ICT tools use in the scope of education in Engineering: a systematic review

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Abstract

Information and communications technology (ICT) has an enormous impact on defining what the classroom and the learning process are in the 21st century. It became necessary to include these resources in the educational environment to improve and make the educational process more efficient. The objective of this article is to identify the ICT educational tools developed, associated, and applied in the field of higher engineering education (EE). Therefore, a Systematic Literature Review (SLR) is performed to consider the different tools present in interactive learning environments and the context in which they are applied. The research questions developed through the PICO method are: What ICTs (interactive tools) have been developed or found to enrich the different smart learning environments and engage active learning in engineering in the past three years? This is then deconstructed in sub-research investigation questions: Q1: How many ICT tools with application in Higher Education for Engineering have been developed or applied in the last three years? Q2: Which are the areas of application or subjects in which its use is appropriate? Q3: What role do the ICT tools perform in the educational process or in the different teaching-learning environments? The SLR allowed to identify the areas for further exploration, grouping them together and explaining the purpose of the different tools and their application. VOSviewer was used to visually analyse network maps of co-occurrence of authors keywords, as well as others that prove to be decisive in characterizing the methodological approach to teaching and in the categorization of tools. Active learning classrooms are now and, in the future, the key point to the evolution of teaching and learning. Its determinant to understand what is currently being developed in this domain for more efficient and fastest adaptation of these valuable resources.

Keywords: ICT; Active Learning; Engineering Education; Interactive tool.

1 Introduction

Information and communication technology (ICT) is considered, nowadays, critical to the quotidian activities, success of companies and a good ally of education (Chandra & Fisher, 2009). Interactive and communicative content can improve the quality of education, transforming learning into an exciting and productive process (Palioura & Dimoulas, 2022). Education must be adaptable to the effective context and because of the conceptualization of the present reality, the educational process currently includes criteria such as multidisciplinary, intradisciplinary and cross-discipline approach (Sodikin, 2017).

The growing awareness of the need for technological innovation is now also a priority for engineering education, with the acquisition of knowledge and development of skills becoming more dynamic through diversified educational methods, the traditional approaches become less inefficient in today's society (Mayer, 2003). For that, it is necessary to adapt and develop resources to engineering, including a multidisciplinary approach that involves the different content of areas related to each concrete study program, to facilitating the development of teachers' technological and pedagogical content too (Heulingn & Wild, 2021).

The potential of digital technologies is distinguished by the cognitive stimulus provided to students (Batyrkhanov et al., 2022), which can constitute learning, research, communication, collaboration, construction, expression and even evaluation content (Zhu et al., 2016).

2 Literature Review

This chapter presents a review of the main concepts related to the theme, including the definition and aim of ICT tools and active learning.

2.1 ICT tools

ICT tools are related to who and what students use, acquire and adapt using technology. Digital competencies, digital literacy, information and computing literacy, internet skills, and ICT competencies and even 21st century competencies are concepts related and directed towards digitization and the use of ICT tools (Ainley et al., 2016; Hatlevik & Christophersen, 2013; van Laar et al., 2017).

It was verified that the ICT definition depends on the enormous number of concepts related to values, attitudes, and knowledge of digital technology, which originated multiple definitions that later support these concepts. The advancement and availability of technological devices led the specialists to agree that the implementation of ICT literacy (students´ use of digital and communication tools) changed (Erstad, 2006).

In the European framework for digital competencies, a more detailed definition declares it as a "confident, critical, and creative use of ICT to achieve goals related to work, employability, learning, leisure, inclusion and/or participation in society" (Ferrari et al., 2013). More recently Sumaimi and Susilawati (2021), affirmed that ICT tools are a "combination of technological devices and resources, which are used to manipulate and connect information. ICT is currently a major player in the education system, bridging forms of knowledge and literacy, the intersection between places of study, homes, schools, workplaces, and communities."

