

WHAT IS A SMART CLASSROOM? A CRITICAL REVIEW OF THE CONCEPT

ELENA MERCEDES FIGUEROA CABRERA

Universitat Rovira i Virgili

RAMON PALAU MARTIN

Universitat Rovira i Virgili

ANTONI MARTINEZ-BALLESTÉ

Universitat Rovira i Virgili

1. INTRODUCTION

In recent decades, Information and Communication Technologies (ICT) have become commonplace in many scenarios. The continuous and progressive use of technological tools, devices and applications has changed the way daily activities are carried out, improving the efficiency, productivity and quality of the services offered.

Especially in education, technology has great potential to transform processes and provide students with new learning opportunities and strategies (Cervera & Johnson, 2015) by transforming traditional classrooms into technologically enriched classrooms. In fact, the integration of technology into education is changing the way we teach and learn in the classroom. Technology-enriched classrooms provide students with a dynamic and stimulating environment that goes beyond traditional, knowledge-based instruction.

In these new educational environments, the concept of smart classroom is in line with the idea of creating collaborative, interactive and personalised learning spaces. Students no longer just listen to the teacher and take notes, but actively participate in the learning process through discussion, experimentation, group work and problem solving. Technology in the smart classroom facilitates access to a variety of educational

resources, encourages creativity and innovation and stimulates the development of skills such as critical thinking, effective communication and collaboration.

1.1. THE SMART CLASSROOM SCENARIO

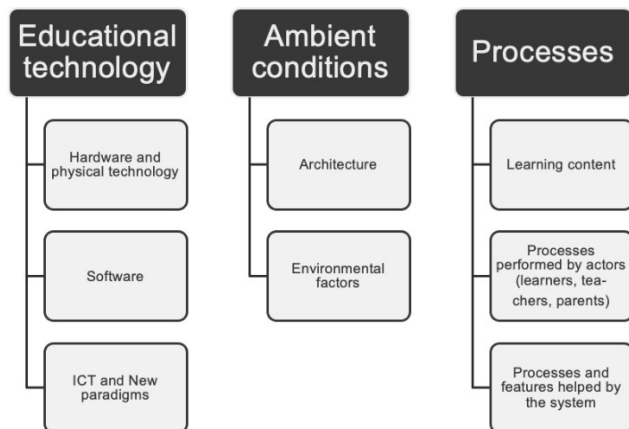
The introduction of smart classrooms represents a significant development in education, integrating technology to enhance the teaching and learning process. This innovative environment offers unique opportunities and provides teachers with advanced digital tools that facilitate access to quality educational resources of interest to students.

Currently, the concept of smart classroom is related to the presence of technological devices such as digital boards, computers, tablets, projectors and learning management systems. This technological infrastructure enables a personalised learning process that adapts to the individual needs of each student and promotes a different approach in the classroom. In this context, teachers play a fundamental role as learning facilitators, utilising the technological tools available.

However, in a truly intelligent classroom, the data collected in the physical learning space should be analysed to obtain information about students and teachers and provide the latter with relevant information to improve their work. Therefore, the concept of smart classroom also includes the use of data and artificial intelligence (AI) to detect patterns and anomalies and predict future behaviours to improve teaching and learning process.

(Palau & Mogas Recalde, 2019) offer an integrative conceptualisation of Smart Learning Environments (SLEs) and smart classrooms, in which they identify three dimensions that must coexist in these scenarios: educational technology, ambient conditions and the processes that are carried out (Figure 1).

FIGURE 1. Dimensions and categories in a smart classroom.



Adapted from source: Systematic literature review for a characterisation of the smart learning environments. *Propuestas multidisciplinares de innovación e intervención educativa*, 55-71 por Palau, R., & Mogas, J. (2020).

Note that in this new conception of the classroom with technology a number of concepts are to be considered, namely digital and mobile devices, sensors and recognition systems, learning management systems and the introduction of modern paradigms such as cloud computing, big data, data analytics, learning, Internet of Things, artificial intelligence and augmented and virtual reality (Cebrián et al., 2020).

There are several popular concepts in which the word “smart” is used. For example, a smart city is an urban area that utilises various types of digital technologies and data collection methods to improve the efficiency of services, increase the quality of life of residents and reduce resource consumption. Smart health refers to the integration of technology and digital innovations into healthcare systems to improve patient care and increase efficiency. This includes the use of various tools such as wearable devices, mobile apps, telemedicine platforms, electronic health records and artificial intelligence (AI) to monitor health status and provide personalised interventions. Finally, smart industry, also known as Industry 4.0, refers to the integration of advanced digital technologies into manufacturing and industrial processes to create more efficient, flexible and connected systems.

