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PAPER

Designing a Smart Classroom Based on a Multi-Screen Interactive Learning System for Improving Student Satisfaction

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ABSTRACT

There are several issues with traditional classroom teaching, including the sporadic presentation of lecture materials, the reliance on a single, traditional teaching method, and a lack of student engagement and initiative. These problems seriously impact the quality of engineering education. Combining the advantages of mobile learning and multi-screen displays, this paper proposes a smart classroom architecture based on a multi-screen interactive learning system (MSILS). The proposed smart classroom system supports students in conducting learning activities in a multi-screen learning environment. Its goal is to enhance interaction and increase student satisfaction in engineering classroom learning. For the evaluation, an experiment was conducted in a science and engineering-related course at a university in China. The research results show that students who received instruction with the proposed system reported higher satisfaction in four areas: information technology, teaching methods, perceived value, and learning satisfaction. Approximately 90% of the 629 undergraduate students who participated in the experiment expressed their desire to continue their studies in this smart classroom. This indicates that students are more interested, expectant, helpful, and engaged in the target courses they are taking after using the smart classroom system.

KEYWORDS

smart classroom, multi-screen learning environment, student satisfaction, M-learning

1 INTRODUCTION

In recent decades, the rapid development of information and communication technologies (ICTs) has profoundly transformed the social fabric with unprecedented speed and scope. These advancements have had a significant impact on various aspects of life, including work, communication, lifestyle, and the environment [1]. In education, ICTs, such as the internet and interactive multimedia, are being integrated

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into formal teaching and learning processes, especially in K-12 education [2]. They have also become widely used technologies in supporting school education reform in the era of educational informatics [3]. Smart classrooms integrate sensor technologies, communication technologies, and artificial intelligence into classrooms in an unobtrusive way. This further motivates researchers to promote educational innovation through the integration of technology. Previous studies have utilized ICTs to improve the learning environment [4], optimize the presentation of teaching and learning content [5], promote easy access to learning resources [6], and enhance classroom interaction [7]. Therefore, the use of ICTs in the classroom helps to improve the teaching and learning process to some extent [8, 9, 10].

A classroom is an important learning space used for teaching and learning activities [11]. The adoption of emerging technologies in the classroom has resulted in a transition from the traditional "blackboard and chalk" approach to the modern "computer and projection" model [12]. Although this transformation has facilitated teaching and learning to some extent, there are still many problems in the classroom teaching process for engineering education majors today. These problems include: (1) teachers frequently switching between slides and writing on the blackboard and multimedia podium, which limits the flexibility of teaching; (2) teaching methods that are single and traditional, with most teachers still relying mainly on lectures, which fails to meet the interactive needs of students in modern teaching [13]; (3) the "intermittent" presentation of lecture materials, which disrupts the connection between the teaching content and increases the cognitive load of students [14, 15]; and (4) students passively listening to lectures in a single-screen display environment, which provides them with little opportunity for imagination, hands-on manipulation, interaction, or creative design [16]. These conditions adversely affect knowledge construction in multiple aspects and hinder the completion of effective knowledge transfer, thus impeding students' understanding of the engineering curriculum.

To some extent, the current problems faced by traditional classrooms are related to how teachers utilize technology in the learning process [17]. A qualitative study conducted by Hung and Chou [18] found that teachers used low-end technology (e.g., overhead projectors, VCRs, and slide projectors) in the classroom, even though newer and more advanced technologies were available. Acknowledging the challenges of using technological innovations in the classroom, scholars have argued for the need to shift attention from technology and software to the design of classroom environments and learning methods [19], such as mobile learning (M-learning).

Mobile learning is defined as the process of learning and teaching using mobile devices [20]. The benefits of M-learning stem from the portability, flexibility, and context of mobile technologies. These technologies facilitate learning, promote collaboration, and encourage both independent and cooperative learning for life [21, 22]. In this context, an increasing number of educational institutions, especially higher education institutions, are considering embracing smart mobile devices as part of their classroom learning aids [23, 24]. Teachers interact with screens (blackboards, projection screens, etc.) in the classroom while communicating and engaging with online interactive educational content and digital learning resources through the use of mobile devices such as smartphones, tablets, and laptops [25]. These portable computing devices are designed without a keyboard and are usually equipped with a touchscreen display or a stylus-based input system. Therefore, the accessibility and availability of mobile devices provide students with timely learning opportunities and new multi-screen interaction opportunities.