In the scope of the different ways to define the concept, it is clear that ICT tools are related to information and communication and this conceptual expansion is related to the extension, development, and involvement of the different ways to include ICT in the quotidian and inclusive in the aim of education.

2.2 Active Learning

Active Learning is defined by Prince (2004) as "adopting instructional practices that engage students in the learning process". Different methods implemented in the scope of active learning intends to provide a dynamic and effective way to assimilate knowledge making this approach more efficient than the traditional, improving conceptual learning. Felder et al., (2000) show that the following eight methos are intrinsically connected with engineering education engagement: use instructional objectives, reveal the material is relevant, teach inductively, balance concrete and abstract information, use active learning, use cooperative group learning, make fair test challenging and show concern about student learning. Active learning involves different methods (flipped classes, cooperative group learning, panels, debates, quiz shows, service learning, PBL, among others) but for implementation of this type of learning is essential to adopt technologies, especially nowadays, in the classroom or in the learning environment.

Smart learning environments or smart classrooms are supported by technology and digital devices and aims to reach all students improving student-teacher interaction (Mikulecký, 2012), involving students, instructors or an instructional system, depending on the settings of learning and support staff that can be designers or technical specialists being necessary the inclusion of class´s culture, course, institution and community (Spector, 2014).

Smart classroom empowers smart education (Uskov et al., 2015) that allows flexibility learning related to time and place (Zhu et al., 2016) allied with the appropriate pedagogical approaches, strategies categories for studying, and the employment of ICT tools (Venkatesh et al., 2014).

3 Research Methodology

To achieve the research purpose, firstly we consider the PICO (Patient or Problem, Intervention, Comparison, Outcome/s) method, that helps to define the aim of the search based on critical questions, as in this case (Akobeng, 2005). Afterwards, a Systematic Literature Review (SLR) was carried out, based on The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA; Page et al., 2021). Finally, the VOSviewer (version 1.6.16), a software tool that supports qualitative analyses, was used helping the bibliometrics analysis namely the co-occurrence analyze of keywords visually (van EckNees & Waltman, 2019).

Related to PICO the problem or population that is fundamental for this research is the higher education community. In the scope of the intervention, it is presented the problem of developed ICT tools in the final year and after Covid-19. One of the objectives of this research is to compare the tools developed in the scope of the different curricular areas of engineering. Hence, the outcome that is intended to achieve with this research is to associate the different tools found with the SLR and with the different areas or curricular unities (CU) of engineering. The main research question is: Which are the ICTs (interactive tools) developed or found for enrich the different smart learning environments and engage the active learning in engineering in the past three years? This is deconstructed in the tree sub-research questions: Q1: How many ICT tools with application in Higher Education for Engineering have been developed or applied in the last three years? Q2: Which are the areas of application or subjects in which its use is appropriate? Q3: What role do the ICT tools perform in the educational process or in the different teaching-learning environments?

The subsequent flow diagram of the results obtained in the different application stages of the PRISMA method from 2020 is shown in Figure 1.