1.2. THE APPLICATION OF ARTIFICIAL INTELLIGENCE IN THE CLASSROOM

AI is one of the branches of computer science that is attracting the most interest today due to its enormous range of applications. AI is used in various scenarios with the aim of fulfilling data processing and analysis tasks. Developing intelligent methods and algorithms makes it possible to carry out analyses and obtain useful results for solving problems that require more complex computerised tasks.

The use of AI for decision-making is one of its most important applications. In general, AI systems can be used to support or replace human decision-makers (Duan et al., 2019). These systems characterised by AI for decision-making make it possible to save costs, create strategies, optimise processes and can be used in various scenarios to help improve them.

The education sector can benefit from the application of AI decision making. These predictive techniques and methods are used with the aim of promoting learning and designing better teaching methods, as well as assessing the initial state of students, their level of motivation, concentration and behaviour and making predictions about their development in order to propose the implementation of corrective actions that improve the teaching and learning process. Ambient Intelligence (AmI), intelligent environments or cognitive systems are some of the tools that support and develop these processes.

In the literature, there are several proposals for the use of AI in the classroom for a specific purpose. There are articles on air quality monitoring (Tagliabue et al., 2021), facial analysis to control attendance in class or to analyse the teacher's speech during the lecture (Parambil et al., 2022), (Razzaq et al., 2021), emotion recognition (Y. Kim et al., 2018), (Kinshuk et al., 2016), attendance monitoring (Mrabet & Moussa, 2017) and others.

Actually, the term “smart classroom” is often used to describe a physical learning space, usually a classroom, that is enriched with technology (Jantakun et al., 2023), (Kaur et al., 2022), it does not always include the use of data analysis and AI.

1.2.1. Internet of Things Devices

The Internet of Things (IoT) refers to a network of interconnected devices equipped with sensors, software and other technologies that enable them to collect and exchange data with each other or with a centralised system over IP networks (from local area networks, wired or wireless, to remote cloud servers).

The main goal of IoT is to facilitate communication and interaction between devices to automate processes, monitor and analyse data and ultimately improve efficiency, productivity and convenience in various fields such as home automation, healthcare, transportation, manufacturing, agriculture and more.

IoT devices typically consist of sensors to collect data, processors to process the data, connectivity components to transmit data and sometimes actuators that perform actions based on the data or commands received. The data collected by IoT devices can be analysed to gain insights, make predictions, optimise processes and trigger actions or alerts in real time.

Simple IoT devices, such as simple sensors or small networked devices, can be relatively inexpensive. These devices usually have limited functions and capabilities.

However, more complex IoT devices with advanced features, higher processing power, sophisticated sensors and robust connectivity options can be more expensive. For example, smart home automation systems, industrial IoT sensors for complex manufacturing processes or connected medical devices may have a higher price tag due to their advanced features and specialised requirements.

Several IoT devices can be used within the smart classroom ecosystem:

- **Air quality sensors.** These devices measure the concentration of microscopic particles in the air as well as the presence of gases such as carbon dioxide. By providing real-time air quality data, these sensors enable the smart classroom to make informed decisions to reduce exposure to pollutants, improve

indoor air quality and take action to reduce emissions and enhance overall environmental health.

- **Temperature and humidity sensors.** They are able to measure the current temperature in the classroom. Typically, air temperature sensors are also able to measure air humidity.
- **Sound sensors.** Based on microphones, they provide information about the sound pressure in the classroom. In order to provide effective measures, a number of sound measure points should be considered. There are off-the-shelf devices devoted to detecting whether the noise level in the classroom is beyond a certain threshold that alert, for instance by turning on a red light.
- **Light sensors.** They detect whether illumination conditions meet the requirements for a comfortable learning space. Note that a number of such sensors must be distributed across the classroom since different light conditions can be expected in different areas.
- **Cameras.** There is a variety of cameras that can be used within the smart classroom ecosystem: overhead cameras, surveillance cameras, desktop cameras (useful in environments where computer exercises are carried out and the teacher cannot see the students' faces), etc. Also important are cameras equipped with AI algorithms that can recognise faces and count attendance in the classroom, as well as cameras specialised in detecting emotions based on facial expressions.
- **Smart bracelets.** Another relevant type of IoT devices are smart bracelets that focus on measuring physiological parameters such as heart rate or electrodermal activity (EDA). These data can be useful to collect information on how students are feeling (to assess if they are able to learn) and also teachers (to recognise stressful situations).
- **Tablet.** This device will be used to show the teachers relevant information, in a timely manner, about the state of the classroom context, the students and, if applicable, the teachers themselves.

