.

Some of the most important objectives and priorities established in the area of education and training for Horizon 2030 are the following [21]:

- Enable skills such as problem-solving, decision-making, leadership, team spirit, entrepreneurship and multiculturalism. Key to this is knowledge-sharing and social-learning.
- The implementation of the Learning Factory, focused on learning by doing, based on the dual approach.
- The development of digital skills and the integration of e-learning [22] in manufacturing, by strengthening the links between the academic and professional environment.

The interest of these objectives and priorities lies in responding to the educational needs demanded by companies in the manufacturing sector in relation to the circular economy model currently proposed.

Advanced and sustainable manufacturing makes it possible to improve the production capacity, taking into account increased efficiency in the use of energy and materials, reducing emissions through process-control technologies, efficient engine systems and product life cycle management, integrating digital technologies in production processes, combining flexibility, precision and zero defects [23]. For this to be possible, it is necessary to have collaborative work between human and technological factors and the optimization of the physical and cognitive workload of Operator 5.0 by means of sensors [24].

Therefore, engineers adapted to hybrid jobs are needed, requiring the mastery of several set of competencies such as knowledge in networking, communication, cyber-physical systems, Big Data, programming, design, marketing and AI, among others [25].

The situation can be improved by bringing contributions from the professional and other multidisciplinary scientific fields, to provide students with creative and critical-thinking competencies that emerge from addressing the problems in the workplace [26], competencies that require their integration into new educational curricula and teaching methods at all levels, in a scalable and easily transferable way [27].

The aim of this paper is to propose the design of a neuro-competence engineering environment that bridges the gap between the skills acquired and those demanded by the manufacturing sector, focusing on the human factor and the task to be performed, as opposed to a vision more focused on the technological factor. Based on the research objective and study of literature sources, we formulate the following research question (RQ):

RQ: Is it possible improve the competencies acquired by engineers in the manufacturing sector under a sustainable and Industry 5.0 approach?

To this end, in the Materials and Methods section, we proposed a status quo review. Research work and practices recently carried out in the academic and professional contexts are considered through two bibliometric studies and the study of its associated bibliography. The first one identifies the drivers on which to base the design of the neuro-competencies of the instructional engineering environment and the trend towards curriculum development under dual training models. The second one serves to identify the trends followed to date in education and training within the subject area of engineering, associated with the sustainable development goals (SDGs) set by the UN and Horizon 2030, as one of the three basic pillars. In the results section, we show the research and proposals carried out by the authors obtained from the bibliographic search and proposed a model for the improvement of competence acquisition and management through the cross-cutting inclusion of cognitive neuroscience and the contributions of AT and LVR. In the discussion section, we discuss the contributions of the reviewed authors. Finally, as a conclusion, our model can be used to improve the acquisition and management of competencies by focusing on the human factor as opposed to the technological factor.

2. Materials and Methods

The aim of this status quo review [28] is to consider recent academic and professional research and practice in relation to the competences acquired by engineers in the manufacturing sector under an Industry 4.0 approach. To this end, two bibliometric studies were carried out.

2.1. Bibliometric Study 1

A study has been carried out in relation to digital transformation, in the academic and professional contexts, for the acquisition of the competencies that enable engineers to respond to the demands of the smart manufacturing sector, finding an appropriate match between the professional profile and the requirements demanded by companies. To this end, we use the Scopus databases. The semantic search of the associated terms is carried out automatically by means of a calculation algorithm. The automatic selection process of information obtained from the scientific literature is carried out by means of a quantitative analysis (based on the analysis of co-occurrence of all keywords) and qualitative analysis (by identifying the semantic field of review) through bibliometric maps [29]. The reason for choosing this technique is that, due to its characteristics, it constitutes an effective indicator in the evaluation of the impact of the terms that form part of the semantic field. In order to obtain a correlation between search parameters, allowing the integration and analysis of the same, the processes associated with the acquisition, selection, analysis and organisation of information are carried out as prior processes [30]. As text-mining tools for the elaboration of concept maps [31], different types of software can be found for this purpose. For this review, we considered used the free software VOSViewer developed at the Centre for Science and Technology Studies [32].

The methodology used is based on the analysis of keywords (KWs), which are automatically retrieved words reflecting the dynamics of the field being queried, and the relationship between them. It can be described by the following phases:

- Data collection through the use of databases.
- Obtaining the units of analysis or KWs automatically using the software VOSviewer.
- Obtaining the co-occurrence frequency and similarity index using the aforementioned software.

- Graphic visualisation of the results obtained.

For a good design, the bibliometric indicators were aimed at searching for significant aspects that would allow us to resolve the question posed, and for this purpose, they had to be expressed in such a way that quantitative data could be extracted from them that would lead to the subsequent analysis of the situation defined.

The search strategy used in the Scopus database, limited to the time period from January 2000 to April 2019, was defined as follows:

"Industry 4.0" AND "manufacturing" AND "learning".

Based on the frequency of occurrences and co-occurrences of the KWs, the terms obtained were identified automatically. The minimum number of occurrences of a KW was chosen as five, after checking by trial and error that this was an adequate value, so that out of the 1532 KWs, 74 KWs fell within the established criteria, Figure 3.

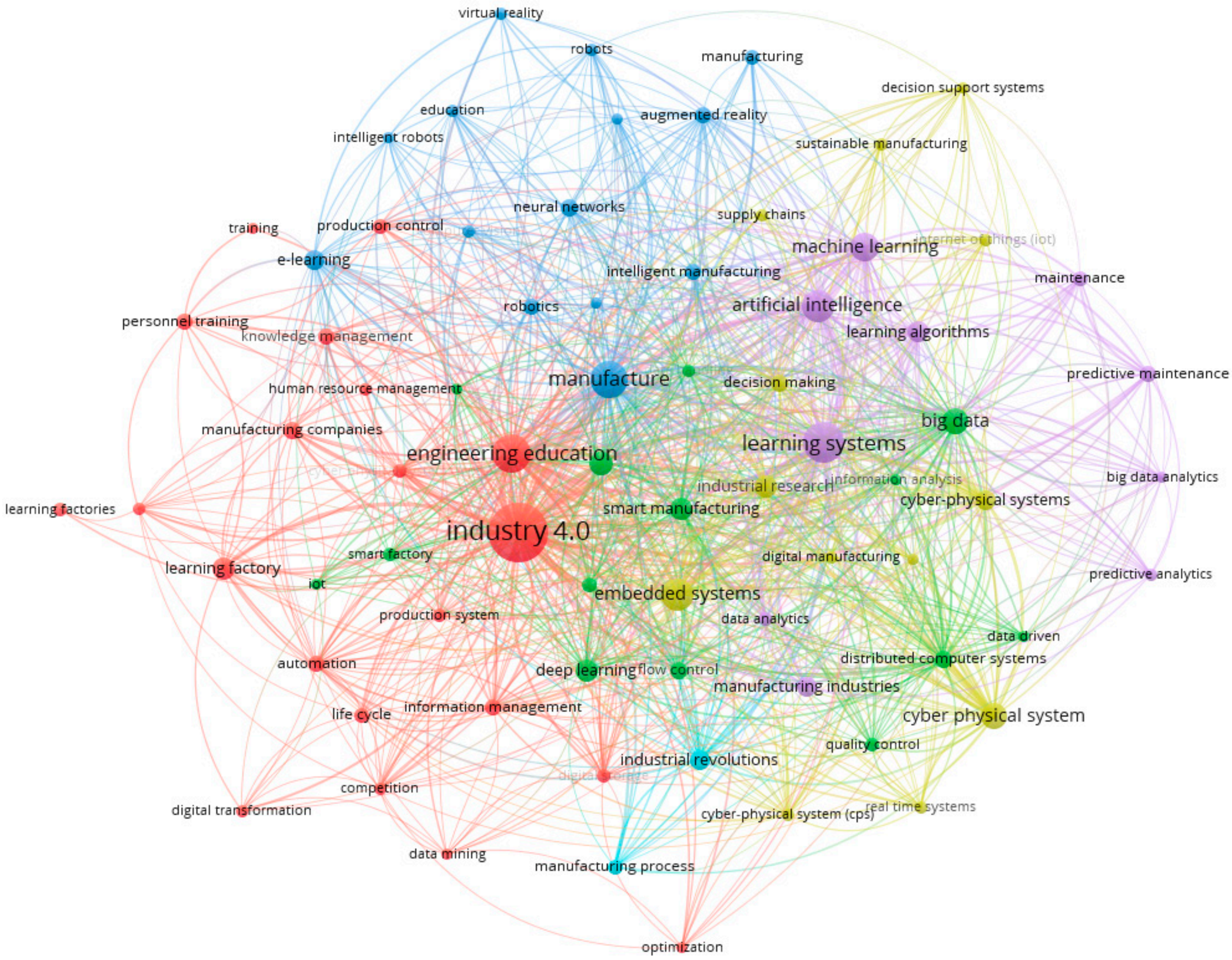

Figure 3. Keywords obtained from the Scopus-base search. Image obtained using VOSviewer software.