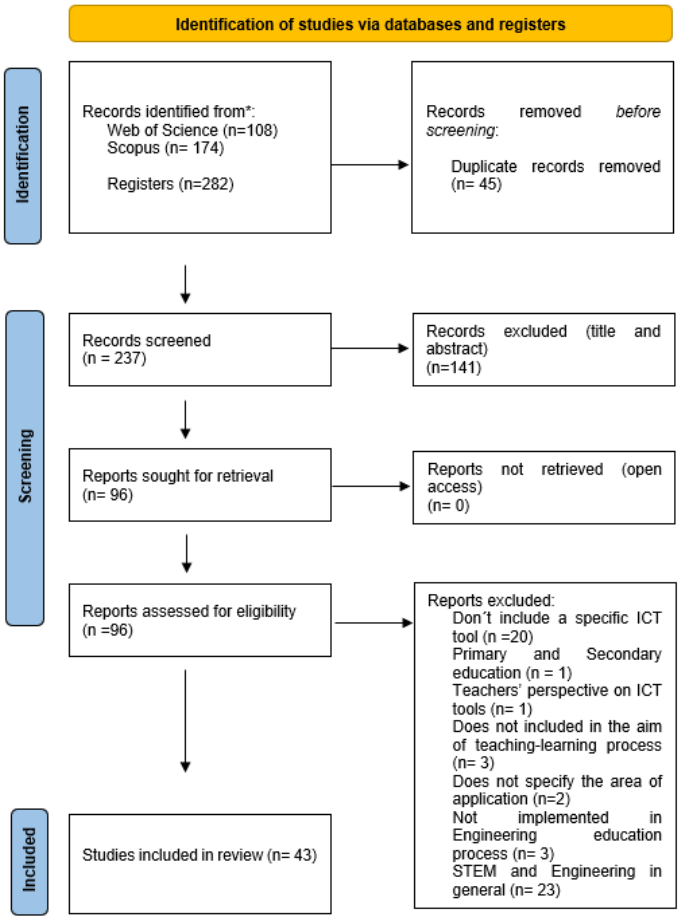

Figure 1: Application scheme of the PRISMA method (Page et al., 2021)

This research covered a set of 2 global databases (Web of Science and Scopus), from January 2020 to February 2023. The following string: "((("smart learning environment*") OR ("active learning") OR ("teaching") OR ("learning")) AND (("interactive tool") OR ("ict")) AND (("engineering") OR ("engenharia")))" was used, considering title or abstract or author keywords. Initially, due the large number of results in WoS (n=1, 685) and Scopus (n= 2,604) was applied the language filter (only English or Portuguese papers) and exclude all the results that do not have open access on either database.

An analysis of the selected articles (n=43) was, afterwards, performed. With the reading, it was possible to retain the included tools, organizing them by the area of engineering to which they belong, and an analysis was also made of their purpose and use in the teaching context, as shown in Table 1.
This analysis allowed to understand that tools are related to certain teaching methodologies approaches which leaves us to believe that they are developed for reinforcing active and practical learning.

4 Discussion

For better understanding and description of the main areas, concepts and focus of investigation the software VOSViewer was used to visually analyze the network maps of co-occurrence of keywords. The analysis was performed based on the keywords identified by the authors of the scientific articles. A total of 218 keywords were considered, being that all keywords appeared at least once and seven appeared at least three times. Figure 2 and 3 showed the overlay and network maps of keywords co-occurrence, respectively. Of the 218 keywords, only 125 are connected to each other. The size of circles represents the occurrence of a keyword, the thickness of the connection line shows the proximity of relationship between two keywords.

Figure 2 shows that, apparently, the emerging of virtual laboratories has a strong relation with chemical engineering (Martin-Villalba & Urquia, 2022), but this concept is also relevant in other areas such as electrical, environmental and maintenance engineering as identified during the SLR (Dong et al., 2020; Guo et al., 2022; Kans et al., 2020). It is also important to highlight subject areas as "computational fluid dynamics" (CFD) and "backtracking" by the relationship maintained in the different year (Gajbhiye et al., 2020; Seddighi et al., 2020; Solmaz & Van Gerven, 2022). "Adaptation" is a word that is commonly used not only in the context of learning-teaching methodologies but also of tools, a reaction possibly triggered by the experience gained with the pandemic and the need to adapt and digitize educational resources. In contrast "covid-19", "blended learning" and "moodle" are concepts that have been explored for a longer time, in the wake of the post-pandemic. The dimensions and behaviours of "engineering education" and "higher education" seem to follow a natural path as these are terms whose functions remain intact over time Over time, the preferred teaching strategies and tools evolve, as a result of innovation and improvements made in the teaching-learning process, as can be seen in the cases of "blended learning" of "moodle", these are more associated with the years 2020- 21 and more recently "online teaching", "gamification" and "adaptation" in a more recent era, as well as in the field of technological tools, "backtracking", "virtual laboratories", "visualization" are starting to be highlighted. associated with 2022, thus also contributing to the development of active learning.