In this way, they can make decisions based on the conditions detected by artificial intelligence from the smart classroom data. In addition, through the tablet you can download historical information about the data captured through the IoT.

Unfortunately, although all these devices are available and, in general, have a moderate cost, their integration into the smart classroom and other environments is not easy due to interoperability issues between the devices. Specifically, one of the important issues is that manufacturers build closed systems that can only be operated by means of their specific applications. In contrast, using devices whose manufacturers offer open data access in real time should be favoured.

Regarding network technologies within this scenario, Wi-Fi, Bluetooth, and Zigbee are typical technologies to interconnect IoT devices:

- **Wi-Fi** provides high-speed interconnection between IoT devices, without being dependent on physical wires. This technology is largely used in home and office networks.
- **Bluetooth** enables energy-efficient communication over short distances, ideal for wearable technology and IoT sensors.
- Similarly, **Zigbee** supports low-power data links, and is typically used for smart lighting and industrial automation.

With these technologies a network infrastructure for the smart classroom can be designed.

1.2.2. Artificial Intelligence Techniques

AI techniques have evolved in recent decades and have recently become very popular as they are accessible to the general public. Image recognition systems, writing suggestions using predictive text or predicting the time of arrival at a destination are just some of the applications we use in our daily lives. Recently, generative AI has entered the scene with great vigour, specially thanks to applications based on language models.

Notwithstanding, in the field of smart classrooms, the AI techniques that are being used aim to recognise certain situations based on data analysis. Here are some of the techniques that could be used.

For instance, data could be analysed using **data mining**. This is a set of techniques about using various statistical and machine learning techniques to discover patterns and trends in data. Similarly, **process mining** utilizes event logs from information systems to visualize, analyse, and improve business processes. By examining real-time data, it reveals insights into process performance, compliance, and potential areas for enhancement, facilitating informed decision-making and optimization efforts. In addition, **classification techniques** could be used to learn relationships from data and/or make predictions about new data. Some well-known methods in this area are k-nearest neighbours (KNN), support vector machines (SVM) and decision trees.

However, the AI technique that has become increasingly popular in recent decades is **Artificial Neural Networks** (ANNs). These are computational structures made up of interconnected components called neurons, organised in layers that include an input layer, one or more hidden layers and an output layer. Essentially, the neurons perform computations on the input data to produce an output. To perform tasks accurately, ANNs must be trained extensively with large data sets. During training, the weights are iteratively adjusted to optimise the accuracy of the output. With the tremendous increase in computational power, ANNs can consist of a large number of neurons and layers and, hence, deep learning techniques have emerged to solve numerous problems that require extensive data processing. One of the best-known deep learning techniques is Convolutional Neural Networks (CNNs), which are often used for tasks such as image classification and object detection. Moreover, Recurrent Neural Network (RNN) are designed to process sequential data by maintaining considering information from previous time steps and thus are suitable to tasks such as natural language processing, time series analysis, and sequential data generation.

2. CONTRIBUTION AND PLAN OF THE ARTICLE

In our article, we examine the use of the term smart classroom in the scientific literature and provide a categorisation of the different variants of this concept. We have adopted the methodology proposed by (Vom Brocke et al., 2009) for conducting literature reviews. In accordance with this methodology, we addressed the definition of the scope of the review, conceptualised the topic and conducted the bibliographic search.

The document is organised as follows: Section 3 describes the methodology used for the literature review. Section 4 analyses the results found in relation to the treatment of the term 'smart classroom' in the search conducted. Finally, Section 5 concludes the article and points out some final considerations in this area.

3. METHODS

In this section, we describe the process of selecting the literature to be analysed, define the scope of the review, and describe the selection methodology.

3.1. REVIEW SCOPE

We investigate whether “smart classrooms” simply concern the introduction of ICT as a learning tool or whether, in contrast, they analyse data on the classroom environment, teachers and students. The review is aimed at professionals in the education and technology sector who are interested in understanding what is currently understood by smart classrooms and the actual benefits of technology in these spaces.

