Cloud-Edge Computing Technology-Based Internet of Things System for Smart Classroom Environment

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Abstract—Aiming at the many challenges faced by the current smart classroom environment under the traditional cloud computing model, such as excessive data volume causing high pressure on the central nodes, network congestion and real-time problems, an IoT system architecture based on cloud-edge computing technology is proposed. The architecture starts from the idea of distributing the data concentrated in the cloud center to the edge nodes, and consists of four parts: sensor layer, edge computing layer, core network layer and platform application layer, which are used to obtain multi-source heterogeneous data, configure edge nodes on demand, transmit information and provide various educational services, respectively. By storing, computing and analyzing part of the data through edge nodes, it can effectively relieve the computing pressure and storage pressure of the central cloud server and reduce the network latency, thus providing better assistance to the smart classroom environment. A survey was also conducted by means of questionnaires to teachers and students in the smart classrooms of a Chinese university where the proposed system was implemented. The results show that 100.00% of the teachers and 97.14% of the students who participated in the questionnaire survey think that the system can effectively collect educational data and give feedback to students, 96.00% of the teachers and 91.43% of the students think that it can facilitate classroom teaching and bring enjoyable experience to teachers and students, and the overall satisfaction of students and teachers is high. Therefore, the proposed IoT system architecture based on cloud-edge computing technology is fully feasible and can provide a reference for the research, construction and application of smart classroom environment.

Keywords—smart classroom environment, IoT, cloud-edge computing, smart classroom, edge node, cloud platform

1 Introduction

With the rapid advancement of "Internet +" in the field of education, the smart classroom based on modern information technology has gradually entered into educational practice. The smart classroom model is a new model based on artificial intelligence based on the traditional classroom. The traditional classroom model [1–2] has shortcomings such as being unable to perceive students' emotions, being teacher-centered, and having weak interaction between students, which makes it difficult to meet the new demands of intelligent learning. Papadakis et al. [3–4] pointed out that modern teaching methods combine teaching and innovation, which is an innovative challenge for both teachers and students. At the same time, during the COVID-19 pandemic [5–6], digital learning technology has brought great transformation to school education institutions. Therefore, modern computer technology can be combined with traditional classrooms to form a smart classroom environment [7–8], especially the integration and application of information technology such as cloud computing [9], big data [10], artificial intelligence [11] and classroom learning. The smart classroom environment [12] can perceive, collect and analyze data in various educational scenarios, thereby aggregating teaching resources, presenting visualized knowledge, understanding the status of learners, organizing various teaching activities, and realizing student-centered multi-teaching in class. Interactive mode, and efficient teaching through modeling and analysis of data and evaluation after class to obtain feedback, and ultimately promote the reorganization of the teaching process and the innovation of teaching models. Many colleges and universities have carried out theoretical exploration and practical application of smart classrooms, but they are mainly concentrated in formal physical spaces, such as the TEAL (technology enabled active learning) classroom of MIT [13–14], the smart classroom of Central China Normal University [15–16], etc., although they have achieved good optimization and innovation, they only stay in the technology of data collection and analysis, and do not seek to improve the results of poor performance and apply them in the smart classroom environment to continue to optimize the smart classroom.

In the intelligent classroom environment of everything connected, the traditional cloud computing and big data [17–20] model mainly suffers from the following shortcomings: (i) the intelligent classroom will generate a large amount of data on the physical environment, audio and video of teachers and students, and teaching resources due to the diversity of its equipment, and a teaching building often has dozens or even hundreds of classrooms, so if the school transfers all the collected data to the cloud platform, it will give If schools transfer all the collected data to the cloud platform, it will bring tremendous pressure on network bandwidth and cloud computing servers, easily causing "central node" failure to form network congestion; (ii) is not conducive to data security and privacy protection. Teacher and student information occupies a large part of all the data generated by the smart classroom, for example, if all the student audio and video data collected by high-definition cameras are transmitted to the cloud, and the leakage of information in the cloud will increase the risk of leaking user privacy, and the issue of user personal data security will become increasingly important; (iii) at the same time, all terminal devices request the response of the same cloud computing center server through the network, which is easy to cause delays in the computing system and cannot meet the real-time requirements of some classroom services. In response to the above problems, edge computing models for generating and computing massive data by edge devices have emerged. Cloud-edge collaboration [21–23] is to no longer centralize the data storage, transmission and computation operations of the whole system with the cloud server, but to analyze the data with high real-time and low value or pre-process the data to be transmitted to the cloud service through the edge nodes [24]. The task division of cloud servers by these edge nodes can reduce the pressure on cloud servers for data storage, computation, and analysis to meet the business requirements of low latency and high bandwidth, and avoid network congestion caused by large-scale and frequent data communication with cloud servers. Currently, the cloud-edge collaboration framework is widely used, and applying the cloud-edge collaboration framework to cognitive services [25] can make the framework self-adaptive through continuous model training, which can provide cognitive services with long duration, fast response time, and high accuracy rate. The cloud-edge collaboration framework can also be applied to smartwatches [26], which allows edge devices (smartwatches) to rely on edge servers (smartphones) to keep users informed in real-time to indicate the current training status without having to rely on cloud servers to reduce latency issues.

With the need to improve the data processing capability of the smart classroom environment, this paper proposes an IoT system architecture based on cloud-edge computing technology using cloud, edge, Internet, and integrated sensing with the edge as the core. The IoT architecture proposed in this paper makes the innovation of adding cloud-edge collaboration technology based on the improvement of traditional smart classroom based on physical space only for devices. The rest of the paper is organized as follows: Section 2 introduces the IoT system architecture and cloud-edge computing technology used in this study. In Section 3, taking the smart classroom as an example, we describe the IoT system in detail, including the implementation and functions, as well as its feedback of teachers and students during the classroom teaching process supported by IoT systems. Section 4 summaries the research and puts forward the future work direction.