This has changed the reliance of traditional classrooms on a single screen for teaching. In addition, the literature indicates that M-learning offers considerable benefits by fostering creative, collaborative, and interactive abilities and capacities within learning environments [26].

At the same time, large displays have higher resolutions, and computers have more power to support multiple displays and animations. As a result, many large lecture halls are now equipped with multiple projector screens or liquid crystal displays (LCDs) [27]. This transformation has converted our learning space from a single-screen learning environment to a multi-screen learning environment. The multi-screen learning environment is commonly referred to as a computer-based smart learning environment that enables learners to display and compare various sources of learning information simultaneously using multiple screens. Research has shown that multi-screen displays are effective in reducing cognitive load and enhancing learning. For example, Chang et al. [28] found that learning content presented in a dual-screen learning environment was less cognitively taxing for learners than in a single-screen display environment. Cheng et al. [29] developed a three-projector presentation system based on constructivist learning theory and demonstrated the effectiveness of a multi-display system in improving learning efficiency.

Interactive learning, creative thinking, and problem-solving skills, as well as problem-based learning (PBL), are crucial elements in enhancing the engineering education curriculum [30]. Multiple-screen displays and mobile technologies have the potential to create collaborative, synchronous, competitive, and interactive physical learning environments that support PBL, team-based learning, and interactive learning. Although technology has great potential to enrich teaching and learning experiences [31], its application in university classrooms for engineering education majors remains an emerging and unclear issue [32]. How to integrate emerging technologies, instructional design, and classroom learning environments to tackle the challenges present in traditional engineering education classrooms and guide engineering education research and practice deserves our attention.

With the above considerations in mind, we propose a smart classroom architecture based on the multi-screen interactive learning system (MSILS) that combines the advantages of multi-screen display and M-learning. The main objective of this research is to create an interactive multi-screen learning environment in a smart classroom. This will be achieved by utilizing various screens, such as smartphones, tablets, laptops, and instructional LCDs. The aim is to enhance engineering students' comprehension of the subject matter, promote classroom engagement, and enhance overall student satisfaction with the learning process. In our smart classroom system, we designed and implemented a MSILS. We deployed this system in the classroom and collected feedback from the students after the course. Then, we analyzed the results and discussed the benefits of implementing this smart classroom system.

2 BACKGROUND AND RELATED WORK

2.1 Smart classroom

Due to the constantly changing learning environment, the definition of a smart classroom is continuously developing and evolving. Research on smart classrooms, both domestically and internationally, can be traced back to the early 21st century. According to the evolution of its connotation and concept, as well as the development of curriculum implementation, smart classrooms can be divided into two stages of development. The first generation of smart classrooms (2001–2007) focused on how to communicate instructional content to both local students (i.e., students learning face-to-face in a physical classroom) and remote oronline students (i.e., students participating in the course from an online or remote location) [33]. Teachers employ a multimodal approach to teaching and learning, which incorporates high-definition video, high-quality audio, and real-time discussions between students attending in person and those participating remotely. The objective is to ensure that students engaged in distance learning achieve the same learning outcomes as their peers in traditional classroom settings. The second generation of smart classrooms (2008–present) mainly relies on mobile technology and learning analytics. It involves the use of mobile devices by learners and automated communication between these devices and the smart environment in smart classrooms [34]. For example, Huang et al. [35] proposed a context-aware smart classroom system architecture, while Li [36] considered a smart classroom as a technology-supported learning environment. This smart learning environment offers learners personalized, smart, and adaptive learning settings by analyzing and detecting their surroundings to better cater to their needs.

Considering the various existing technologies available for the analysis, interaction, and conceptualization of teaching and learning, this paper proposes the following definitions: A smart classroom can be defined as a technology-enabled smart learning environment equipped with a variety of hardware (such as LCDs, mobile terminals, sensors, cameras, RFID readers, movable tables and chairs, and speakers) and software (such as online interactive learning platforms, learning management systems, and virtual learning environments). The main goal of a smart classroom is to leverage technology to support more effective and efficient learning for students while also providing instructional convenience for teachers.