From the methodology followed, 203 papers were obtained, some of which refer to the Learning Systems area. Table 1 shows some of the authors associated with the drivers that appear in this area.

Table 1. Some authors associated to the area called "Learning Systems".

Area: Learning Systems		
Drivers	**References**	**Authors**
Learning Factory	[33]	Centea, D.; Elbestawi, M.; Singh, I.; Wanyama, T.
	[34]	Schallock, B.; Rybski, C.; Jochem, R.; Kohl, H.
Test Beds	[35]	ElMaraghy, H.; Moussa, M.; ElMaraghy, W.; Abbas, M.
	[36]	Elbestawi, M.; Centea, D.; Singh, I.; Wanyama, T.
Learning	[37]	Enke, J.; Glass, R.; Kreß, A.; Hambach, J.; Tisch, M.; Metternich, J.
	[38]	Küsters, D.; Praß, N.; Gloy, Y.S.
Training	[39]	Romero, D.; Bernus, P.; Noran, O.; Stahre, J.; Berglund, Å.F.
	[40]	Taylor, M.P.; Boxall, P.; Chen, J.J.J.; Xu, X.; Liew, A.; Adenijib, A.
Connectivism	[41]	Clinton, G.; Lee, E.; Logan, R.
	[42]	Siemens, G.

2.2. Bibliometric Study 2

In order to present the research focused on connectivist strategies, within the context of engineering and instructional systems, a bibliometric study was carried out. The reason for carrying out this analysis, related to the connectivist theory, lies in considering it as the learning theory for the digital era. This is of interest for its projection in the IC environment, as well as for the design of interfaces in manufacturing environments under Industry 4.0 [43], which entail the improvement in the acquisition and training of the required neuro-competencies.

Two types of information can be obtained from the bibliometric analysis, one that evaluates the performance and scientific production and the other related to the creation of associated maps that show the connection and evolution of scientific knowledge. The latter involves understanding the evolution of knowledge over time according to the degree of dedication of the scientific community at a given moment in time.

For this work, the software VOSViewer, developed by the Centre for Science and Technology at the University of Leiden (the Netherlands), is used [32].

For this study, the Scopus database has been consulted, using the search "connectivism", filtering results within the subject area of engineering, from January 2004 to July 2019, establishing the search in title, abstract and keywords.

Based on the frequency of occurrences and co-occurrences of the KWs, the terms obtained were identified automatically, choosing one instance as the minimum number of occurrences of a KW; 410 KWs fell within the established criteria, of which the 52 most representative are shown in Table 2.

Table 2. Representative table of the 52 KWs with the highest number of occurrences of the total 410 KWs.

Keyword	*Occurrences*	*Total Link Strength*
connectivism	27	325
e-learning	16	215
education	12	186
teaching	10	143
students	9	141
social networking (online)	8	109
collaborative learning	5	66
engineering education	5	75
knowledge management	5	74

Table 2. *Cont.*

Keyword	*Occurrences*	*Total Link Strength*
online systems	4	59
social media	4	49
computer aided instruction	3	55
distance education	3	45
learning systems	3	42
moocs	3	32
social learning	3	30
social networks	3	53
technology	3	41
virtual reality	3	51
web 2.0	3	22
world wide web	3	38
21st century learning	2	33
application programs	2	29
assessment	2	14
cognitive city	2	10
data mining	2	35
digital age	2	31
educational technology	2	30
fuzzy logic	2	10
higher education	2	17
informal learning	2	16
information and communication technologies	2	33
innovation	2	20
knowledge acquisition	2	17
learning	2	12
learning activity	2	21
learning analytics	2	14
learning environments	2	34
on-line education	2	24
online	2	19
problem solving	2	22
semantics	2	33
situated learning	2	14
smart city	2	10
websites	2	35
5-dimensional evaluation model	1	19
academic resilience	1	11
accreditation	1	10
activity coefficients	1	14
activity theory	1	14
adaptive capacity	1	20

KWs may be grouped into clusters. A cluster is a set of items included in the map. The size of the clusters was determined, among other factors, by the number of KWs in the cluster, as well as the frequency of occurrence of the KWs. The bibliometric density map shows the different clusters randomly associated with colours, as shown in Figure 4.

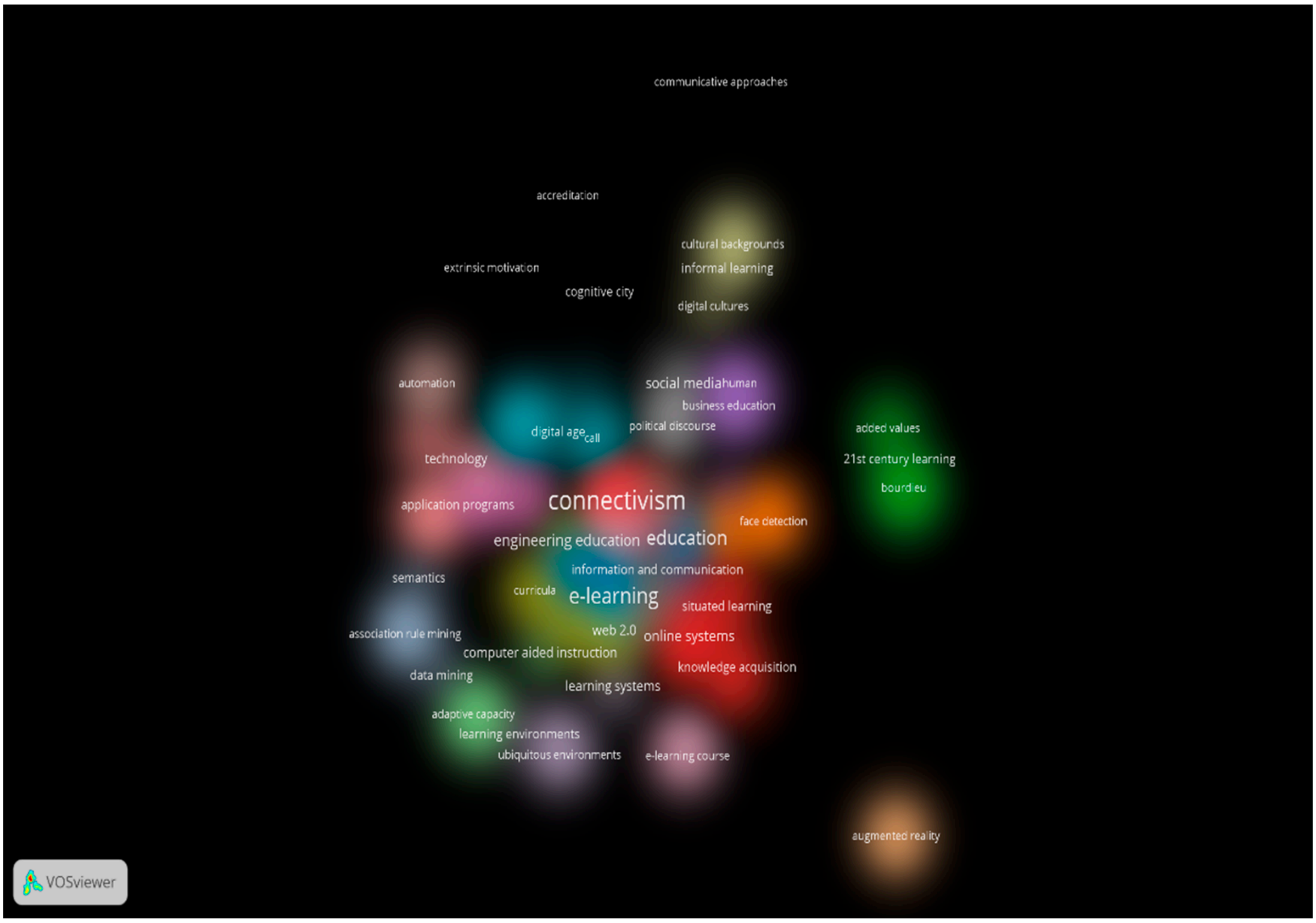

Figure 4. Cluster density map of the bibliometric analysis carried out. Image obtained using VOSviewer software.