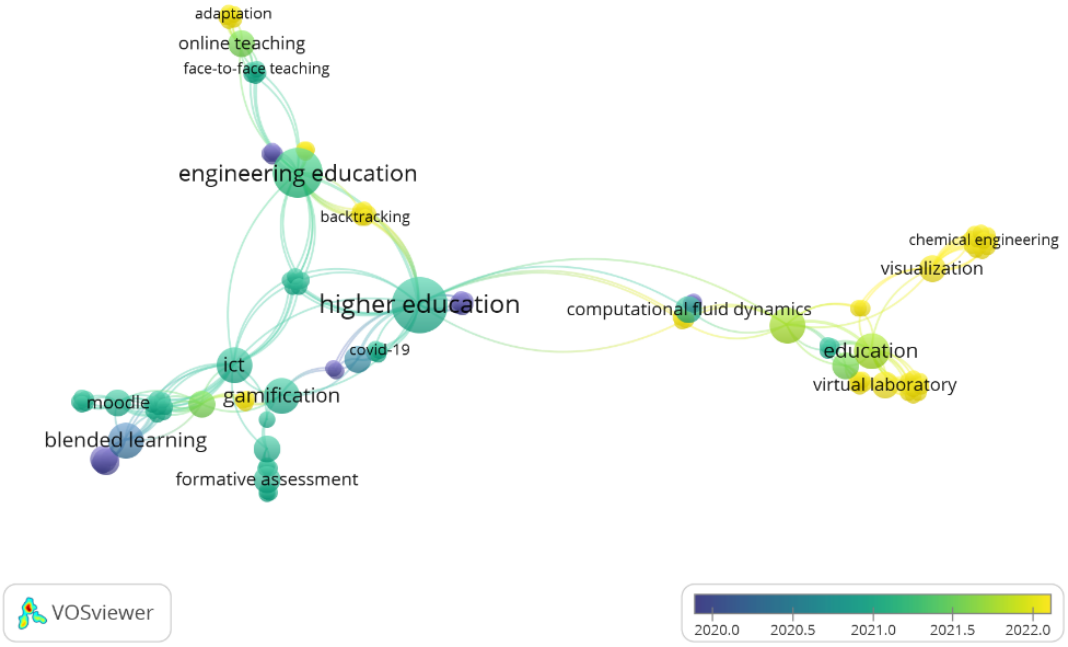

Figure 2: Overlay map visualization of keywords over the three years under analysis

Table 1. SLR articles analysis.

Areas	Articles	Tools	Aim of the tools
Computer Engineering	(Bhamre & Jagtap, 2021)	ICT Tool MKCL SuperCampus	The software application gives a real-time statistical result to the teacher related to answers given by students during the class.
	(Mora et al., 2020)	Learning web-platform	Peer review is evaluated and monitored by the web platform.
	(Nasralla, 2022)	ICTs for backtracking learning	This approach is illustrated with the n-queens problem (tool) and the purpose is for students graphically observe the execution step-by-step of backtracking algorithms.
	(Nadeem et al., 2022)	AR4FSM mobile application	With this app students can learn about finite-state machine (FSM) concepts from lectures, tutorials, and practical hands-on experience combined with a commercial timing simulation tool.
	(Pertegal-Felices et al., 2020)	Kahoot tool for sustainable education	This gamification approach through Kahoot shows an easy way of formative assessment in this case, on this case in Computer Engineering.
	(Pratibha et al., 2021)	Flipped mode of learning using the Learning Management System ICTs	This study includes MOODLE for virtual learning with the Learner's Centric MOOCs (LCM). LCM model is implemented through LMS (moodle platform) and this is to assuring the increase of effective Feedback and Assessment. This also includes video format and quizzes.
	(Chacon et al., 2021)	JavaScript Simulations (EJsS)	Easy JavaScript Simulations (EJsS) is an open-source tool that allows those with limited programming experience to straightforwardly bundle an interactive computer science or engineer simulation in an HTML+ JavaScript webpage.
	(Rahman et al., 2021)	AOJ system (course) and ALDS (course) tools	This can be useful for education, educational data mining, data analytics, and behaviour analysis. OJs have significant importance because conduct programming practices, competitions, assignments, and tests.
	(Seddighi et al., 2020)	Python (Jupyter) Notebook	This tool is used in Computational Fluid Dynamics (CFD) and combined with an industry-standard package.
Program / Software Engineering	(Petchamé et al., 2021)	La Salle URL Smart Classroom	SC uses a Sound system, Image System, Smart Board and Software to connect with off-campus students.
	(Farah et al., 2022)	Chatbot- Lint Bot	Online learning application that simulates the code review features available on social coding platforms and allows