2 IoT system for smart classroom environment based on cloud-edge computing

2.1 System architecture

Figure 1 shows the IoT system architecture based on cloud-edge computing technology, which is composed of four layers: sensor layer, edge computing layer, core network layer, and platform application layer. (i) The IoT devices in the sensor layer can obtain multi-source heterogeneous data from the smart classroom environment, such as environment data (e.g. temperature, humidity and CO_2), identity data (e.g. QR code [27], RFID [28] and face image) and device data (e.g. device location, operation status and fault message) from the IoT system, teaching resources, classroom interaction data and teaching journals from the teaching software system, and students' physiological data (e.g. GSR [29], ECG [30] and EEG [31]) from the wearable devices. Connected to edge nodes by various communication interface protocols (e.g. WiFi [32], ZigBee [33], Bluetooth [34], RS232/485, etc.), they collect educational data in synchronous and asynchronous modes. (ii) The edge computing layer is configured with a stationary edge node (SEN) or mobile edge node (MEN) according to the needs of the users. Each edge node has its own storage and computing devices for storing information regarding the associated node, IoT sensing device, and sensing data. The collected data are pre-processed and analyzed in time to accelerate the decision-making process. For instance, upon receiving data regarding the temperature, humidity, and illuminance from the environmental sensors, the control host of the IoT system will process and analyze them before instantaneously making some adjustment to the lamp intensity and curtain operation. (iii) The core network layer acts, to transmit the information exchange data, as a bridge between the edge computing layer and cloud computing services layer. In general, the core network layers can be based on the public telecommunication networks, the internet, and industrial specialized communication networks (such as 4G/5G cellular mobile network). (iv) The cloud computing services layer is provided with a high-performance database server, a computing server, and an application server. A large amount of educational data collected by edge nodes are stored in this layer for big data analysis and mining, thereby serving all types of educational applications. In addition, the cloud computing services layer contains different edge application service packages that provide support for updating and iterating the edge nodes.

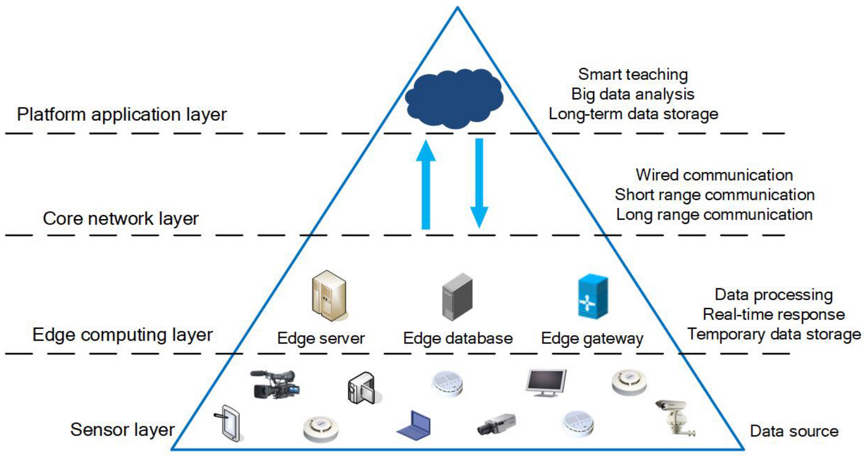

Fig. 1. IoT system architecture for smart classroom environments

2.2 Deployment and networking of edge nodes

Based on the location attributes, edge node can be further categorized into stationary edge nodes (SENs) and mobile edge nodes (MENs). In the smart classroom environment, an edge node is a distributed network node that has certain computing and storage capacities and integrates all the related IoT device nodes and wearable device nodes at the edge of the IoT system. On the one hand, the IoT device nodes collects data regarding the educational environments, teaching contents, and teaching behaviors from the underlying heterogeneous sensors, such as the RFID reader, temperature and humidity sensors, audio collectors, and surveillance cameras, through a range of communication interfaces such as RS232/RS485, Zigbee, Bluetooth, WiFi, and infrared; On the other hand, some data (e.g. real-time physiological, psychological and emotional data) is collected and processed by the wearable device nodes, such as smart bracelets, smart glasses, and VR devices, as well as the integrated sensors such as those of the fingerprint, location, gravity, audio, and video. All collected data is either processed and stored in the smart terminal or uploaded to a gateway server for edge computing (data processing and storage) and subsequently converged to a central cloud server for dynamic control of the corresponding controller/actuator. In addition to undertaking tasks such as switching protocols and collecting sensing data, SEN and MEN contribute to edge computing. They are edge gateways in the classroom through which data collection and processing are made possible within the smart classroom, which greatly improve the processing capacity and response speed of the local IoT devices. Figure 2 presents the topological structure of edge nodes constituting the cloud-edge computing-based IoT system of smart classrooms.