There is a greater interrelation between the KWs forming the clusters located in the central area of the bibliographic map, while there is less interrelation between KWs in the clusters located in the margins of the map.

Figure 5 shows the density map formed by each of the 410 KWs obtained (due to the scale factor to be able to see the complete panoramic representation, only some of the 410 KWs that make up the density map can be named). It can be seen that the yellow areas show a higher density of co-occurrence of KWs than the green and blue areas.

This density map makes it possible to visualise the areas where there is a higher frequency of co-occurrence between KWs with greater weight.

There are maps that allow a temporal analysis for the identification of trends, analysing the evolution of the terms that have been carried out in the studied area.

The labelled bibliometric map in Figure 6 depicted emerging areas of study in relation to the established search. These areas are coloured yellow and correspond to the most current works published in relation to the field of study. This makes it possible to detect the keywords (KWs) with the greatest potential for study at present.

Table 3 shows some of the authors obtained from bibliometric study 2 based on the term “connectivism” within the subject area of engineering.

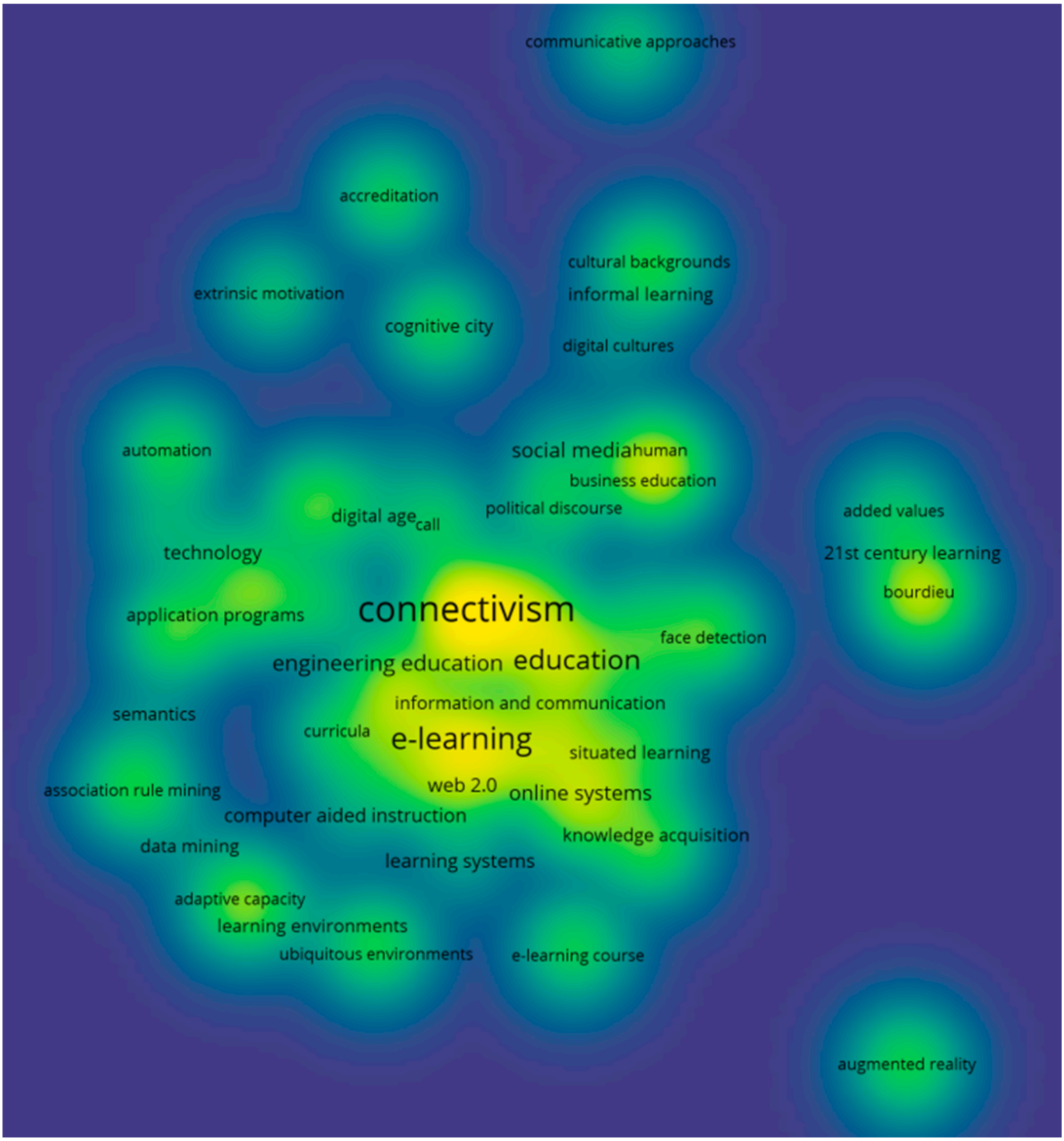

Figure 5. Density map per KW within the bibliometric analysis carried out. Image obtained using VOSviewer software.

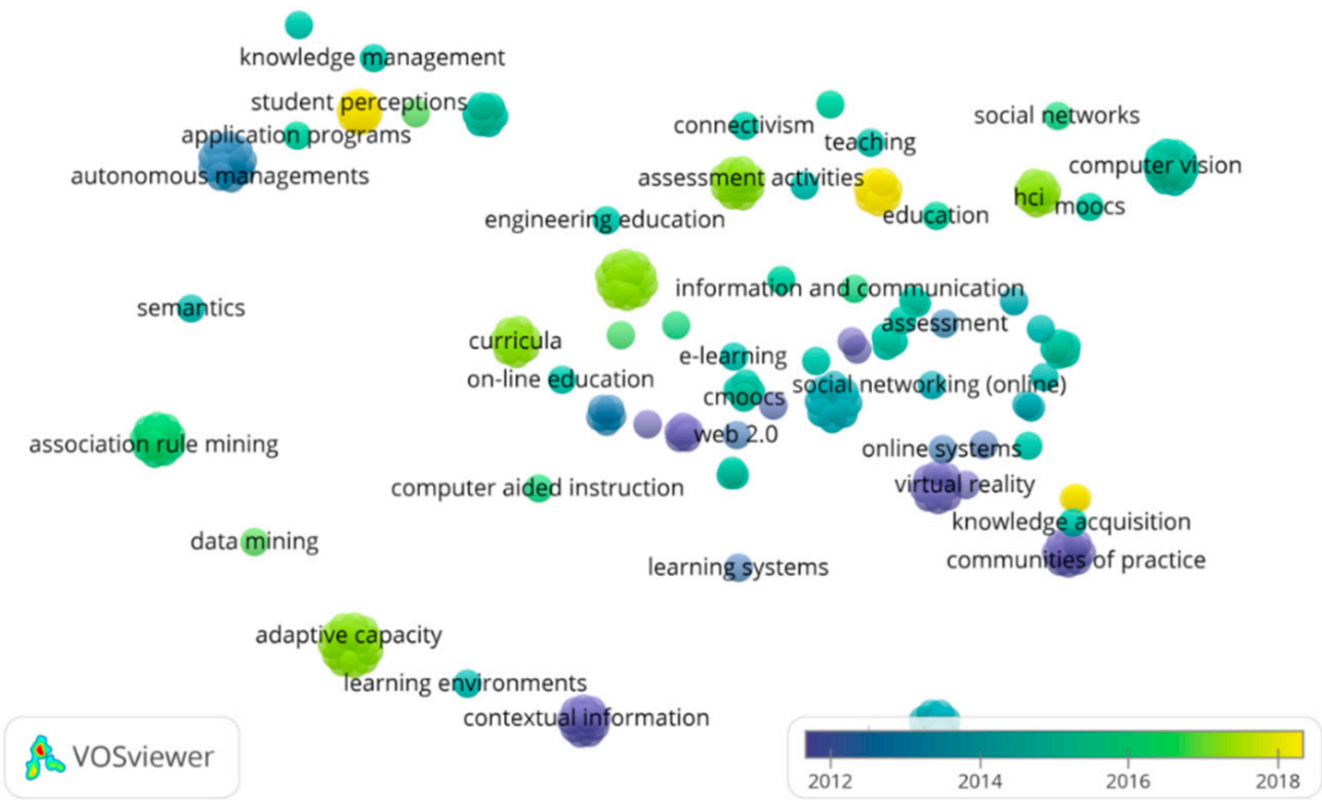

Figure 6. Bibliometric map for the identification of trends within the bibliometric analysis carried out. Image obtained using VOSviewer software.