Areas	Articles	Tools	Aim of the tools
			instructors to interact with students using an online learning environment.
	(Chikurtev et al., 2021)	Software tools for robots and sensors	Software tools and applications for producing several digital resources with applications in robotics are presented: Gazebo, Robot Operating System, Arduino. The process and the technologies used to build a digital resource (simulation model) through a Gazebo simulator for working with robots and sensors are described in this approach.
Mechanical /Control Engineering	(Lampón et al., 2022)	Tool using Sysquake	This tool was used in the master of control engineering to facilitate the study and learning of control systems.
	(Pando Cerra et al., 2023)	Mechanical Engineering Computer-aided design (CAD) tools using Problem-based learning methodology (PBL)	This approach allows students, using PBL and a new interactive tool called TrainCAD, the self-assessment of 2D-CAD models designed in AutoCAD.
	(Becattini et al., 2020)	E-learning platform for PBL	In this PBL was used, besides the e-platform the successive tools: WhatsApp, (slack.com), Trello (trello.com), Adobe Connect, OwnCloud repository, CAD tools, 3D models, such as GrabCAD.com and traceparts.com and Google Docs.
	(Bhamre et al., 2021)	MKCL SuperCampus	MKCL SuperCampus, was used to pose questions and to track real-time individual performance in the classroom.
	(Horvat et al., 2021)	ICTs for PBL implementation	In this article the tools used were Adobe Connect (Meetings, virtual brainstorming); Moodle (Communication with a coach, Information about the process and ICTs); OwnCloud (Storing files); MS Excel (Gantt chart); Trello (Task management); Miro (Problem framing, Functional decomposition, Idea generation); Espacenet (Patent landscaping); MS Word (Agenda, meeting minutes) and CAD/CAE/PDM (CAD modelling, analysis, data management). Student teams also used: video WhatsApp and email, Google Drive, Excel and Google Spreadsheet. Related to taskwork: ResearchGate; physical effects (e.g. productioninspiration.com); nature-inspired solutions (e.g. asknature.org); Google Forms; (draw.io); enabling collaborative work (e.g. MS Visio, MS Word); CAD tools (e.g. SolidWorks, AutoCAD, Autodesk Fusion 360); CAD models (e.g. GrabCAD, Traceparts) or to vote while making decisions related to various design aspects (e.g. easypolls.net); a tool for making videos (e.g. Adobe Premiere) and Google Docs.
Chemical Engineering	(Martin-Villalba & Urquia, 2022)	Collaborative virtual laboratory	Modelica library is used in this paper, because this tool can facilitate the implementation of collaborative virtual labs using only the Modelica language and this can promote the collaborative learning.
	(Solmaz & Van Gerven, 2022)	CFD simulation tool available for laptop and phone	This work presents a versatile development methodology to implement interactive CFD simulations with cross-platform environments such as desktop and virtual reality applications. Some of the tools identified are laptop using Ubuntu 14 OS, OpenFOAM v6 and COMSOL v5.6, mixerVessel2D tutorial, k-epsilon turbulence model was used to model fluid flow with 2D and steady-state arrangements and a 3D transient simulation.
	(Romero et al., 2021)	Moodle and Socrative	This article shows the advantages of Moodle and Socrative use in lectures.
	(Gajbhiye et al., 2020)	CFD tool	CFD is useful to understand students to implement modern mathematical tools as well as evaluate standard protocols followed in the industries. In this case, students use the interface of ANSYS Design Modeler and Fluent through and hands-on training and simulations have been carried out.