3.2. CONCEPTUALISATION

In smart classrooms, a number of comprehensive concepts are being developed in which several terms and disciplines come together. Some of these are smart education, learning environments, smart campuses, smart schools, etc, for which the term “smart” with processing and analysing environmental data.

Smart classrooms are a multidisciplinary field of study (Jantakun et al., 2023) and therefore a variety of research has been conducted associated with display devices, sensors, image recognition and the influence of technology and its adoption (Kaur et al., 2022). Other authors (Diaz León et al., 2016), (Roberts, 2000) see the smart classroom as a closed space that utilises technology to enhance the teaching and learning process.

Indeed, the concept is gaining prominence in the literature and is at the centre of much of the research currently being developed in the field of education. However, due to the diversity of studies conducted, it is still difficult to see the classroom as a space where technology can capture data and use it to make automated decisions. In this sense, definitions such as Koper's a starting point for a new conceptualisation. For the sake of clarity, we have focused on the concept of the 'smart classroom', when data collected in the physical learning space can be analysed to provide information about students and teachers. We also believe that the use of artificial intelligence should be considered to assess and provide relevant information about the immediate environment, assessment of emotions (both student and teacher), motivation, assessment of student learning levels, and other elements. Therefore, items that do not involve physical space and utilise artificial intelligence technologies and techniques are considered out of scope.

3.3. LITERATURE SELECTION

To select the literature, a bibliographical search was carried out in the Scopus scientific database, which contains a large number of publications on the subject of education. A two-stage review methodology was applied, consisting of an initial search phase and a final screening phase. This methodology is illustrated in Figure 2.

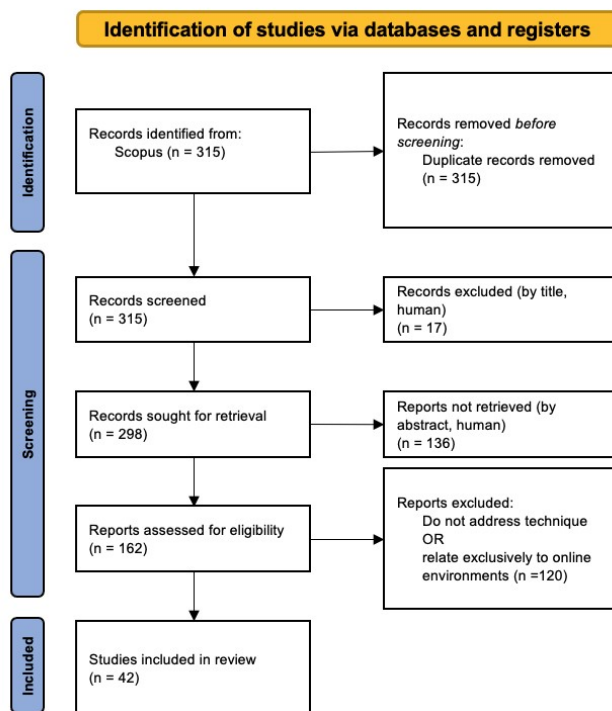
The search included peer-reviewed articles published in scientific journals and conference proceedings and only considered publications published in English and Spanish. We also focused on articles in which the term Smart Classroom appeared explicitly in the title of the article. The articles analysed were published from the beginning until 2024. The literature search was conducted in such a way that as many articles as

possible that matched our study were recorded and labelled with the search query:

TITLE ("Smart Classroom*") AND (LIMIT-TO (DOCTYPE, "cp") OR
LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re"))

This search yielded 315 results. In the identification phase, the full texts were reviewed (if the full article was available) to select those that included the classroom environment in their implementation according to our conception of smart classroom (Koper, 2014). Articles referring to virtual learning environments were excluded.