Table 3. Some authors and their papers associated with the literature review related to connectivism.

References	Authors	Title
[44]	Wei, X.; Zhou, H.	Functional design of the virtual learning community based on the connectivism learning theory
[45]	Ebner, M., Lienhardt, C., Rohs, M. & Meyer, I.	Microblogs in higher education-a chance to facilitate informal and process-oriented learning?
[46]	Hemmi, A., Bayne, S. & Land, R.	The appropriation and repurposing of social technologies in higher education
[47]	Miralbell, O.	Social networking sites and collaborative learning in tourism
[48]	Yusof, S.I.M., Jumahat, T., Mohamed, Z., Ubaidullah, N.H.	A measurement model of connectivism in adopting web 2.0
[49]	Blot, G., Saurel, P., Rousseaux, F.	Pattern discovery in e-learning courses: A time-based approach
[50]	Downes, S.	Connectivism and Connective Knowledge: essays on meaning and learning networks
[51]	Rosa Yeh, C., Singhateh, B.	The effect of connectivism practices on organizational learning in Taiwan's computer industry
[52]	Kop, R., Carroll, F.	Cloud computing and creativity: learning on a massive open online course
[53]	Ioannou, O.	Design studio education in the online paradigm: Introducing online educational tools and practices to an undergraduate design studio course

3. Results

This section shows the results obtained from the methodology applied based on the bibliographic analysis of the authors and the terms (KWs) obtained through the application of the VOSviewer software. In the first bibliometric study, we obtained four areas of interest. Each area of interest contains associated innovation drivers. The area of "learning systems" contains the driver called "connectivism"; this is the term that has been analysed by the second bibliometric study, which was used for the design of the defined neurocompetence engineering environment. Finally, we propose our model of a neuro-competence approach for sustainable engineering for the implementation in a learning factory. This is the model that we have considered to be valid for dual education a training.

3.1. Results of the Bibliometric Study 1

The semantic field has been ordered by areas taking into account the influence of the term Industry 4.0 applied to the manufacturing sector. The areas of study generated in response to the instructional design drivers, and which are composed of a selection of keywords obtained from the database search, are the following:

- Digital transformation.
- Knowledge management.
- Learning systems.
- Life cycle.

The drivers associated with each of the areas are shown in the Figure 7.

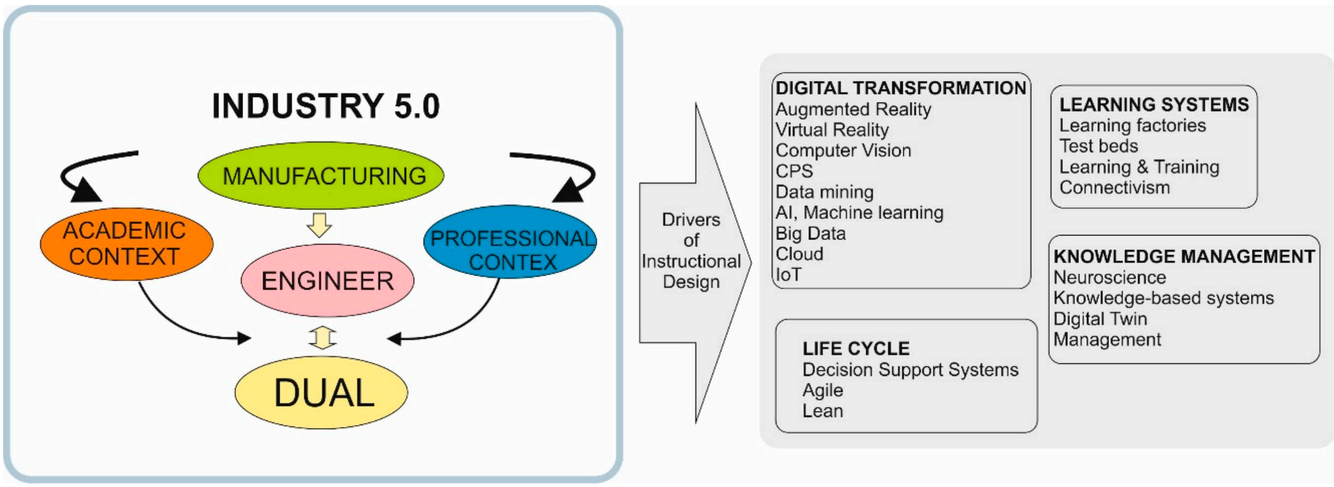

Figure 7. Drivers of instructional design.

The area of "learning systems" contains the driver called "connectivism"; this is the term that has been analysed by the second bibliometric study.

3.2. Results of the Bibliometric Study 2

The objective of the second bibliometric study was the identification of the most important publications related to connectivism, within the context of engineering and instructional systems. The main information retrieved is described below, in the literature review of connectivism.

3.2.1. Literature Review of Connectivism

The learning community has been described as a digital learning ecosystem composed of biotic and abiotic components [44], which consists of actors (learners, teachers, etc.), content and activities (teaching, learning, research, etc.). Social collaborative learning is combined with networked learning, so that engineers can study independently online or engage in collaborative learning anywhere and anytime. Wei and Zhou proposed six learning community models: the real-time discussion community, Bulletin Board Systems (BBS) learning community, course learning community, inquiry-based learning community, learning resource community and informal social learning community [44]. According to the eight principles on the instructional process in connectivism, these authors have designed a new model of virtual learning community based on high connection, a variety of activities, sufficient resources, encouraging information sharing and service, making the community more convenient.

In this sense, Web X.0 technologies enhance communication skills and can be used for formal instructional design [45–47]. Social networking sites have become part of learners' everyday lives [48]. These sites take into account the social nature of knowledge construction and together with Web X.0 entail the creation of personal knowledge in different contexts and with varied characteristics. Content management system (CMS)-type tools exist to customise home pages by creating different modules using different widgets.

Yusof et al. [48] have explored five factors of connectivism using principal component analysis and tested it using confirmatory factor analysis. This model of connectivism can be explained by five factors: diversity, openness, autonomy, interactivity and self-regulated strategies, which turn out to be fundamental for the adoption of Web X.0 in a given context.

In addition, a resource does not have the same impact at the beginning and at the end of a learning process, so a time graph can inform learners about priority and important tasks or resources to be achieved in a timeline [49]. In this sense, work has focused on eliciting interactions between learners and e-learning materials to discover patterns [50], such is the case of time graph representation based on social network analysis and the use of temporal metrics [54].

Introducing social collaborative learning in the professional context, Hurley and Hult [55] defined organisational learning as an organisation-wide activity to create and use knowledge to enhance competitive advantage, and there is a relationship between social networking and organisational learning. In this sense, some knowledge management practices included communities of practice and e-learning [51].

Regarding the possibility of offering access to knowledge in the form of courses anytime, anywhere, massive open online courses (MOOCs) have proved to be a clear example of this. They are online courses with the option of free and open registration. Therefore, their instructional design should be as open as possible, and it is useful to employ methodologies and techniques that favour peer-to-peer relationships focused on self-learning. In these cases, the social instructional process should be included in the form of blogs, wikis, chats and discussion forums [56]. There are two main types: cMOOC and xMOOC [57]. The first one is based on the principles of connectivism, whereas the second one has a broader conception. While cMOOC participants are expected to contribute through different platforms (e.g., blogs), xMOOC is offered on university-based platforms [58]. Four types of activities can be found within cMOOCs [59] that enhance the acquisition of neuro-competencies: aggregating, relating, creating and sharing. A feature that enhances the use of MOOCs is related to the production of digital artefacts by learners, rather than being mere consumers of technological products, which increases learners' engagement with their learning process [52]. It is more common to find tools and teacher feedback for the first one than for the other. Another difference between the two is that one is characterised by generative knowledge, while the other is characterised by declarative knowledge [60]. While the first one promotes the use of open licenses, the openness of the second one is limited [61]. On the other hand, iMOOC is a platform based on adaptive instructional process and information [62], in which the tools offered by the platform involve creating and choosing different groups by associating them with different course resources, containing features of both. In this sense, an experience was carried out to create a collaborative peer-to-peer environment to facilitate knowledge sharing [53]. The course was developed in a traditional, online and on-site classroom, whose teachers operated as content curators [63], using a MOOC platform for online transmission and as a repository of what was done in class. Another communication tool were blogs, considered as one of the main tools for competence acquisition in the context of connectivism. Blogs were used later for their presentations and as a record of students' group activities. Students used it at the beginning of the course to present their work. Their publication helped to determine the quality characteristics of the learner group. Skype was used as a way of communication, as invitation to lectures, while email was used for scheduling purposes, e.g., for last-minute announcements.