Areas	Articles	Tools	Aim of the tools
Mathematics Engineering	(Sri Vinodhini et al., 2021)	Smart Board using ICTs	Smart Board approach in formative assessment including ICT tools as Think Pair Share, Plickers cards, Polls for formative assessment.
	(Illanes et al., 2022)	Leaning process for calculus course using ICTs	The ICTs used besides the traditional ones (used for geometry), in the computer configuration the student had a notebook, cell phone or tablet, internet, GeoGebra (free version), QR code, educational videos, and applets. The language and procedures are of a graphic, geometric, and descriptive type. In the case of algebraic configuration, they had all of that and an educational software such as Symbolab (free version) and Wolfram Alpha (free version).
	(Parody et al., 2022)	Classcraft tool	This tool is supported by a digital platform and a mobile application that has been developed to answer teachers' classroom management needs and is aim is to enhance the interest of students helping in the development of critical thinking, communication, collaboration, and creativity.
Electrical Engineering	(Valiente et al., 2021)	Tools used for "Machines and Mechanisms Theory" subjects	The aim of this article was to collect the following tools used for the teaching/learning process: Google Suit, Google Hangouts (chat outlook) and Google Groups (forum outlook) were chosen to arrange half of the students in a test group and for practical classes different simulation software's were used, but mostly, AutoCAD and Matlab.
	(Daineko et al., 2022)	Digital Educational Platform	To improve and promote remote access the aim of this platform give access to educational materials and can monitor the level of student's performance too in the aim of the study of modern Ultra high frequency (UHF) and extremely high frequency (EHF) radio systems. Includes a database of collected laboratory results and the list of virtual labs that are part of the educational platform, as well as devices and measuring instruments used in the virtual lab (vector network analyzer ZVA-40; vector network analyzer E8363B PNA Network Analyzer; digital oscilloscope RTC1000; spectrum analyzer FPC1500). Also, the signal generator SMC 100A can be used in this context. The remote access implemented uses Unity 3D.
	(Obukhova et al., 2020)	ICT tools for Blended learning	The tools applied in this methodology for electrical engineering were Skype, Viber, WhatsApp and the capabilities available on the internet.
	(Dong et al., 2020)	Online Laboratory	This paper´s objective is to apply online lessons with hardware, software and ICT platforms including the flipped learning methodology.
Manufacturing Engineering	(Mahmood et al., 2021)	Virtual Learning Factory Toolkit (VLFT)	This article shows a set of digital tools operated in production management with engineering education. The tools included are Java Modelling Tools (JMT), OntoGui (GUI), Unity3D, VEB.js (Virtual Environment based on Babylon.js) and ApertusVR-based applications.
Automotive Engineering	(Hernández-Chávez et al., 2021)	Virtual Reality Tool	In the scope of automotive systems engineering was developed a tool to use as an immersive virtual learning strategy for Oculus Rift S Virtual Reality glasses and through Leap Motion Controller™ infrared sensors- VR that allows students to understand the operation of the four-stroke engine through animation and the assembly and disassembly of its main pieces.
Environmental Engineering	(Roundy et al., 2022)	Web-based platform (HydroLearn)	Use of the platform (HydroLearn) including Jupyter Notebooks and Google Collabs. This approach also includes using problem-based situations for better understanding of climate and the hydrologic cycle.
	(Galustyan et al., 2020)	ICT tools for Blended Learning	The tools used were Learning management systems (Moodle, Edmodo). Tools for creating and publishing content and training objects (1C test designer). Tools for communication and feedback (Vebinar.ru, Skype, Google Chat.). Tools for collaboration (Google Docs). Tools for creating communities (social network Facebook). Tools for planning educational activities (electronic journals).