2.2 Content presentation tools

The conventional method of visualizing information involves the use of visual aids like blackboards and whiteboards. A whiteboard has the advantage over a blackboard of being dust-free, but it costs more. With the development of display technologies, computers and projectors were introduced into classrooms in the 1990s [37]. The use of projectors allows teachers to display figures, images, animations, audio, and video information on a large screen, greatly facilitating students' meaningful construction of knowledge. The later emergence of the interactive whiteboard had a significant impact on traditional methods of teaching and learning. This innovation solved the problem of the previous multimedia projection system, which did not allow for two-way interaction. As a result, teachers no longer had to constantly move between the computer and the blackboard. As a result, "slide-based" linear presentations have become the most common form of teaching in university classrooms today. However, the most commonly used presentation tools, such as Microsoft PowerPoint and Apple's Keynote, only support a single, continuous, frame-by-frame presentation of content on a single screen [38]. This limitation makes it challenging to effectively explain complex, nonlinear concepts [15]. In addition, the amount of information that can be displayed on each slide is limited by the available display space. This often requires teachers to divide instructional material into sections or remove details in order to fit the slides. This intermittent display of information greatly affects students' understanding of the learning content.

As multimedia teaching devices continue to evolve, researchers are exploring ways to incorporate larger displays to maximize visual areas. Various tools have been developed to make use of the expanded screen space and improve classroom learning [39]. These systems typically utilize two or more projectors to expand the overall display area. Additional screens are used to display PPTs, videos, animations, and other classroom materials related to key concepts.

Today, with the advancement of multi-display and touch-screen technology, split-screen display multimedia teaching systems are being used in the teaching process. These systems enable teachers and students to interact on a multitouch-enabled screen while simultaneously utilizing multiple additional screens. This capability not only restores the traditional teaching skills provided by the whiteboard but also frees the teacher from the computer, greatly enhancing interactions between teachers and students, students and students, teachers and resources, and students and resources. This effectively improves the teaching effect.

2.3 Aim and research questions

The main objective of this study is to examine the influence of the proposed smart classroom architecture, based on the MSILS, on students' learning in science and technology classrooms. The findings will be used to assess the effectiveness of the smart classroom. The specific research questions in this study are as follows:

RQ1: What is the architecture of the proposed smart classroom system?
RQ2: Can the proposed smart classroom system enhance classroom interaction and increase student satisfaction?
RQ3: What are the students' responses to the proposed smart classroom system?

3 SMART CLASSROOM ARCHITECTURE BASED ON THE MSILS

3.1 System architecture

Figure 1 presents a simplified view of the system architecture. The proposed architecture for a smart classroom primarily consists of the MSILS, a high-definition direct recording and remote interaction system, an Internet of Things (IoT) system, and a data center. The main hardware and software equipment involved includes LCDs, multi-screen interactive teaching software, computer hosts, education cloud platforms, video matrices, HD cameras, smart central control systems, Bring Your Own Device terminals, etc. The main roles in the system are teachers, students, and the administrator. The administrator is primarily responsible for managing users, remotely managing classrooms, and maintaining the cloud server. Teachers and students can access learning resources and data on the cloud server through responsive web pages and mobile devices.