Another contribution of the connectivist paradigm has been found in the use of the computer vision algorithm in MOOCs, which can overcome the absence of a human trainer, and in this case, it is the computer that communicates with the learner. The methodology used has four phases: face tracking, face detection, connectivism and focus capture [64]. Finally, it should be taken into account that MOOCs generate a large amount of data on learner behaviour [60], which requires answering questions about the ownership and responsible use of this data [65].

3.2.2. Proposal

However, even with all the progress made so far, there is still a mismatch between the characteristics of the human factor and the type of the tasks to be performed, mainly due to the technological change experienced since the fourth industrial revolution [37,66]. The NCE model, which is proposed in the following section, can bridge this gap, reducing the complexity associated with the variety of the characteristics of the human factor and the tasks to be performed, both in the academic and professional contexts, through information and communication architectures integrated in the university and in the company [67].

This model facilitates the approach between the academic and professional context, focusing the operational efficiency of the model in terms of the use and minimisation of resources, which, together with the incorporation of the dual system, makes it possible to transfer knowledge bilaterally between the two contexts, managing to promote research and innovation more effectively [68]—see Figure 8.

A transformation is taking place in the demand for professional profiles associated with technical education and especially with engineering. This is fundamentally due to the requirement associated with the technological changes introduced, as well as related to knowledge management and sustainability, which makes it necessary to redefine the bases of productivity, employment and educational models. In the context of Industry 5.0, the importance of acquiring competencies centred on ICT, technological know-how and transversal competencies, such as those related to teamwork, decision-making, communication skills, resilience, creativity and permanent curiosity, can be observed. The effectiveness in the acquisition and execution of these competencies can be improved by neuroscience contributions in a quantifiable way through neurofeedback, which favours the continuous improvement process associated with EC [69].

In research related to cognitive neuroscience [70,71], for its projection in EC and the techniques that underpin it, such as neuro-learning [72,73] and neuro-education [74,75], the relationships between the brain processes associated with the different cognitive functions that are involved in the acquisition of competencies and their instruction are studied. These include neurocognitive processes associated with attention, motivation, emotions, affect, memory and planning, the knowledge and management of which will determine more efficient processes for engineers in the acquisition and management of their competencies. Among the techniques that provide information related to the nervous system is EEG, which measures the electrophysiological activity of the brain [76]. With this technique, electrodes can be placed on the scalp, on the cortical surface or intracerebrally, involving the analysis of the brain's electrical fields, with the placement of electrodes on the scalp being the standard EEG modality, Figure 9.

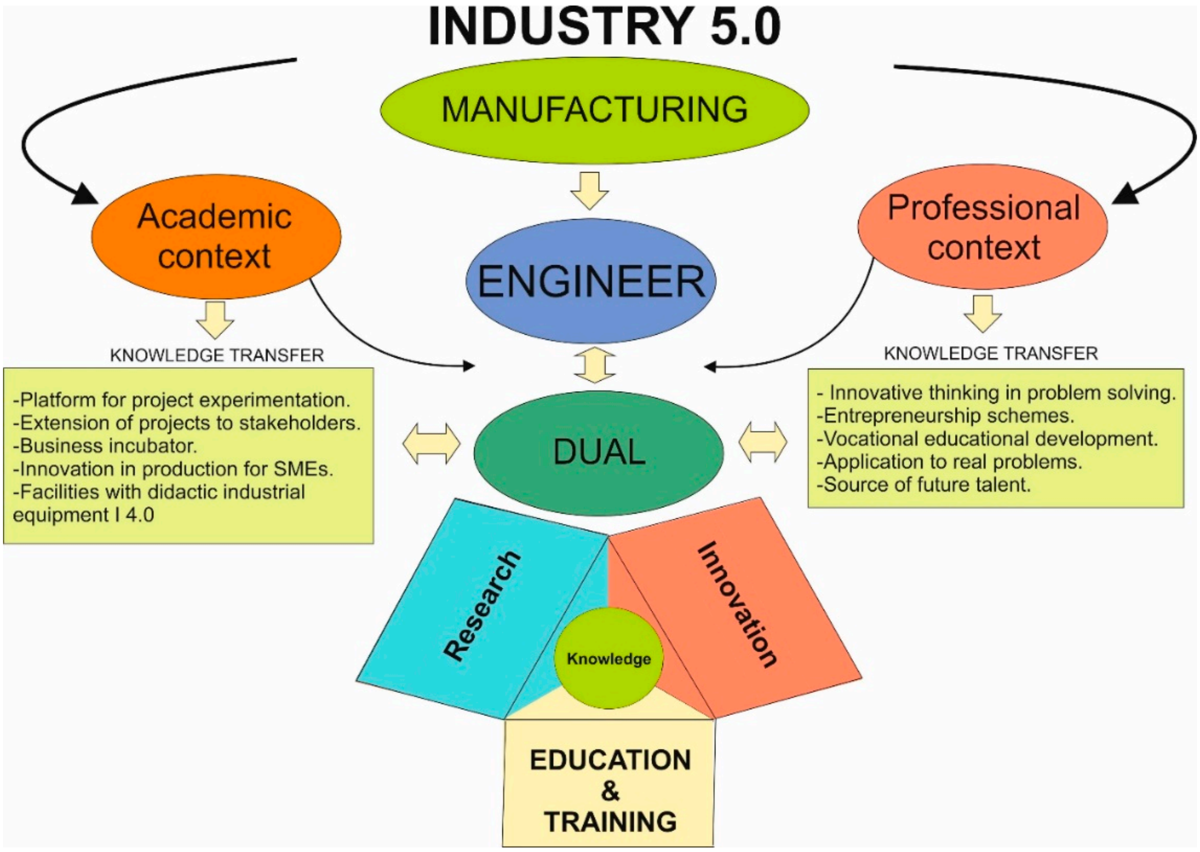

Figure 8. Model of introduction between the academic and professional field.

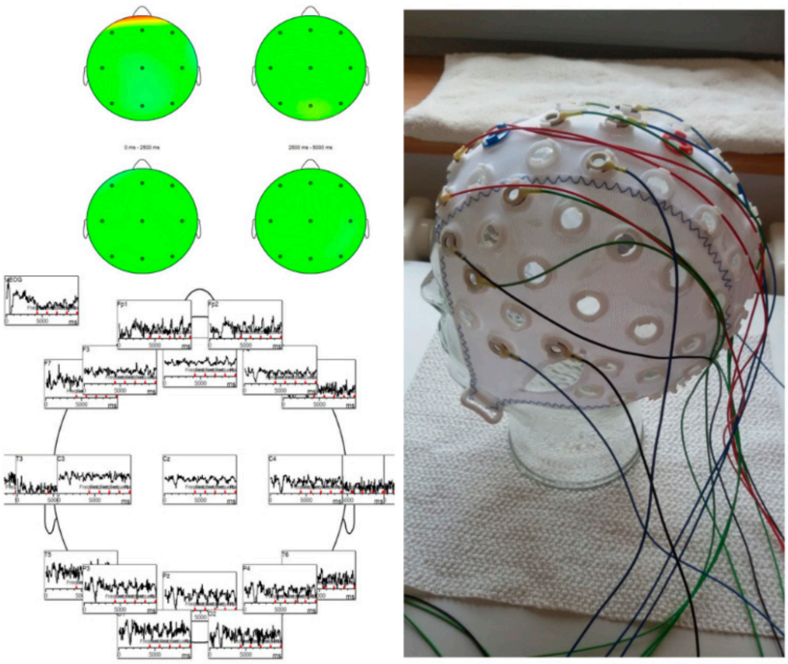

Figure 9. Electrode scalp for data collection via specialised software for localization of the engineer's brain activity while performing a task using EEG. The image on the left was obtained using the software Brain Vision Analyzer.