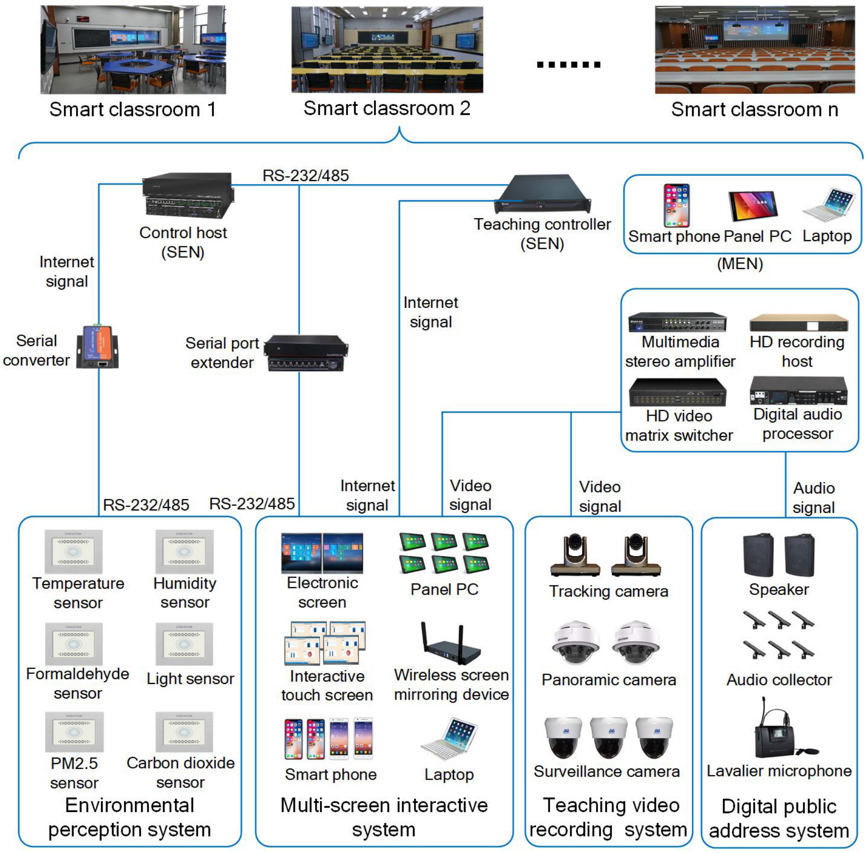

Fig. 2. Topological graph of edge nodes in IoT system

The sensing device layer in the IoT system is equipped with various systems featuring teaching facilities and functional nodes, based on the requirements concerning specific applications, performances, and techniques of smart classrooms, including multi-screen interaction systems, live teaching systems, environment sensing systems, and digital public addressing systems. The aforementioned systems are networked with SENs or MENs through different communication methods such as WiFi, RS232/RS-485, and Ethernet. The interactive touch screen, teaching controller, and environmental sensor adopt the RS-232/RS-485 communication protocol; The electronic curtain, remotely controlled lamps, and air-conditioning systems are controlled through relay, and the remaining devices exchange data via WiFi or Ethernet. All the devices and functional nodes are directly or indirectly connected to the SEN, such as the control host of IoT, and MEN, such as a mobile phone, laptop, or desktop, to achieve radiated interconnection and the star topology. Adopting embedded architecture, the control host in smart classrooms is integrated with multi-path control interfaces including the RS232/RS-485 communication interface, network interface, IR interface, relay interface, digital I/O interface, and bus interface. Therefore, it supports various types of control devices. In addition, the teaching controller in smart classrooms can be viewed as another type of edge gateway into which the classroom teaching software systems have been integrated. It assists in both lesson preparation and lecturing as well as recording of teaching behaviors such as PPT lecturing, interaction feedback, classroom quizzes, and self-directed learning. The spatial arrangement and smart classroom scene of the teaching infrastructure and all the functional nodes are presented in Figure 3a and 3b. By inserting the campus card into the card reader, the teacher can automatically start up the devices and systems within the smart classroom. Thereafter, the teacher/student can control these devices through the classroom control panel embedded in the multi-media podium, as shown in Figure 3c. The control covers such devices as classroom lights, curtains, screens, and HD recorders. The devices can also be applied to different teaching scenarios including traditional teaching, group discussion, intergroup sharing, wireless projection, and video teaching. For instance, when a video teaching scenario is activated, the curtain, light, and interactive touch screen would be automatically shut down to create an atmosphere for the present teaching pattern. The classroom constructed according to the cloud-edge computing-based IoT system architecture provides a smart control function. It can automatically adjust the light intensity as per the environmental illumination to save energy. Some mobile control terminal interfaces are reserved for the classroom IoT system; Therefore, the users may choose a smart pad or mobile phone as a mobile control terminal. The control interface may also be customized according to the type of classroom.

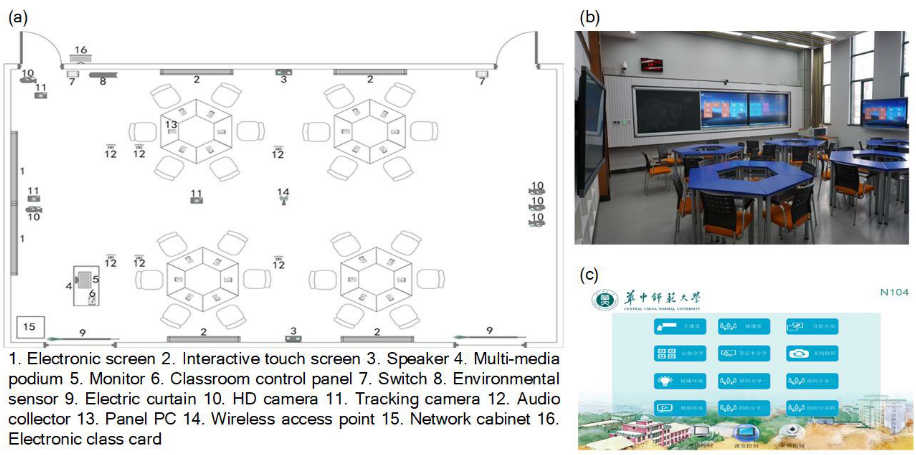

Fig. 3. Arrangement of IoT devices and smart classroom scene

2.3 Cloud computing services

With the support of intelligent technology, data storage, data transmission and data processing have been completed together after the SENs and MENs are configured. However, if you want to further analyze and mine data to provide back-end support application services for smart teaching, the central cloud server is an essential core component. It efficiently realizes the data interaction between the application services of the central cloud server and the edge nodes/IoT sensors, and provides three types of services. The cloud platform is divided into three layers as per universal cloud computing architecture, namely infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS) (Figure 4).