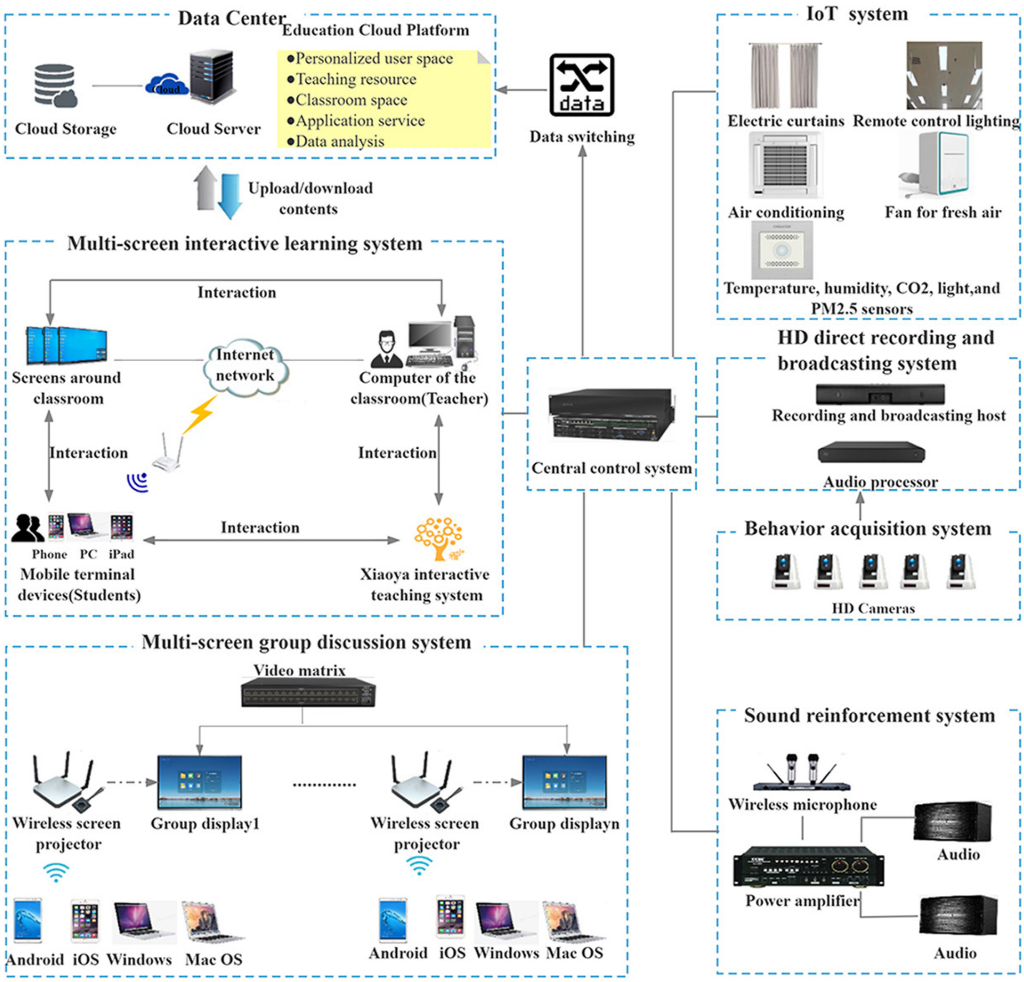

Fig. 1. Smart classroom architecture based on the MSILS

The MSILS consists of multiple interactive LCDs (including dual screens and multiple side screens), a computer host, a video switching (hybrid) matrix, mobile terminal devices, movable tables and chairs, the Xiaoya interactive teaching system, and other software and hardware. Among these components, the dual screen serves as the primary display device for the teacher's lecture, while the side screen is utilized for group interaction and synchronous display. Mobile devices serve as terminal devices for personal interaction and are utilized for real-time classroom interaction with the teacher. The mobile Internet provides a multimedia connectivity environment for multiple screens. It supports connecting the teacher's host, smart mobile devices on the student's side, and additional N auxiliary screens. The teacher-side and classroom-side screens are connected via a wired network, while the interaction between student terminals relies on wireless network connections. The Xiaoya interactive teaching system is an online learning platform independently developed by team members. It is utilized in the classroom to improve interactions. Moreover, the MSILS can support multi-screen group teaching, problem-based learning (PBL), and inquiry-based learning. This convenience allows for the implementation of various innovative classroom teaching methods.

It is worth mentioning that Xiaoya is a relatively new tool for providing a student response system, similar to Socrative [40], Kahoot [41], and ZUVIO [42]. Xiaoya can provide functions that help teachers create student-centered interactive learning activities. It enables students to use mobile devices (such as smartphones, tablets, and laptops) connected to the internet to answer questions posed by the teachers. This technology also allows the teacher to monitor students' diagnostic and formative assessments. The teacher designs the activities, controls the flow of questions, and views real-time statistical analysis results using the Xiaoya teacher interface (as shown in Figure 2). The students simply log in to their devices and interact in real time with the content using the Xiaoya Student interface (as shown in Figure 3a). There is a timer that counts down the answer time while answering questions (Figure 3b), which can be seen as the implementation of a competitive learning strategy.