FIGURE 2. Synthesis of the search, screening and selection methodology



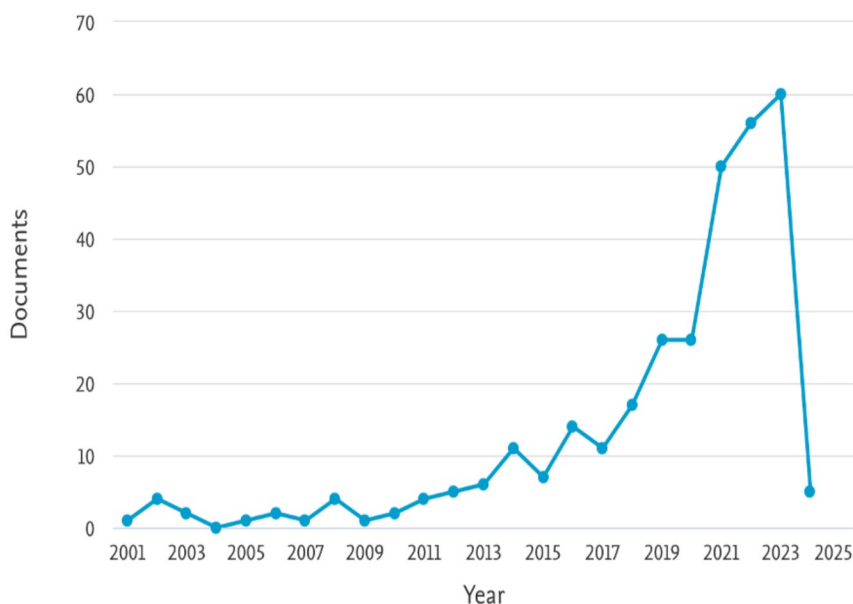
Source: authors

4. RESULTS AND DISCUSSION

The articles included in the review consider the term smart classroom, examine various features and offer solutions in the context of learning

spaces. The articles dealing with this topic (315 articles) are distributed from 2001 to the present, as shown in Figure 2.

FIGURE 2. Distribution per year of the articles that address the topic.

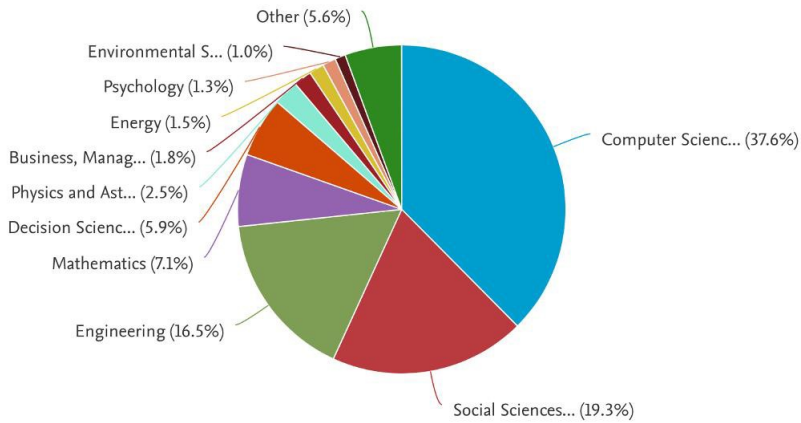


Source: Scopus database

Since 2017, there has been a growth in research on smart classrooms related to the spread of ICT in the education sector as well as in the rest of society. It is significant that in the last 3 years there has been an increase in research that considers the use of technologies in the classroom to improve the teaching process.

Likewise, most of the articles found are conferences and journal articles and tend to be in the fields of computer science, social sciences and engineering, as they are research areas directly related to the topic. As can be seen in Figure 3, more than 70% of the articles are related to these fields, indicating that the new vision that is emerging for the smart classroom requires the integration of many of these disciplines to achieve better results.

FIGURE 3. Distribution of articles that address the topic Smart classroom by subject area.



Source: Scopus database

3.1. ANALYSIS OF THE SELECTED ARTICLES

After the screening phase, 39 articles were obtained (see Table 1). In this section we summarise the main findings from their analysis.

TABLE 1. Summary of the results after the screening phase with the years of publication, the total number of articles found per year, the selection of articles to be analysed and a classification regarding the use of AI and the physical classroom.

Year	Articles		Use of AI		Physical Classroom	
	Total	Selected	Yes	No	Yes	No
2017	11	1	-	1	1	-
2018	17	1	-	1	1	-
2019	26	2	-	2	1	1
2020	26	3	1	2	2	1
2021	50	3	1	2	2	1
2022	56	12	8	4	10	2
2023	60	14	5	9	12	2
2024	5	3	1	2	2	1
Total	251	39	16	23	31	8

Source: authors

As we have already mentioned, the articles relating to the term smart classroom are most representative from 2017 onwards and the articles selected for analysis are also distributed over these years. Before 2017, we did not find any articles that met the selection criteria. We can also notice that most of the research on this topic is focused on the years 2022 and 2023, as 41% of the articles represent these years. This result shows us that the research community is increasingly interested in topics related to smart classrooms and their contribution to learning.

Another element was the question of whether these studies actually apply artificial Intelligence in the classroom. We found that 16 articles used AI as an outcome of the investigation or as part of the outcome. The majority did not use it to predict future behaviours or recommend desired states, but only to assess a particular feature through a model or algorithm.