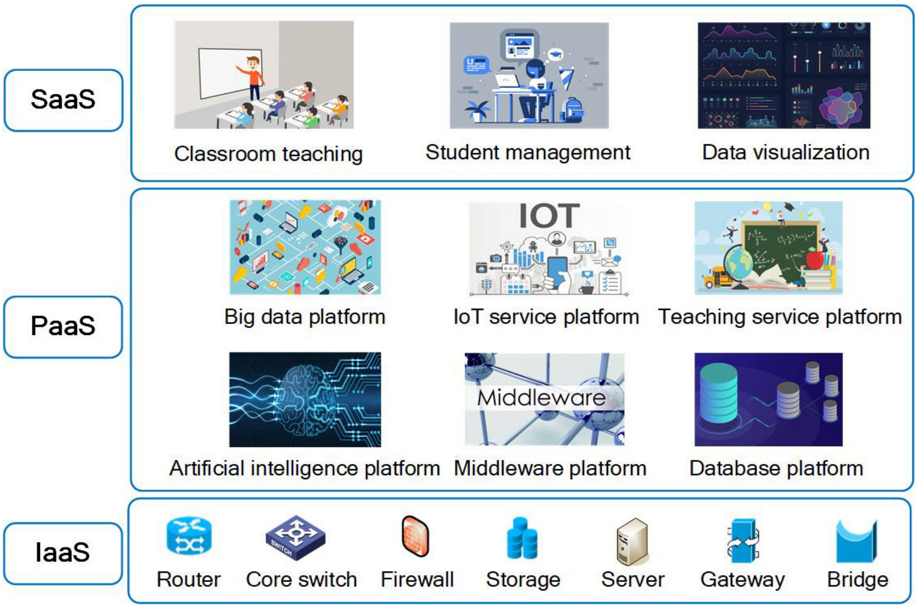

Fig. 4. Cloud platform architecture of IoT

After IaaS provides users with various computing, storage and other resources at the bottom as services, PaaS is responsible for supporting users' multi-type application services. Among them, the IoT service platform and teaching service platform are integrated with multiple functions such as diversified teaching, individualized learning, digital resource generation and promotion, smart control, and operation and maintenance management, which are crucial to the ability of cloud computing and services. At the IoT service platform, it is downward-connected to the sensing device layer to exert control over sensing devices and upward-connected to provide application services and uniform interfaces, supporting one-key batch control, real-time device state motoring, and remote assistance, covering different campuses, teaching buildings, and smart classrooms on different floors, as shown in Figure 5a. However, real-time monitoring of classroom scenes has a certain degree of delay because it is related to the number of monitoring classrooms, video resolution, and network speed. Furthermore, as a free, flexible, and open online course learning service platform, the teaching service support platform is inclusive of the following components and functionalities: uniform identification, spatial services, learning resources, curriculum center, community communication, educational big data, and instant messaging, as shown in Figure 5b. With these diversified functions, it can provide powerful support to the teachers for conducting mixed teaching and to the students for achieving ubiquitous learning. The IoT services support platform and teaching services platform offer all types of application services, such as smart resources and smart management, to both the PC terminals and mobile applications. The teachers and students are granted access to the resources and services available on the platforms through different browsers and mobile terminals after logging in through a unified identification portal.

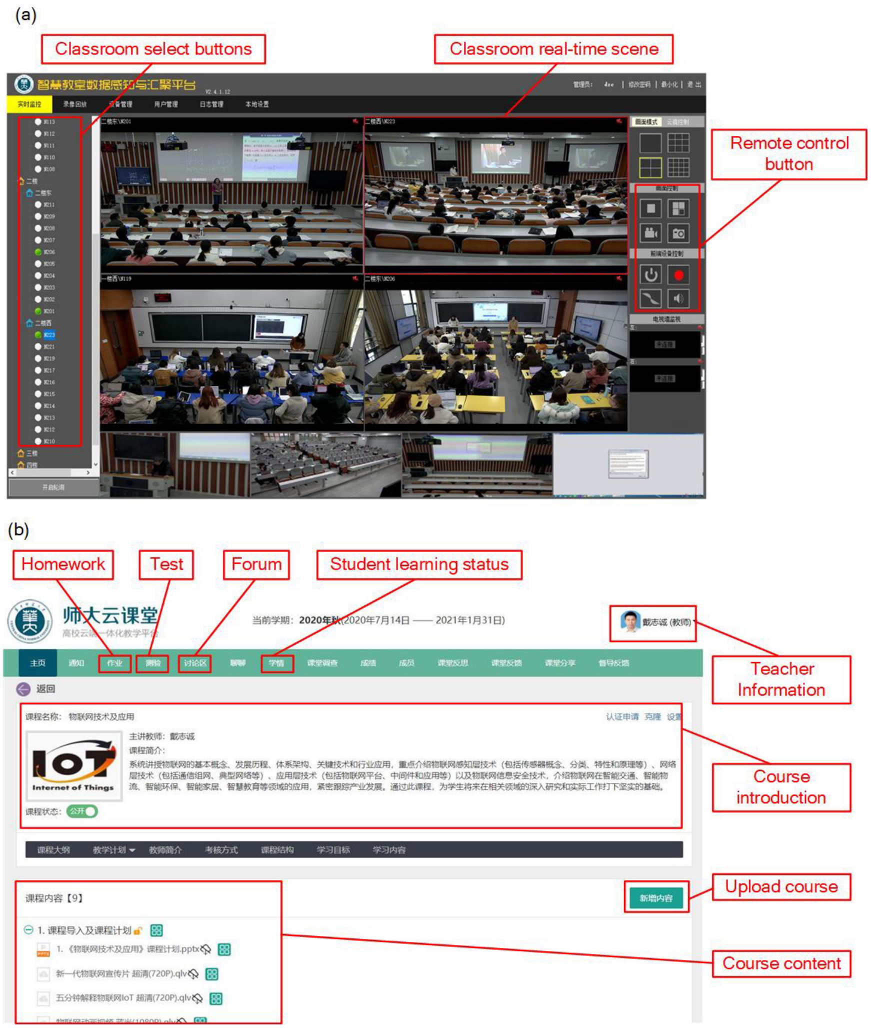

Fig. 5. IoT cloud platform interactive interface

2.4 Cloud-edge collaboration

IoT devices in smart classrooms often generate a large amount of data that may strain the network and cloud. In addition, some applications require wider connectivity, lower latency, and better control. Therefore, edge nodes can be used to cope with the computation and storage of data within their scope. Given that most of the data are not intended for one-time use and that the processed data still need to be collected from the edge nodes to the cloud server, cloud computing is primarily first used for big data analysis/mining and data sharing and then for training and upgrading of algorithmic models. Upgraded algorithms are later pushed to the front end to update and upgrade the front-end devices and complete a self-learning closed loop. Cloud computing should work in close coordination with edge computing to match the various scenarios and maximize their application values. The cloud-edge collaborative mechanism can be described as follows:

(1) In the smart classroom, cloud-edge collaboration can better support real-time processing. Edge computing usually focuses on providing real-time or short-term data analysis. For example, after the environmental sensor detects data, due to the small amount of environmental parameter information, easy analysis and timely feedback, the data will be automatically saved in the database of the Internet of things (SEN) control host; Subsequently, after further calculation and analysis of the data, the feedback will be transmitted to the classroom terminals (e.g. lights and curtains) to create a more comfortable teaching environment. In this process, from the perspective of the IoT system architecture (see Figure 1), the environmental sensors belong to the sensor layer, and the control host acts as the edge computing layer. Moreover, the fragmented environment data collected without complex analysis helps the IoT system dynamically adjust the environment, which greatly alleviates the pressure of data storage and analysis in the cloud data center and improves the timeliness of environmental control in the smart classroom. In addition, the collected data can also be sent to the cloud server, which can be checked by managers online in real time to prevent improper response in an emergency, as shown in Figure 6a.