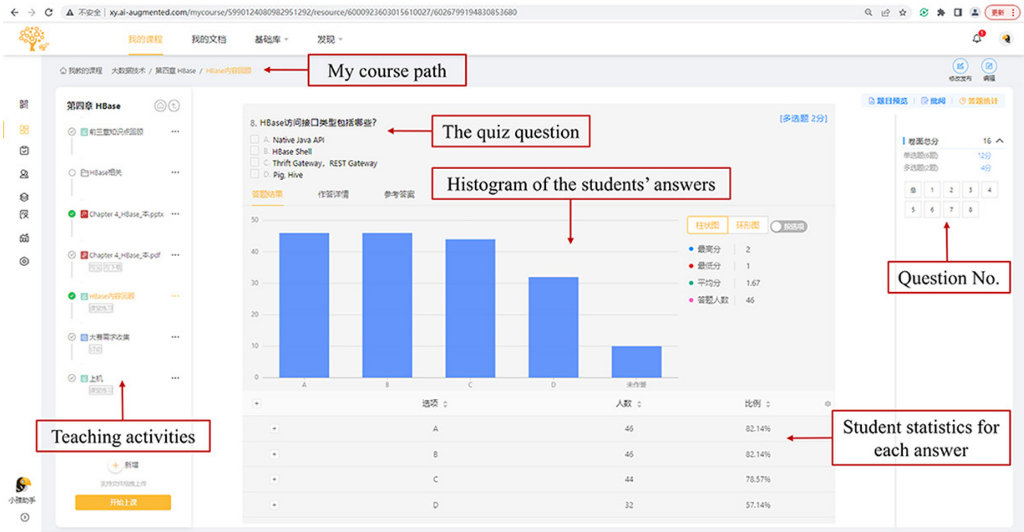

Fig. 2. Teacher's view of Xiaoya's histogram of the students' responses after an exercise

Fig. 3. (a) Using the Xiaoya Student App to answer a question by touching button (b) A timer displayed on the smartphone screen begins to count down while replying to students' answers to questions

The HD direct recording and remote interaction system mainly consists of a recording host, audio processor, pickup microphone, HD camera, hanging microphone, tracking locator, interactive control panel, and cloud classroom platform, along with other equipment and software. The smart classroom is primarily responsible for recording high-definition footage of classroom teaching, capturing all the voices, videos, and other activities of both teachers and students. The recorded HD video can also be uploaded synchronously to the cloud classroom platform.

The IoT system is mainly composed of a control host, video matrix, environmental sensor, IoT controller, and control panel. The IoT system can control the power switches, lighting, air conditioning, curtains, screens, and video signals in the classroom. Through IoT control, it enables smart control of all devices. The system is integrated with the campus one-card system, which allows for teacher identification and the activation and deactivation of teaching equipment. Environmental sensors are used to collect parameters, such as temperature, humidity, CO_2 levels, and PM2.5 levels, in the classroom environment. Based on the collected environmental parameters, classroom lighting, air conditioning, curtains, and other equipment can be automatically controlled to create a comfortable learning environment.

The data center primarily consists of a cloud-based database server and an education cloud platform. Within the smart learning environment, a cloud-based database server is responsible for storing and maintaining all data, including data from the teaching process of teachers and the learning process of students in the Xiaoya interactive teaching system, smart terminals, and virtual classrooms. The education cloud platform refers to a smart classroom cloud platform that integrates a wide range of high-quality teaching resources, smart subject support tools, online learning communities, and third-party services. It provides education participants with comprehensive teaching, learning, practice, testing, and evaluation tools before, during, and after the classes. Our self-developed educational resources and applications are deployed on the cloud platform. Teachers, students, and administrators can upload and download teaching resources from the cloud platform. Additionally, the data generated by each terminal is synchronized to the cloud platform.

The architecture of a smart classroom based on the MSILS differs from that of a traditional classroom, which typically consists of a "chalk and blackboard" or "computer and projection" setup. "Based on the MSILS, teachers are provided with flexible curricular designs and a preference application that supports in-class interactivity. Meanwhile, students are provided with a wealth of subject matter tools, high-quality teaching resources, and question and answer assessments."

3.2 Specific description of the MSILS

The constituent structure of the MSILS. According to the designed system architecture, the system mainly consists of the system's supporting hardware and the Xiaoya interactive teaching system, along with other software.

Hardware:

1. Touchscreen all-in-one machine.
2. Multiple LCDs with touch functionality.
3. Touchscreen control terminal.
4. Capacitive touch system.

5. Mobile learning devices, such as smartphones, tablets, and personal computers.
6. Teacher's computer.
7. Display connection driver interface (HDMI cable, USB cable, and network cable)
8. Network equipment and servers.
9. There are three sliding blackboards.
10. Swivel tablet chairs for various lecture styles

Software:

1. Education cloud platform
2. Xiaoya interactive teaching system

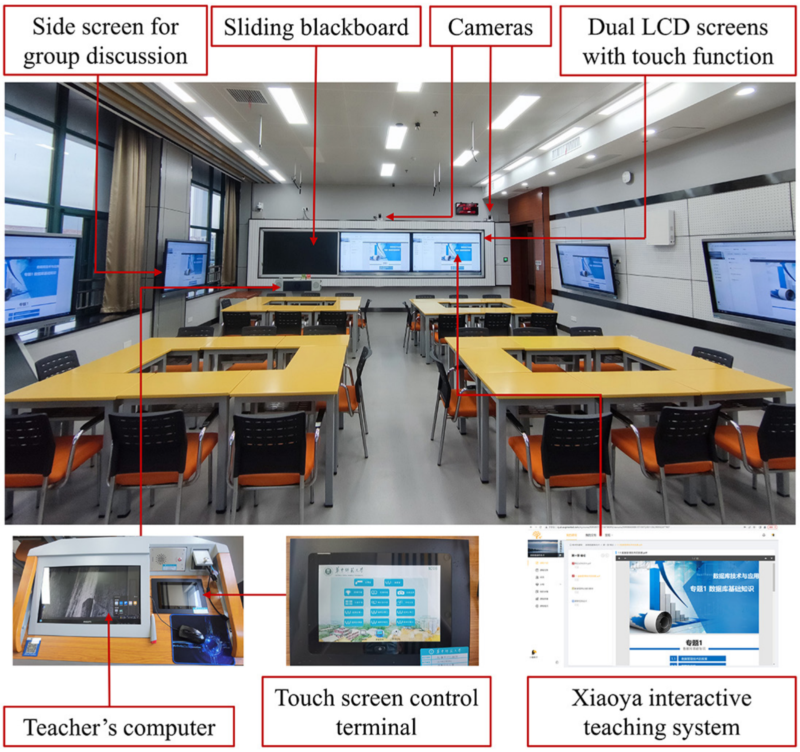

Fig. 4. The MSILS installation in the smart classroom

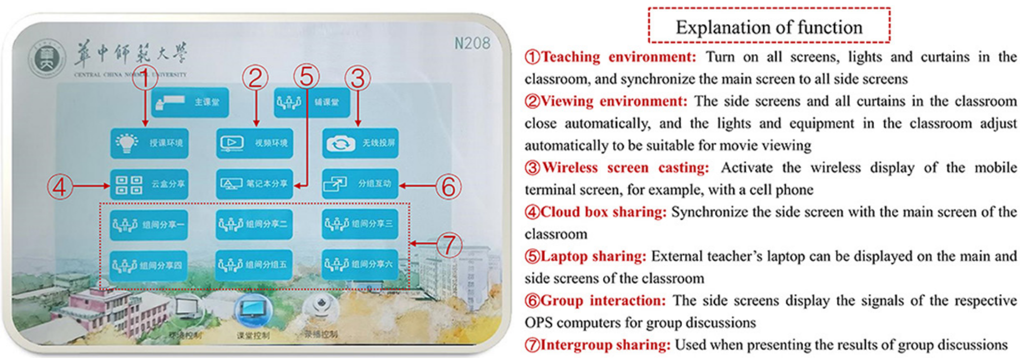

Fig. 5. Function diagram of touch screen control terminal

Figure 4 shows the installation of MSILS in a smart classroom. The touch-screen control terminal, located on the left lectern at the front of the classroom, is used to control the system. Figure 5 illustrates the main functions of the touch-screen control terminal. Multiple digital display areas were established in our system. In addition to the two side-by-side 86-inch touch LCDs (main screen and auxiliary screen) installed on the front wall of the classroom, we have also installed two 65-inch touch all-in-one machines (side screens) at the back and on each side of the classroom walls. The purpose of this design is to maximize the display of information, offering teachers a wider range of options. Moreover, since the tables and chairs are movable, students can freely form discussion groups. This allows students in different positions in the classroom to have a clear view of the teacher's presentation, creating a comfortable learning environment and atmosphere. When teachers teach, they use dual-screen displays (main screen and auxiliary screen) to achieve dual-track teaching. The teaching content is presented in the form of two screens. The main screen is used to display the lecture PowerPoint. The side screen synchronously displays the content from the main screen. The secondary screen is used to operate other learning-related events, such as playing videos, animations, web pages, and other auxiliary teaching resources, to assist in teaching. For example, when explaining a physical phenomenon, one screen can display a PPT with textual content, while another screen can display a video showcasing the physical phenomenon. This approach helps to enhance students' understanding of abstract physical knowledge.

In addition, teachers can achieve dust-free interactive teaching through the two-way touch interaction function of the LCDs. Touch screens with interactive whiteboard functionality provide smart writing capabilities. Simply by tapping on the touch screen using a finger or an accessory like a stylus, users can easily control all applications to write, draw, illustrate, modify, erase, mark up, and more on the instructional content.