It can also be observed that the use of AI in the classroom will be given greater consideration from 2022. Until now, the technologies were only seen as teaching aids, but now they are beginning to find other applications.

Virtually all studies (31) considered the physical classroom for research development, showing that there is an increasing commitment to data analytics in physical environments. However, those proposals that have not directly considered the physical classroom for their research and have only considered conducting lab-level testing.

The existing proposals that do not use AI in the classroom account for 58.9%. Those that make use of AI are generally limited to using these techniques to process captured images (like video footage from students).

In our opinion, these environments cannot be considered smart classrooms, as they do not take into account the collection and analysis of data to obtain information and improve learning processes. When classifying the research to determine whether or not they are considered smart classrooms, the following results, presented in Table 2 were found.

TABLE 2. Classification of studies based on whether they are address Smart Classrooms.

	Use of AI	Use of IoT	Physical classroom	Feedback	Smart Classroom
(Agrawal et al., 2023)					No
(Bhatia & Kaur, 2021)					Partially
(Burunkaya & Duraklar, 2022)					Partially
(Chan et al., 2017)					No
(Chen, 2024)					No
(Dong et al., 2019)					No
(Dou, 2023)					No
(Duvvuri et al., 2023)					No
(Ejaz & Shah, 2022)					Yes
(Enugala & Vuppala, 2018)					No
(Fakhar et al., 2022)					Partially
(Hossenally et al., 2022)					No
(Hu, 2023)					No
(Jia et al., 2021)					No
(J. Huang & Zhou, 2024)					No
(Jiang et al., 2022)					No
(K. Huang et al., 2023)					Partially
(Khan & Zualkerman, 2020)					No
(P. W. Kim, 2019)					Partially
(Kumar et al., 2022)					No
(Lateef & Kamil, 2023)					No
(Li & Chen, 2022)					No
(Liu & Huang, 2023)					No
(Pabba et al., 2023)					No
(Parambil et al., 2022)					No
(Pradeep, 2023)					No
(Premalatha & Hari Krishnan, 2020)					No
(Qianyi & Zhiqiang, 2023)					No
(Radosavljevic et al., 2022)					No
(Ritheesh et al., 2023)					No
(Sahoo et al., 2023)					Partially
(Shang et al., 2021)					Partially
(Shi et al., 2024)					No
(Sun et al., 2022)					No
(Wang et al., 2022)					No
(Yağanoğlu et al., 2023)					No
(Yu et al., 2022)					No
(Z. Zhu et al., 2023)					No
(Q. Zhu, 2020)					No

After our analysis and taking into account our criteria for the design of smart classrooms, we can say that of the articles analysed, only 5 simultaneously fulfil three characteristics that classify them as smart classrooms.

The remaining contributions use technology, but they use technological devices to control the environment (temperature, lighting, air, etc.) or attendance in the classroom, they do not extensively use AI to process data. Another element that is not considered in these studies is the processing of data in real time, which makes it possible to monitor and recommend desired conditions to improve the teaching and learning process, providing feedback in the information flow. Likewise, in most cases, they exclude the figure of the teacher in analysing the environment. Currently, the implementation of this conception of the learning space, the smart classroom, is being promoted, but it does not yet fully meet the needs and the potential it can offer is not fully realised.

6. CONCLUSIONS

The incorporation of ICT in educational institutions implies a transformation process to turn the traditional classroom into a smart classroom. In this article, we present an analysis of the research that considers the term smart classroom in the scientific literature and we categorise the variants of the use of this concept based on the application given to technology in the classroom.

In our conceptualisation of a smart classroom for classifying the research, we start from Koper's proposal of a smart learning environment through the use of digital, contextualised and adaptive devices. We have also analysed the use of AI and IoT devices in the physical space of the classroom. Finally, we classified whether the classrooms are considered smart based on their characteristics.

We found that several researchers are working on how to monitor, regulate and analyse environmental conditions, the detection of emotions related to learning, student motivation, class attendance and, in some individual cases, teacher behaviour.

In short, the implementation of advanced technologies in classrooms and the establishment of smart classrooms may also bring new

challenges and research opportunities, such as data security and privacy, hardware and software costs, standardisation and technology integration in smart classrooms, heterogeneity of information and other challenges. Creating a smart classroom that addresses the solution to one or more of these challenges can be a very beneficial tool to improve the quality of teaching in the current context.

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