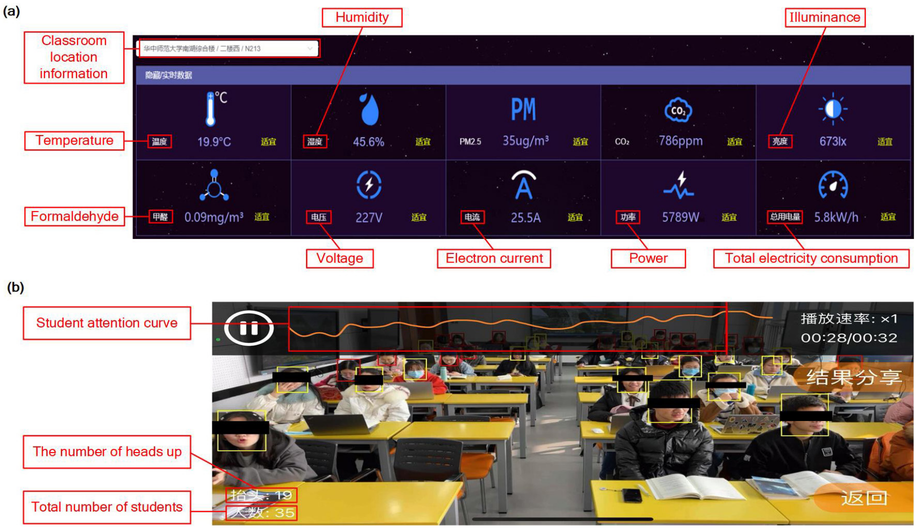

Fig. 6. Real-time environment data and context-aware data

(2) In contrast, cloud computing focuses on big data analysis based on the data obtained from the edge network. It plays an important role in decision support, regular maintenance, and other activities that do not require real-time execution. For example, we can use the collected position information of the students in the classroom, the audio and video data of the students, the operation of the learning system, and the interactive Q&A data to model and analyze the state of the students' learning process. As shown in Figure 6b, the HD camera is used to collect classroom videos and transmit the data to a cloud server for intelligent analysis. Then, the attendance, head-up frequency, attention fluctuations can be statistically analyzed to evaluate students' classroom performance by using AI technologies such as face detection and behavior recognition.

(3) The application has more than 60 smart classrooms, and functions require cloud-edge collaboration. For example, each classroom is equipped with multiple HD cameras and microphones to collect HD video signals (i.e. teacher close-up/panorama, student close-up/panorama), teachers' and students' audio signals, and screen video signals displayed by PPT courseware, all of which are transmitted to the HD recording host (SEN) through HD cables for video capture, image synthesis, and encoding. To avoid the network congestion and delay, the collected data will be temporarily stored in the HD recording host, and uploaded to the cloud server after the network is idle, which fully reflects the advantages of cloud-edge computing technology.

3 Application and results

In recent years, smart classroom environment has already been built in many universities around the world, on this basis, we rely on Central China Normal University to carry out the proposed system architecture. At present, more than 60 smart classrooms (multi-screen interactive classrooms, group discussion classrooms, and remote interactive classrooms) have been built in the university. This study has been established in the smart classrooms in the university for one semester and the feedback is fine, where the IoT system has been implemented. The smart classroom based on the proposed IoT system architecture is equipped with environmental sensors, interactive LCD touchscreen, wireless projector, high-definition (HD) cameras and other wired/wireless electronic devices to realize intelligent perception, control, interaction feedback and management.

3.1 System practice

As one of the two intelligent representatives of the cloud-edge computing technology-based IoT system, smart sensing promotes the IoT system to better collect, record and analyze the massive education data in the smart classroom; Smart teaching is promoted by smart sensing, smart teaching is the second intelligent form of smart classroom environments (e.g. smart classrooms) supported by the IoT system. The smart classroom provides physical and virtual spaces for teaching activities. Figure 7 shows all the teaching/learning activities that teachers and students can perform in the smart classroom with the support of the IoT system.

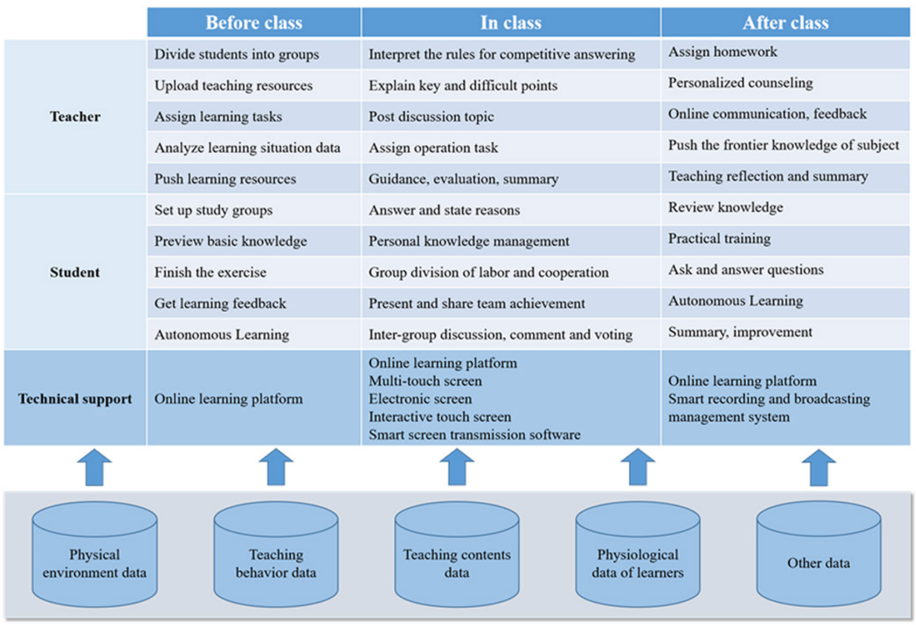

Fig. 7. Classroom teaching process supported by IoT system

In the whole teaching process, teachers and students participate in all links (before class, in class, after class). Before class, the teacher uploads the teaching resources, divides into groups, and distributes tasks through the online learning platform (e.g. cloud classroom, teacher mate), and the students learn independently and complete corresponding learning exercises as required. In class, with the assistance of smart multimedia (e.g. multi-touch screen, electronic screen, interactive touch screen, etc.), the teacher will explain the key and difficult points according to the students' digital learning traces left on the platform before class, and provides some personalized guidance for some students who are puzzled in some knowledge points. Finally, the teacher and the students summarize and evaluate the harvest of this class. After class, the teacher arranges homework on the online learning platform, and the students complete practical training on the basis of reviewing knowledge and continue to learn by themselves to improve their own personal qualities. In this process, the physical environment data, physiological data of learners, teaching behavior data, teaching content data and other data collected and stored by the IoT system reversely promote the behavior and status analysis of each element in the whole teaching process, which provide unlimited support for teaching evaluation, personalized learning and aided decision-making.