Considering the possibility of additional content slides, we have also added three traditional sliding chalkboards to the front wall of the classroom. These chalkboards can be used by the teacher to write with different water pens. We believe that traditional chalkboards have many advantages over traditional slides for teaching and learning, especially in STEM (science, technology, engineering, and math) subjects, which require complex reasoning and explanations. Therefore, the display mode of sliding blackboards and LCDs is adopted. The multi-screen display enables the teacher to deliver a focused lesson on a large screen while also transmitting relevant knowledge links to individual student mobile learning terminal screens. This allows instructional knowledge to be shared in an orderly manner.

The multi-screen interaction function of the MSILS. Compared to the traditional single-screen display environment, the multi-screen learning environment enables real-time multi-screen interactive learning. It provides learners with various levels of adaptation and precision in diversified teaching and learning conditions, including curriculum, course content, learning strategies, and teaching support. In the contemporary multi-screen learning environment, multi-display technology supports various display modes, including lecture sharing mode, group discussion mode, and group display mode, to accommodate different types of classroom organization. Teachers can access various projection modes through the touch-screen control terminal and the teacher's computer on the lectern in the classroom. The four types of display modes supported by the MSILS, as shown in Figure 6, are as follows:

M1: Lecture sharing mode. The lecture sharing mode is the default mode of the system. In this mode, all students' side screens are synchronized to display the same content as the teacher's main screen. The teacher's computer or iPad wirelessly casts to the main screen.

M2: Group discussion mode. In this mode, each group has a display screen for group discussions. Students in each group can mirror content from their smartphones, laptops, and tablets onto the side screen of their own group for presentation and discussion within the group. The screen projection within each group is limited to that specific group.

M3: Group presentation mode. In this mode, the teacher has the ability to freely move the content from a specific group, like Group A's discussion projection screen, to the teacher's main screen. Simultaneously, the teacher can distribute the content from the main screen to the side screens of each discussion group. Students in each group only need to view their own side screens to watch the content displayed on Group A's discussion projection screen, which shows the discussion content of a specific group as a whole.

M4: Free presentation mode. The screen content of the students' mobile devices can be shared with one or several or all of these additional screens.