At the beginning of the last century, the surgeon Krause began the study of the cerebral cortex by electrical stimulation and published a diagram of the areas of cortical function for the treatment of epilepsy [77]. Brodmann, for his part, established more than forty areas and defined associated functions for the different brain structures, publishing the map of areas of the cerebral cortex in 1909 [78]. As an example of what Brodmann studied, five areas of executive function are listed below:

- Areas 9 and 10: dorsolateral-anterior prefrontal cortex (DL-APFC).
- Area 44: pars opercularis.
- Area 45: pars triangularis.
- Area 46: dorsolateral prefrontal cortex (DL-PFC).

The structure of a competence from a cognitivist perspective implies the acquisition of cognitive, affective and metacognitive components, which are associated with technical, contextual and personal domains, supported by basic cognitive processes such as attention, motivation and memory [79]. This vision of competence has to be expanded and updated to include neurophysiological studies, under which the importance of considering the neurobiological part of the human factor and its application in the academic and professional fields is established. The foregoing leads to the study of the role that this part plays in the identification, specification, planning, acquisition and implementation of the competencies required by the engineer (as the human factor) within the SCSSM, compared to the technological component. The human factor thus becomes the priority study factor when we are designing, establishing and developing SCSSM 5.0.

The concept of neuro-competence is defined as a set of knowledge, skills and abilities to particularise a specific fulfilment in a given context, with a neurocognitive and neurobiological substrate. This makes it possible to redefine the concept of competence by transposing it to the field of the application of neuroscience, involving its acquisition and improvement through education and training, aided by techniques such as neurofeedback. Figure 10 shows the scheme that structures neuro-competence.

This makes it possible to establish the link between competence and the neurobiological component associated with the human factor, which generates the matrix of competence relations in Figure 11, which is composed of the relationship established between the cortical areas defined by Brodmann, the cognitive functions, as well as the skills and capabilities of Operator 5.0.

The competency-based instructional approach in the academic, professional and dual environments makes it necessary to develop an NCE model. It is centred on the human factor through the AT and LVR, in which technologies and methodologies are incorporated for the acquisition of competencies based on neuroscience, through the use of the connectivist paradigm, taking into account its development under the criteria of minimum complexity based on its fractal nature. Intelligent information technologies, cyber-physical systems and distributed systems make academic, professional and dual instructional environments possible, in order to facilitate learning situations based on digital twins of students and operators in the cloud, enabling the management of data in real time for competence management appropriate for the requirements given in real time.

The NCE makes it possible to achieve the necessary improvement to make the collaborative work between the human and technological factor effective, focusing the interest of the first and adapting the configuration requirements of the second to those interests through adaptative interfaces. The foregoing affects the achievements of the SDGs established by the UN, as well as in the fulfilment of the objectives of Horizon 2030 proposed, and it is achieved through the identification, specification, planning, acquisition, implementation and evaluation of the engineer´s competencies throughout their academic and professional life cycle—see Figure 12.

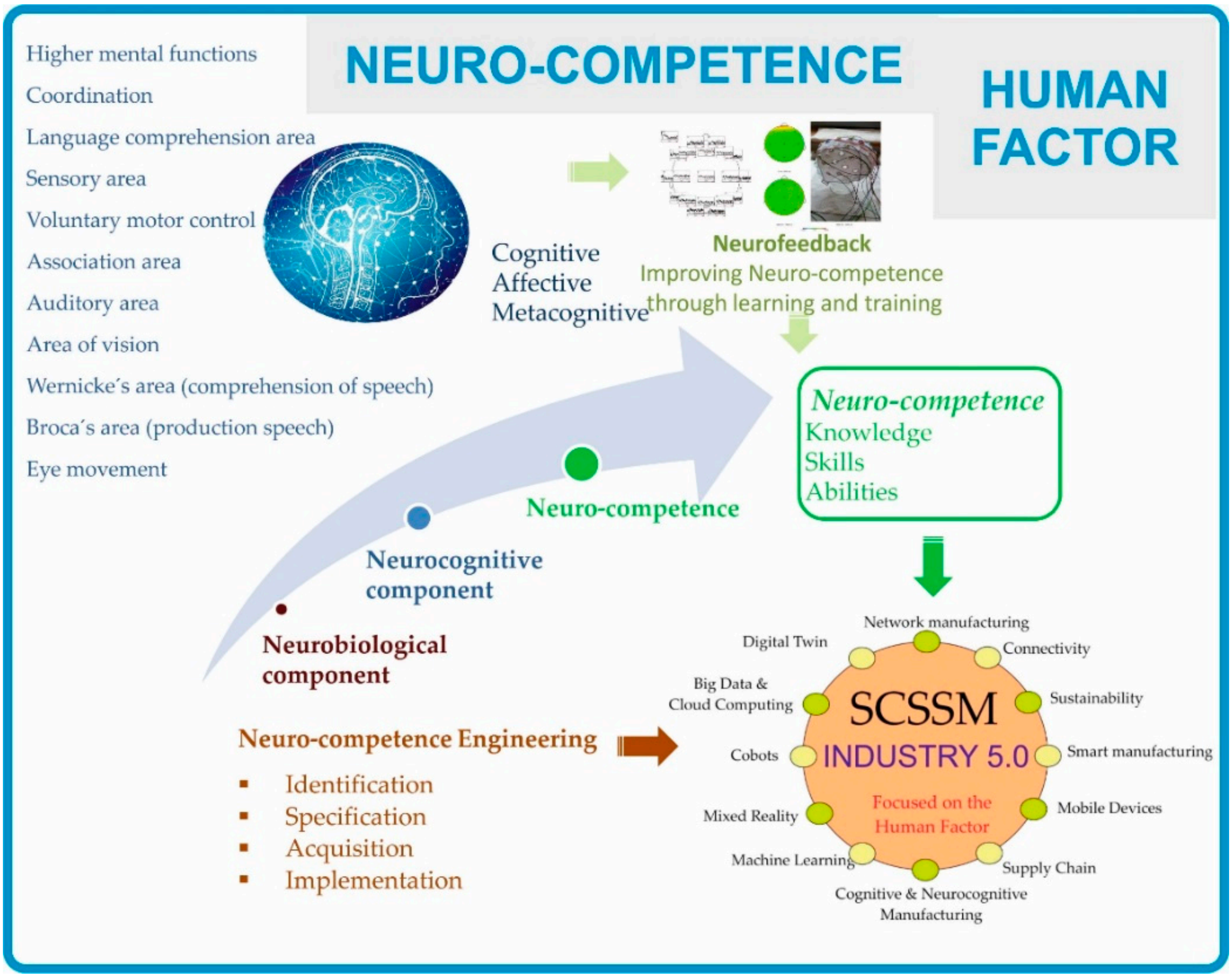

Figure 10. Neuro-competence of the human factor.

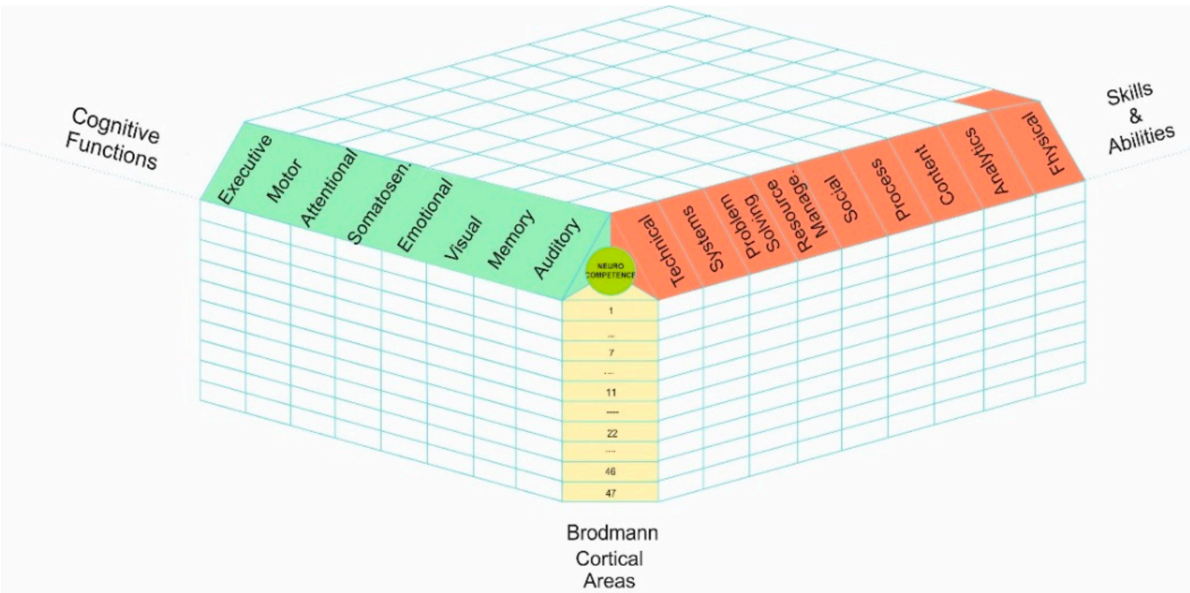

Figure 11. Competency relations matrix.