3.2 System evaluation

To evaluate the impact of the cloud-edge computing technology-based IoT system on teaching and learning, we designed the questionnaire about the experience of smart classroom for teachers and students. The teachers and students were asked to complete the questionnaire and answer 18 Likert-type questions with 5-point Likert scale [35–36], including 9 questions for teachers and the other 9 questions for students; In this questionnaire, multiple options are ranked in the order of "highest to lowest" and these options are coded by assigning a numerical value according to their degree. Among them, a final 5-level Likert scale was confirmed, in which strongly disagree = 1, disagree = 2, neither = 3, agree = 4, and strongly agree = 5. Finally, SPSS 27.0 was used to conduct a reliability analysis and one sample t-test so as to determine whether the sample data collected for analysis is reliable and whether there is a significant difference between the attitude of teachers and students towards the smart classroom and the "normal" value. Figure 8 (teachers' and students' questionnaire results) shows the relative frequency of each question corresponding to each level of satisfaction. In addition, the relevant data in Table 1 was used to reflect the experience of teachers and students in the smart classroom. In general, the feedback from teachers and students is positive.

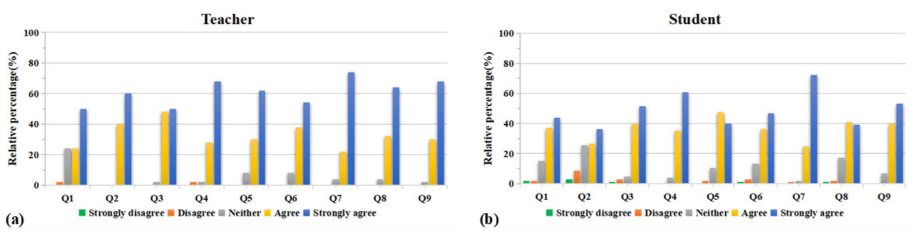

Fig. 8. Results of the teachers' and students' survey in terms of percentage of each level of satisfaction

Table 1. Descriptive statistics of the teachers' and students' survey results

Question Item	Teacher (N = 50)			Student (N = 105)		
	Mean	**SD**	**T (value = 3)**	**Mean**	**SD**	**T (value = 3)**
According to the real-time brightness collected by the light sensor, the lights and curtains in the classroom can be adjusted automatically to create a more comfortable teaching environment	4.22	.887	9.722***	4.19	.900	13.558***
It's convenient to view the data automatically uploaded to the cloud by the audio speaker and camera	4.60	.495	22.862***	3.85	1.099	7.905***
The teaching software collects education data, carries out academic analysis, and gives students feedback and evaluation	4.48	.544	19.251***	4.38	.789	17.932***
I can project contents to large screens from mobile devices for instant viewing and sharing	4.62	.635	18.030***	4.57	.569	28.281***
I can control the indoor lights and curtains as needed to create a more comfortable teaching environment	4.540	.646	16.868***	4.26	.721	17.868***
I can switch the scene control mode to meet different teaching activities, such as video playback mode (one-click to turn off the lights, curtains and side screens), aimed to create a movie-watching atmosphere	4.46	.646	15.992***	4.25	.864	14.804***
Teaching content can be displayed synchronously on the main screen and all side screens for students to watch	4.70	.544	22.098***	4.69	.560	30.839***
Each group can discuss freely and share the discussion results to all other screens with the group interaction mode	4.60	.571	19.799***	4.15	.841	14.040***
I am willing to teach and learn in the smart classroom	4.66	.519	22.598***	4.47	.621	24.193***

Note: ***$p < 0.001$.

In Figure 8a, 50 teachers who have carried out innovative and interactive teaching activities in smart classrooms were selected to complete the questionnaire, and 50 copies were collected. The effective rate was 100.00%. The questionnaire covers all links of the teaching process (before class, in class, and after class), paying more attention to teachers' feelings on the two major wisdoms of the smart classroom "smart sensing (environmental sensing and subject sensing)" and "smart teaching". As shown in Figure 8a, the proportion of dissenting opinions does not exceed 5.00% to each item. Most teachers' attitudes towards each item are between agree and strongly agree, indicating that they are relatively satisfied with the smart classroom in general. What's more, the average value of each item has reached 4 points or more (out of 5 points, see Table 1), showing that the satisfaction of each link in the whole teaching process tends to be consistent, and the wisdom of the smart classroom has been unanimously recognized.

As the main participants in the smart classroom, we distributed questionnaires to 108 students who have completed a semester course in the smart classroom. The recovery rate was 100.00% and the efficiency was 97.22%. Similar to the teachers' questionnaire, the student' questionnaire also covered all aspects of the students' learning process and the two aspects of wisdoms in the smart classroom. As shown in Figure 8b, the students also agree with the opinions expressed by the questionnaire on each item, accounting for half of them. However, it is worth noting that compared with that of teachers, the overall mean value of students' questionnaire has decreased owing to the considerable increase in the proportion of students who hold a neutral position in the questionnaire, especially in Q2 (convenient to view the data automatically uploaded to the cloud by the audio speaker and camera) and Q8 (discuss freely and share the discussion results to all other screens with the group interaction mode), which reflects the future improvement of the smart classrooms to some extent.

In order to confirm whether the collected samples are reliable and whether there is a significant difference between the attitudes of teachers and students towards the smart classroom and the "normal" value, we imported the data into SPSS 27.0, and found that the Cronbach's Alpha of the teacher' and student' questionnaire were 0.824 and 0.881 respectively, indicating that the reliability of the research data is high; At the same time, we have analyzed the mean, standard deviation and t-value of each item in the questionnaire, as shown in Table 1. By reading a large number of relevant literature and referring to the analysis of the satisfaction of teachers and students with smart classrooms at home and abroad, the t-test value of teacher-student questionnaire is set to 3. In Table 1, the mean value of each item of teachers is greater than 4 (out of 5 points) and the mean value of all items of students is greater than 3.5 (out of 5 points). Combined with the standard deviation of each item, the rationality of the set t-test value is revealed. The results show that there are items with significance ($p < 0.001$), and the mean value of almost all items is greater than 4. In short, the overall satisfaction of students and teachers is high. Among them, in Figure 8, 100.00% of teachers and 97.14% of students agreed that the system can effectively collect educational data and give students feedback; 96.00% of teachers and 91.43% of students believed that it can promote classroom teaching and bring pleasant experience to teachers and students. These data confirm that the smart classroom formed by the cloud-edge computing technology-based IoT systems promotes the effective interaction between teachers-students and students-students, and improves the learning efficiency and teaching effect.