Areas	Articles	Tools	Aim of the tools
	(Guo et al., 2022)	Web-based virtual laboratory on microgrids	This laboratory is multidisciplinary topics and include pedagogical material about renewable energy, power electronics, power systems, control, and communication. The virtual laboratory was developed using NI LabVIEW, Microsoft. Net Core, and MATLAB/Simulink.
Industrial Management Engineering	(Salah et al., 2020)	Tools for 4.0 industry	The teaching and training methodology used in this paper is inspired by Jungmann's research cycle, synchronized with Kolb's learning cycle. The tools included 3D printing, Autocad designs and worked on CATIA software required for the 3D printer, conveyor loop system from the L loop to the desired O loop and e-Cockpit software configured the WAGO PFC.
	(Moreno & Bartolomé, 2021)	SRPs and Q–A maps	This combination of methodology (SRP) and tool Q-A maps (using posteriorly internet) was used for teaching in Industrial Management and the aim is to improve web-based inquiry learning.
	(Krajčovič et al., 2022)	VR for workplace	This tool uses VR for workplace analysis and optimization. In this approach, authors also included a 3D game engine using C# programming language.
Quality Engineering	(Unzueta & Eguren, 2021)	ICTs for statistic subjects using blended learning methodology	Statistical analysis has a unique place in Quality Engineering. Tools mentioned: Moodle platform; Excel simulator; SIPOC tool; Ishikawa, histograms, doing-tools (ANOVA, factorial design-2k, fractional factorial design-2k-p, t-test and regression), using one simulator to obtain the necessary data from the injection process.
Graphic Engineering	(Veide et al., 2020)	Interactive and Animated Drawing Teaching- DIAD Tools	These tools are used with the aim of graphical engineering and include educational videos on topics of engineering graphics and descriptive geometry.
	(Vergara et al., 2021)	Interactive Virtual Platform-IVP	This tool aims are to increase students' spatial vision skills while learning industrial, for radiographic inspection. Other tools included were three-dimensional model, two-dimensional drawings, Microsoft Word drawing tools, Autodesk AutoCAD, BFD, Autodesk 3DS Max and Epic Unreal Engine 4 (UE4).
Maintenance engineering	(Kans et al., 2020)	Remote Laboratory	The ICT follows MIMOSA CRIS and OSA-CBM standards that allow remote connection with distant students and a test rig, being possible to perform condition monitoring, diagnostic and prognostic.
Civil Engineering	(Conesa, 2022)	ICT resources for online environment	This online environment is used for getting knowledge different aspects of ports in Europe and uses documentaries, video reports and interactive web resources.
Telecommunications engineering	(García-Sánchez & Luján-García, 2020)	MACbioIDi glossary	The aim of the project mentioned on this article is to create a collaborative bilingual, English-Spanish glossary and the tools used for accomplishing this aim were GitHub, Building 3D Slicer, Python, Python Numpy, Matplotlib, QT framework and VTK.
Power Engineering	(Haidar et al., 2021)	METF platform w/simulation tool	Application of PBL methodology using METF-based graphic simulation environment as an approach to teaching SG-related subjects.