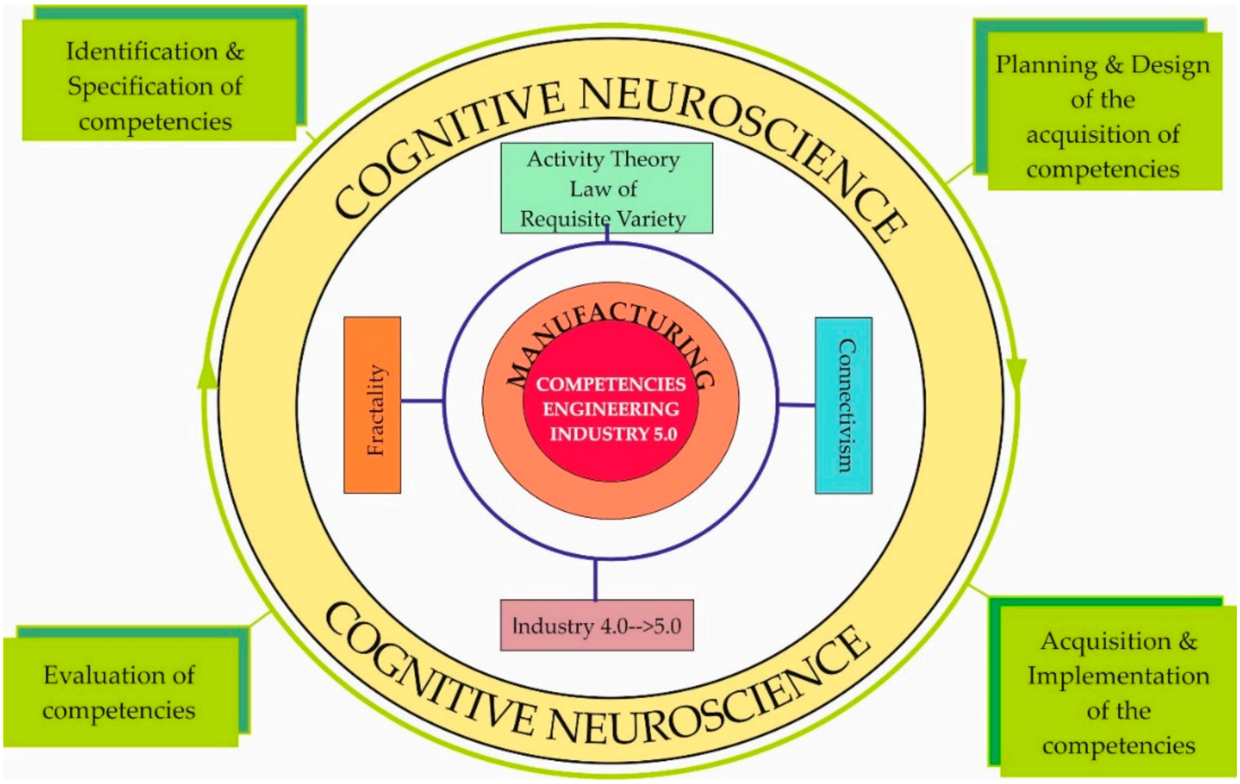

Figure 12. Instructional design model for Horizon 2030.

The elements interaction of the SCSSM is described through the AT and revolve around the human-centred design of the system, which takes into account its particular neurocognitive, physical and psychological characteristics. The analysis of these characteristics by means of the LVR establish a process design in accordance with the tasks to be performed by the engineer. The appropriate design of the human–machine interface requires this adjustment at the level of execution, communication and co-evolution in the smart factory in real time. The characterisation of competencies based on neurophysiology transforms them into neurocompetencies, which entails the transition from characteristic to parameter, which in turn leads to better quantifiability, replicability and scalability.

In this sense, virtual reality technologies through the simulation of contexts reproduce real manufacturing conditions, so that operators or students, through haptic devices, can interact with the system to carry out analysis and predictive maintenance. In addition, there is the possibility of monitoring neurophysiological reactions through biosensors during the simulations, involving the novice professional to reach the level of expert in a shorter period of time under controlled operating conditions [67], which may be of interest to companies seeking the highest possible degree of professionalism in their engineers. This large amount of data from the monitoring of the human factor at the physiological level, mental workload and achievement of results from the realisation of the assigned task, can be integrated centrally in the cloud through the information and communication system of the company or university itself.

The NCE, by adopting a process engineering perspective, makes it possible to systematise the design and management of the neuro-competential process through the support of neurophysiology, becoming an instrument for continuous improvement at an instructional and professional level. This is made possible by entailing the design and development of quality instructional actions adapted to the characteristics of the engineer and the variety of tasks to be carried out. In this way, the human factor is technologically assisted by intelligent systems and adaptive interfaces with the necessary connectivity within the SCSSM 5.0, Figure 13.

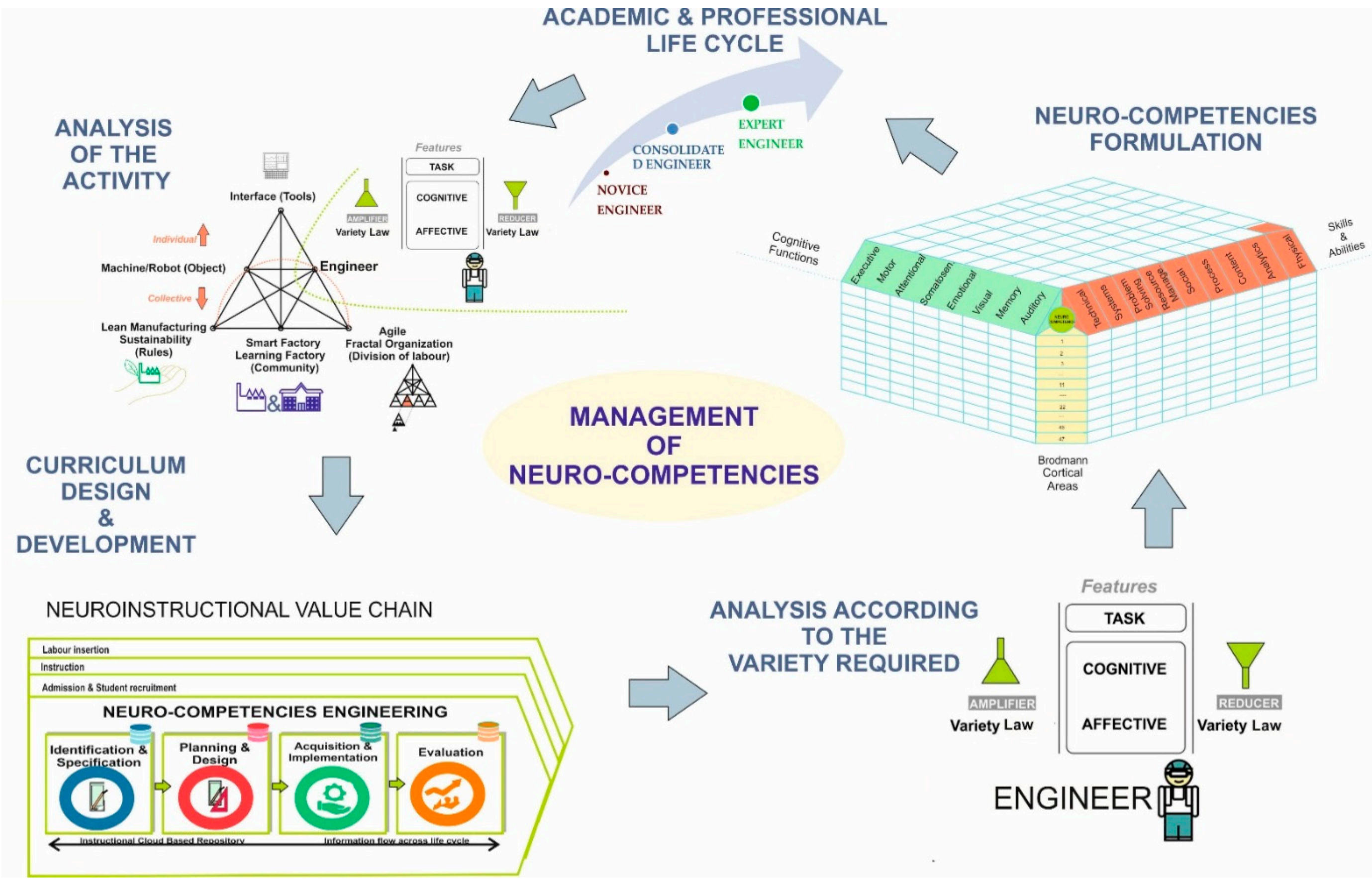

Figure 13. Neuro-competence management model.