4 Conclusions and future work

In summary, starting from the limitations of cloud server center computing and the advantages of edge computing, combined with the needs of smart classroom environment, this paper proposes a smart classroom architecture based on cloud-edge collaboration mechanism. This architecture reduces the storage and computation pressure of the cloud-centered server to a certain extent by task sharing of the edge nodes to the cloud-centered server, relieves the pressure on the cloud computing center, and reduces the system latency to ensure the real-time requirements of teaching. By deploying various sensors and edge node devices in the classroom, we can complete the collection of physical environment data, teaching scene data and teaching behavior data. In the smart classroom environment, the lights and curtains in the classroom can be automatically adjusted according to the real-time brightness collected by the light sensor to create a more comfortable teaching environment. Moreover, the group can share the discussion results to all other screens through the interactive mode, which effectively improves the learning efficiency and experience of students in the classroom, promotes classroom interactive links, teaching evaluation and personalized learning, and achieves good teaching effects. At the same time, the teaching software collects educational data and analyzes it after student feedback and evaluation, which can make further optimization guidance for the smart classroom environment.

Through the IoT architecture combining cloud computing and edge computing proposed in this paper, the smart classroom environment using this architecture can solve three major technical problems: (i) edge nodes such as IoT control hosts and other SENs and cell phones, laptops, desktops, etc. can analyze and gradient process the large amount of fragmented data collected by the underlying sensing devices in the smart classroom, and provide timely feedback to classroom devices, teachers and students with the calculated and analyzed data, reducing data transmission bandwidth and relieve pressure on cloud computing centers; (ii) edge devices can collect and store part of the user information through the underlying heterogeneous sensors without increasing the risk of leakage by transferring all personal information to the cloud, thus protecting data security and privacy; (iii) time-sensitive computing tasks are handed over to edge devices such as multi-screen interactive systems, and time-insensitive computing tasks are transmitted to the central cloud server with the support of high-performance database servers, computing servers, and application servers to reduce the latency of the computing system and ensure the timeliness of some classroom services.

However, although the application case in this paper has preliminarily realized the basic functions of the system framework, it is necessary to consider many factors such as students' acceptance of new things in order to study whether the smart classroom environment based on the cloud-edge collaboration mechanism has a positive impact on students' academic performance. etc., and long-term controlled experiments are needed, which will be further studied as our follow-up work. It is recommended to improve the data confidentiality in this architecture to ensure data security, further train and upgrade the algorithm model, and then push the upgraded algorithm to the edge nodes for update and upgrade, so as to complete the closed loop of self-learning. In the future, we will improve the cloud-edge collaboration technology in the field of smart classrooms in order to provide innovative ideas and directions for scholars in this field, so as to continuously improve the quality of teaching and contribute to the cause of education.

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6 References

[1] Altuhaifa, F. (2016). Students' weakness detective in traditional class. System, 5(6). https://doi.org/10.14569/IJARAI.2016.050604
[2] McFarland, D., & Hamilton, D. (2005). Factors affecting student performance and satisfaction: Online versus traditional course delivery. Journal of Computer Information Systems, 46(2), 25–32.
[3] Poultsakis, S., Papadakis, S., Kalogiannakis, M., Psycharis, S. (2021). The management of digital learning objects of natural sciences and digital experiment simulation tools by teachers. Advances in Mobile Learning Educational Research, 1(2), 58–71. https://doi.org/10.25082/AMLER.2021.02.002
[4] Papadakis, S. (2021). Advances in mobile learning educational research (AMLER): Mobile learning as an educational reform. Advances in Mobile Learning Educational Research, 1(1), 1–4. https://doi.org/10.25082/AMLER.2021.01.001
[5] Karakose, T., Yirci, R., Papadakis, S., Ozdemir, T. Y., Demirkol, M., Polat, H. (2021). Science mapping of the global knowledge base on management, leadership, and administration related to COVID-19 for promoting the sustainability of scientific research. Sustainability, 13(17), 9631. https://doi.org/10.3390/su13179631
[6] Karakose, T., Polat, H., Papadakis, S. (2021). Examining teachers' perspectives on school principals' digital leadership roles and technology capabilities during the COVID-19 pandemic. Sustainability, 13(23), 13448. https://doi.org/10.3390/su132313448
[7] Wang, X., Li, M., Li, C. (2019). Smart classroom: Optimize and innovative-based on compared with traditional classroom. International Journal of Information and Education Technology, 9(10), 741–745. https://doi.org/10.18178/ijiet.2019.9.10.1296
[8] Zhang, K. (2021). Design and implementation of smart classroom based on internet of things and cloud computing. International Journal of Information Technologies and Systems Approach (IJITSA), 14(2), 38–51. https://doi.org/10.4018/IJITSA.2021070103
[9] Cheng, L. D., Wang, X. C. (2013, October). Mobile application tools for learning and quiz based on Android. In 2013 IEEE 63rd Annual Conference International Council for Education Media (ICEM) (pp. 1–1). IEEE.
[10] Gong, Y., Liu, X., Dai, L. H. (2021, December). Construction of English smart classroom learning model based on big data technology. In 2021 3rd International Conference on Internet Technology and Educational Informization (ITEI) (pp. 321–324). IEEE. https://doi.org/10.1109/ITEI55021.2021.00080
[11] Dimitriadou, E., Lanitis, A. (2022, June). The Role of Artificial Intelligence in Smart Classes: A survey. In 2022 IEEE 21st Mediterranean Electrotechnical Conference (MELECON) (pp. 642–647). IEEE. https://doi.org/10.1109/MELECON53508.2022.9843020
[12] Wang, J., Tigelaar, D. E., Luo, J., Admiraal, W. (2022). Teacher beliefs, classroom process quality, and student engagement in the smart classroom learning environment: A multilevel analysis. Computers & Education, 183: 104501. https://doi.org/10.1016/j.compedu.2022.104501