Figure 3 allows the identification of four clusters, based on the keywords analysis, identified by different colors (green, red, blue and yellow) and to conceptualize the main conclusions obtained from the analysis of the articles, it is possible to highlight that the concepts "higher education" and "engineering education" have a solid prevalence, also because they are key concepts used in the research (green cluster). However, "education", "covid-19", "face-to-face teaching" and in opposition "emergency remote teaching" are words that may constitute a second plane of relevance in terms of frequency of use. Though, as previously noted, "chemical engineering" has a prominent place, with "virtual laboratories" being the tools with the greatest focus on

development (red cluster). Curiously, here it is possible to observe that, "formative assessment" is heavily used and as verified in SLR, this evaluation method is often associated with the use of "gamification". The same happens with "Moodle" and "blended learning", the former being a prestigious tool for managing the educational process (yellow).

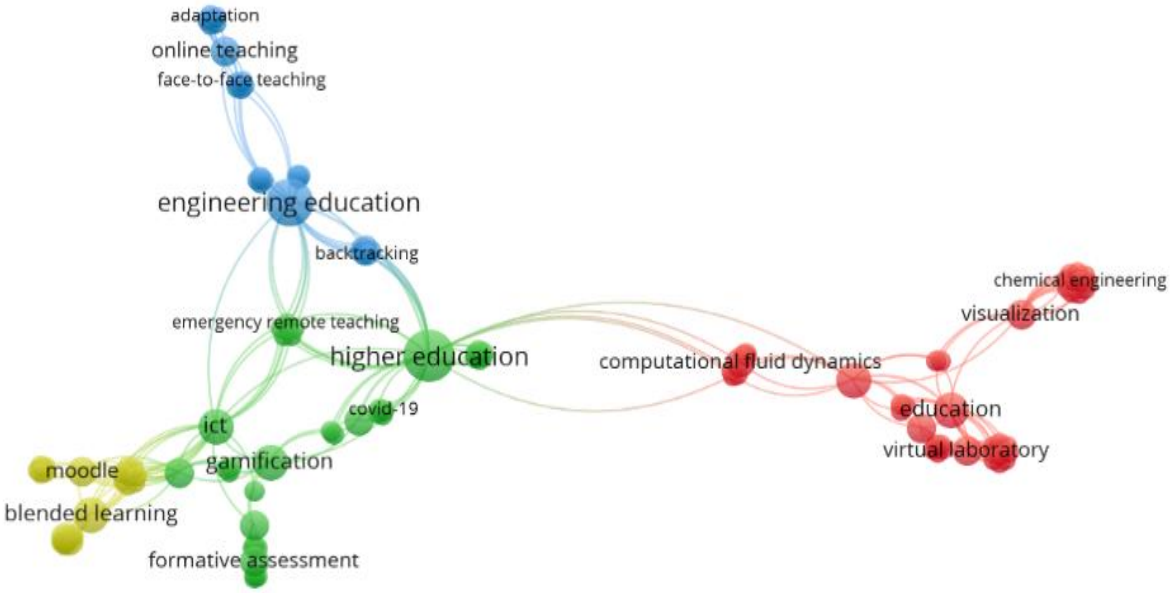

Figure 3: Most relevant keywords

5 Conclusions and Future Work

This paper reviews the use of ICT in the different fields of Engineering in the scope of higher education. This research can provide useful and valuable descriptions of technologies that could constitute the concept of the contemporaneous educational and learning processes in engineering higher education utilized in the context of smart learning environments.

With the SLR analysis it is possible to conclude that most of the tools are related to computer and chemical engineering and a large part are simulation tools. There is also an adaptation of existing tools and even use and conciliation of them with more recent ones.

The use of the bibliometric VOSviewer visualization software enabled to confirm a relation between the authors´ keywords that reveal a preponderant role in "formative assessment", "blended learning" "online teaching" e "virtual laboratory" in higher engineering education.

With the concern of making teaching accessible but also dynamic for greater assimilation of concepts, the creation and adaptation of tools turns was necessary. These tools allied with active teaching methodologies provide a significant and effective development of skills and competences in students.

Future work includes to understand how certain tools are suitable or not for certain teaching methodologies, establishing starting points for a greater and more effective construction and adaptation of resources in higher education, allowing effective development and preparation of students' skills for the labour market.

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