The neurocognitive processes associated with engineering instruction will operate at three different levels [79]:

- Low level, where the uptake, registration and meaning of information, such as sensory, perceptual and attentional processes, take place.
- Medium level, involving memory, learning, oral and written communication.
- High level, such as reasoning, creativity, decision-making and problem-solving.

The development of the NCE model in the academic and professional context involves the articulation of a set of processes, with a series of inputs (objectives or requirements) and a series of outputs (acquired or deliverable competencies, human and technological resources). The complete process is conceived on the basis of a modular architecture that makes it possible to reduce its complexity and the effort associated with its realisation [80,81]. This approach has also attracted the interest of researchers in instructional process design, who have called it a fractal curriculum [82]. In this sense, the presence that fractality has had with respect to the goal of minimising the static and dynamic complexity of manufacturing systems is noteworthy, giving rise to a field of research and professional practice called fractal manufacturing [83–85]. This reinforces the idea of keeping it in mind in relation to the NCE model.

To reduce complexity, a fractal approach is used, geared to the possibilities offered by a rapidly expanding digital environment. Learning is no longer an activity that takes place on an individual level, but also on a social level, and consists of the process of connecting specialised nodes or sources of information that provide support during the instructional process [86], demonstrating the importance also of considering connectivism theory in the complete process.

It is proposed to fractalise, starting from a basic structure, and to progressively incorporate complexity in the instructional design and implementation, serving recursively throughout the academic and professional life cycle of the engineer. To this end, we can recognise a first design at the macro level formed by the didactic programme, a second meso level that corresponds to the didactic or work unit and a third micro level of the design of the learning situation. The objectives, contents, methods and evaluation will be the axes from which this fractal geometry will continue to develop. Each activity system develops a mediated interaction of people, environments, rules and tools established for that system.

In addition, taking into account the social nature of learning, the term social cognition is incorporated, which encompasses the cognitive, perceptual and behavioural processes that occur in interactions at the social level. Social neuroscience is a branch of cognitive neuroscience that studies the biological bases of social behaviour, in relation to social and behavioural processes, using the techniques of neuroscience [87]; however, while neuroscience is focused on the study of the individual, social neuroscience focuses on the interaction of several individuals [88]. Its contributions in intelligent manufacturing are focused on human–human, human–robot interaction and social behaviour between robots. The foregoing involves understanding the cognitive and social processes that arise from the interaction between the elements that constitute the SCSSM, focusing its attention on the design and cognitive processes associated with them, in relation to the interfaces required for effective collaboration between the elements of the system. Furthermore, it can be found in conjunction with the study of augmented cognition and operational neuroscience that are concerned with monitoring the cognitive state of the engineer as the operator using biosensors [89,90], which facilitates a more ecological approach between the elements. Thus, it is possible to explain social cognitive and affective processes using three levels of analysis [91–93]:

- The social perspective, taking into account attitude, culture and motivation.
- The cognitive perspective, focusing on social information processing.
- A perspective focusing on the neural substrates associated with the previous perspectives.

In the professional field, it is applicable in affective, natural and personalised human-robot communication [94,95]. The aim is to replicate the ability of humans to make inferences about the mental states of other humans, as well as their ability to anticipate certain situations [96–98]. In these cases, the concept of mirror neurons is applied in robot-to-robot communication [99]. There are also studies related to this type of neuron, in which an increase or decrease in the activation of certain brain areas during social interaction varies depending on whether the other member of the social interaction is a human or robot. The aforementioned studies establish that the more humanised the robot is, the more areas of the brain are activated in relation to this characteristic [100,101]. Applications of social neuroscience have been studied in relation to BCI such as emotion detection or EEG control of robotic arms [102,103].

In the academic context, social and emotional components are also found in addition to cognitive and behavioural ones, with applications focused on cognitive processes related to attention, memory and decision-making [104,105]. In learner-centred learning, the role of the learner is active and collaborative with other group members, forming learning communities as knowledge networks through the connectivist paradigm [106,107], emphasising the social and cultural role [108] contained in the learning process, which can be characterised through activity theory [109,110]. In this sense, social neuroscience can favour learning, accelerating it through online tutorials that model the cognitive and affective states of the learner by optimising the educational material that is presented to the learner, for instance, through the use of an app. For the modelling of the cognitive and affective states that entail the design of the educational material, EEG, eye-tracking and biosensors, among others, can be used to empirically evaluate the degree of achievement of the goals pursued. The same usefulness can be found in the study of emotion, demonstrating that it plays an important role in the learning process [111].

In this sense, a future line of work is opened up, which will entail integration at the educational and training level of the contributions of cognitive neuroscience through the concept of neuro-competence, continuing the development of neuro-instruction in the context of the acquisition and management of competencies associated with engineering, both in the academic and professional context.

4. Discussion

The work developed constitutes a contribution to curriculum design and learning environments for the development of sustainable disciplinary neurocompetences, proposing an instructional engineering environment for the development of neurocompetences for sustainability supported by ICT in the contest of the emerging needs of dual education and training.

The competence engineering model constitutes a framework for organising the complex instructional processes, which are associated with dual education, the digital transformation of instruction and the neuroinstructional approach as a driver of innovation. This is an extension of constructivist instruction with a socio-cognitive orientation, supporting the ubiquitous and embedded character of competences, as well as the sustainability of the different elements of curriculum design and implementation.

The proposed model is limited in terms of the concreteness of its elements, although it provides the value of a proposal under emerging elements of innovation derived from a bibliometric and bibliographic analysis that incorporates the dimensions of innovation shared by the scientific community. It is not possible to compare them with other similar studies as no research areas have been identified along the lines of the proposal formulated in this work.

From the formulated proposal, research areas can be derived for the development and concretion of the model, among which it is possible to consider unified models with ICT technologies for dual training that incorporate training in sustainable disciplinary competences in both the academic and professional contexts.

The implications and techniques of the findings are especially significant for the unification of enterprise learning models through lessons learned in projects and academic models, the incorporation of ubiquitous learning, online, AI supported by ICT, as well as neurodesign and neurolearning, in what we could call instructional design for the brain, and, most importantly, the incorporation of the three dimensions of sustainability into disciplinary learning with the potential of telecommunications and information technology.

5. Conclusions

As we discussed in the introduction section, the proposal and its projection to Industry 5.0 from the SDGs established by the UN for the 2030 Horizon constitute an opportunity for the configuration of instructional systems through the use of intelligent systems and adaptive interfaces, applicable to engineering in both academic and professional contexts or under dual models. The foregoing requires new instructional approaches in which the synergy of academic and professional knowledge is articulated, based on the contributions of KETs and intelligent ICTs. This requires the development of new reference models such as the NCE model, in which the contributions of cognitive neuroscience, the fractal curriculum and connectivism are articulated. This enables a model of ubiquitous learning and training throughout the academic and professional life cycle of the engineer, which is placed at the service of continuous innovation and in which the human factor is the central part of the socio-technical cyber-physical instructional system.

The work carried out has identified the emerging areas of innovation through bibliometric and bibliographic studies, as well as their articulation in the proposal of an instructional engineering model for the development of sustainable disciplinary neurocompetences, supported by ICT and AI in the context of future dual education.

The formulation of the proposal lacks the degree of generality and necessary concreteness, as befits disruptive research work, since the research developed constitutes an instrument for the development of the theory of digitised, sustainable and far-reaching dual instruction, to be developed through future research.

The proposed concept of neuro-competence, from our point of view, is of great heuristic value for the development of a new model of the curriculum, and for its implementation, both in teaching and learning, with a clear neuro-cognitive orientation, taking into account the natural way in which the brain processes information.

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