[13] Dori, Y. J., Belcher, J., Bessette, M., Danziger, M., McKinney, A., Hult, E. (2003). Technology for active learning. Materials Today, 6(12): 44–49. https://doi.org/10.1016/S1369-7021(03)01225-2
[14] Belcher, D. J. (2005). How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts? Journal of the Learning Sciences, 14(2): 243–279. https://doi.org/10.1207/s15327809jls1402_3
[15] MacLeod, J., Yang, H. H., Zhu, S., Lee, Y. H. (2018). Understanding students' preferences toward the smart classroom learning environment: Development and validation of an instrument. Computers & Education, 122: 80–91. https://doi.org/10.1016/j.compedu.2018.03.015
[16] Lu, K., Yang, H. H., Shi, Y. H., Wang, X. (2021). Examining the key influencing factors on college students' higher-order thinking skills in the smart classroom environment. International Journal of Educational Technology in Higher Education, 18: 1. https://doi.org/10.1186/s41239-020-00238-7
[17] Hu, C. F. (2016). Application of e-learning assessment based on AHP-BP algorithm in the cloud computing teaching platform. International Journal of Emerging Technologies in Learning, 11(8): 27–32. https://doi.org/10.3991/ijet.v11i08.6039
[18] Khan, S., Alqahtani, S. (2020). Big data application and its impact on education. International Journal of Emerging Technologies in Learning, 15(17): 36–46. https://doi.org/10.3991/ijet.v15i17.14459
[19] Uzelac, A., Gligoric, N., Krco, S. (2018). System for recognizing lecture quality based on analysis of physical parameters. Telematics and Informatics, 35(3): 579–594. https://doi.org/10.1016/j.tele.2017.06.014
[20] Al-Azawei, A., Baiee, W. R., Mohammed, M. A. (2019). Learners' experience towards e-assessment tools: A comparative study on virtual reality and moodle quiz. International Journal of Emerging Technologies in Learning, 14(5): 34–50. https://doi.org/10.3991/ijet.v14i05.9998
[21] Khan, W. Z., Ahmed, E., Hakak, S., Yaqoob, I., Ahmed, A. (2019). Edge computing: A survey. Future Generation Computer System-The International Journal of Escience, 97: 219–235. https://doi.org/10.1007/s40692-019-00135-7
[22] Shi, W., Dustdar, S. (2016). The promise of edge computing. Computer, 49(5): 78–81. https://doi.org/10.1109/MC.2016.145
[23] De Donno, M., Tange, K., Dragoni, N. (2019). Foundations and evolution of modern computing paradigms: Cloud, iot, edge, and fog. IEEE Access, 7: 150936–150948. https://doi.org/10.1109/ACCESS.2019.2947652
[24] Zhao, W., Liu, J. J., Guo, H. Z., Hara, T. (2018). ETC-IoT: Edge-Node-Assisted transmitting for the cloud-centric internet of things. IEEE Network, 32(3): 101–107. https://doi.org/10.1109/MNET.2018.1700164
[25] Ding, C., Zhou, A., Liu, Y., Chang, R., Hsu, C. H., Wang, S. (2020). A cloud-edge collaboration framework for cognitive service. IEEE Transactions on Cloud Computing, 10(3): 1489–1499. https://doi.org/10.1109/TCC.2020.2997008
[26] Avram, M. R., Pop, F. (2022). Real-time running workouts monitoring using Cloud-Edge computing. Neural Computing and Applications, 1–20. https://doi.org/10.1007/s00521-021-06675-3
[27] Tarjan, L., Senk, I., Tegeltija, S., Stankovski, S., Ostojic, G. (2014). A readability analysis for QR code application in a traceability system. Computers and Electronics in Agriculture, 109: 1–11. https://doi.org/10.1016/j.compag.2014.08.015
[28] Zhong, R. Y., Huang, G. Q., Lan, S. L., Dai, Q. Y., Xu, C., Zhang, T. (2015). A big data approach for logistics trajectory discovery from RFID-enabled production data. International Journal of Production Economics, 165: 260–272. https://doi.org/10.1016/j.ijpe.2015.02.014

[29] Liu, B. Y., Liu, G. Y., Yang, Z. F. (2012). Analysis of affective state from galvanic skin response using correlation dimension and embedding dimension. 2012 5th International Symposium on Computational Intelligence and Design (ISCID), October 28–29, 2012, Hangzhou, China. pp 7–10. https://doi.org/10.1109/ISCID.2012.10
[30] Anisha, M., Kumar, S. S., Benisha, M. (2014). Survey on fetal ECG extraction. 2014 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT), July 10–11, 2014, Kanyakumari, India. pp. 1089–1095. https://doi.org/10.1109/ICCICCT.2014.6993123
[31] Motomura, S., Ohshima, M., Zhong, N. (2015). Usability study of a simplified electroencephalograph as a health-care system. Health Information Science and Systems, 3(1). https://doi.org/10.1186/s13755-015-0012-z
[32] Palattella, M. R., Dohler, M., Grieco, A., Rizzo, G., Torsner, J., Engel, T., Ladid, L. (2016). Internet of Things in the 5G era: Enablers, architecture, and business models. IEEE Journal on Selected Areas in Communications, 34(3): 510–527. https://doi.org/10.1109/JSAC.2016.2525418
[33] Han, D. M., Lim, J. H. (2010). Design and implementation of smart home energy management systems based on ZigBee. IEEE Transactions on Consumer Electronics, 56(3): 1417–1425. https://doi.org/10.1109/TCE.2010.5606278
[34] Yu, Y., Nassar, J., Xu, C. H., Min, J. H., Yang, Y. R., Dai, A., Doshi, R., Huang, A., Song, Y., Gehlhar, R. (2020). Biofuel-powered soft electronic skin with multiplexed and wireless sensing for human-machine interfaces. Science Robotics, 5(41). https://doi.org/10.1126/scirobotics.aaz7946
[35] Roman, C., Delgado, M. A., Garcia-Morales, M. (2021). Socrative, a powerful digital tool for enriching the teaching-learning process and promoting interactive learning in Chemistry and Chemical Engineering studies. Computer Applications in Engineering Education, 1–12. https://doi.org/10.1002/cae.22408
[36] Ceven, S., Albayrak, A. (2020). Design and implementation of modular test equipment for process measurements in mechatronics education. Computer Applications in Engineering Education, 28(2): 324–337. https://doi.org/10.1002/cae.22196

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