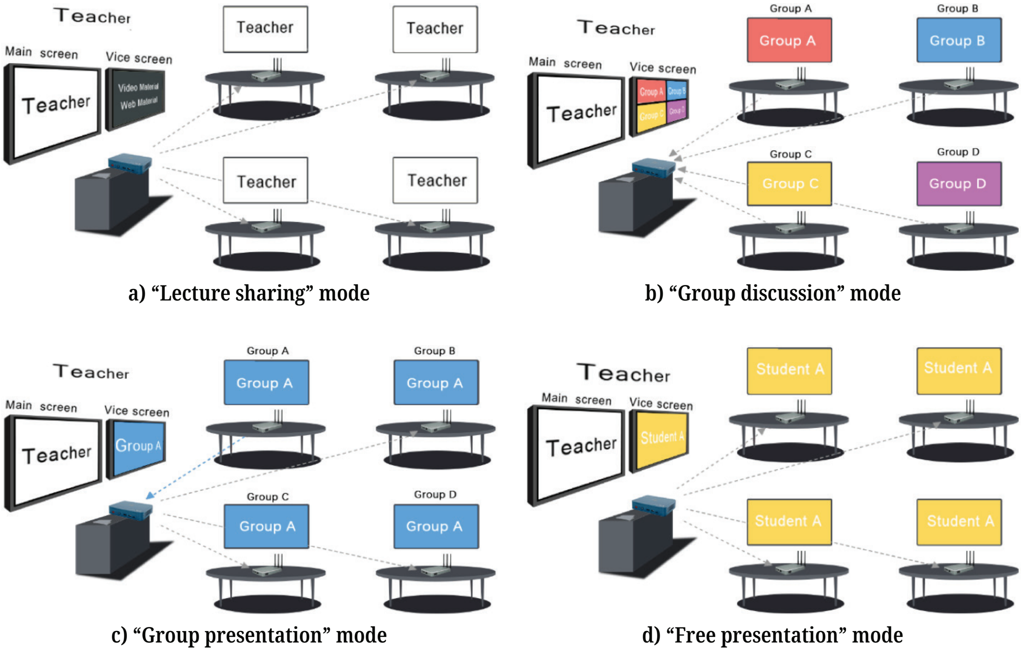

Fig. 6. Four display modes in the smart classroom

4 EVALUATION AND ANALYSIS

To evaluate our proposed smart classroom system, a course experiment was conducted at a university in China. Undergraduate students enrolled in science and engineering courses were invited to participate in this experiment. Before the teaching experiment, training was conducted on the operation of the smart classroom to help teachers become proficient in operating the equipment and enhance their teaching experience. As a result, teachers were able to effectively utilize smart teaching tools and the online learning platform for instruction. Most students were able to complete their daily learning and practical activities in the smart classroom. After the teaching session, the students were instructed to complete an online questionnaire for the purpose of data collection and analysis. The purpose of the questionnaire was to understand the students' attitudes towards participating in teaching activities, as well as their opinions and satisfaction after using the smart classroom. To ensure the validity and scientific rigor of the questionnaire, we provided a clear explanation of its content and purpose at the beginning of the paper. Additionally, we emphasized that the questionnaire was anonymous, ensuring that respondents felt comfortable providing genuine information. The questionnaire contained 15 items from four dimensions, including information technology, pedagogy, perceived value, and learning satisfaction. The questionnaire was answered using a Likert-type scale with five response choices: "1 = strongly disagree," "2 = disagree," "3 = neither," "4 = agree," and "5 = strongly agree." Furthermore, a final question was provided to investigate the students' intention to continue using the smart classroom.

4.1 Participants

In this study, 692 undergraduate students from a university in China were selected. All of the students were science and engineering majors, including fields such as computer science, information and communication engineering, and civil engineering. Additionally, all participants had knowledge of how to use the internet and smart mobile devices. Among these 692 students, 63 individuals' responses were omitted from the data analysis due to incompleteness or obvious patterns in their answers. Therefore, the response rate of the final questionnaire was approximately 90.89% (n = 629). The age of the participants in the sample ranged from 17 to 22 years, with 38.16% being male and 61.84% being female.

4.2 Instruments

At the end of the course, a Likert-style questionnaire was developed to evaluate the smart classroom. This questionnaire was used for data collection, and the resulting dataset was analyzed using SPSS25. We calculated Cronbach's alpha coefficient values for the four dimensions of the questionnaire: information technology, pedagogy, perceived value, and learning satisfaction. The values obtained were 0.729, 0.841, 0.835, and 0.895, respectively. These values indicate an acceptable level of internal consistency for all scales. Cronbach's alpha coefficient for the questionnaire as a whole was 0.933, and the KMO value was 0.943. These results indicate that the four dimensions of the questionnaire demonstrate good reliability in terms of internal consistency.

4.3 Data analysis

Table 1 displays the statistical results of the mean score and standard deviation for each item. Figure 7 shows the percentage composition of each question corresponding to its respective scale level. We can clearly see that the bars of the bar chart, after visualizing the data, are predominantly skewed to the right of the 0 baseline. This indicates that, overall, students have a positive attitude towards teaching and learning activities in the MSILS-based smart classroom.

Table 1. Basic statistics of the survey results

Dimension	Question	Mean	SD	T-Value
Information Technology	Q1. I can easily access various smart devices in the smart classroom (such as iPad, smartphone, touch screen, etc.)	3.89	0.67	33.330*
	Q2. I can easily access rich learning resources using mobile devices	3.54	0.72	18.752*
	Q3. Multi-screen synchronous display of teaching content can reduce my cognitive load and promote my understanding of the subject matter	3.90	0.62	36.155*
Pedagogy	Q4. In class, I can better interact with teachers and classmates	3.73	0.63	29.275*
	Q5. I can interact well with the equipment in the classroom or the timely feedback system	3.63	0.66	24.002*
	Q6. I think the smart classroom is useful in supporting a variety of teaching methods and teaching models to carry out personalized teaching	3.83	0.56	37.642*
	Q7. Using mobile terminal devices, subject tools and other learning support can support me to complete learning tasks faster and focus on classroom activities	3.81	0.62	33.076*
Perceived Value	Q8. I think learning in the smart classroom can help me better experience the subject theme	4.06	0.69	38.367*
	Q9. I think taking classes in the smart classroom helps me better master the course content and improve my learning efficiency	3.72	0.70	25.835*
	Q10. I think the smart classroom can support personalized learning and promote in-depth learning	3.79	0.67	29.378*
	Q11. I think learning in the smart classroom can effectively improve my academic performance in this course	3.63	0.69	22.870*
Learning Satisfaction	Q12. Learning in the smart classroom has achieved the desired results	3.92	0.59	39.507*
	Q13. I am very satisfied with the learning process in the smart classroom	3.86	0.55	39.249*
	Q14. I am very satisfied with the learning effect in the smart classroom	3.80	0.60	33.525*
	Q15. Taking classes in the smart classroom has improved my learning enthusiasm and participation	3.84	0.61	34.431*

Note: *$P < 0.05$.

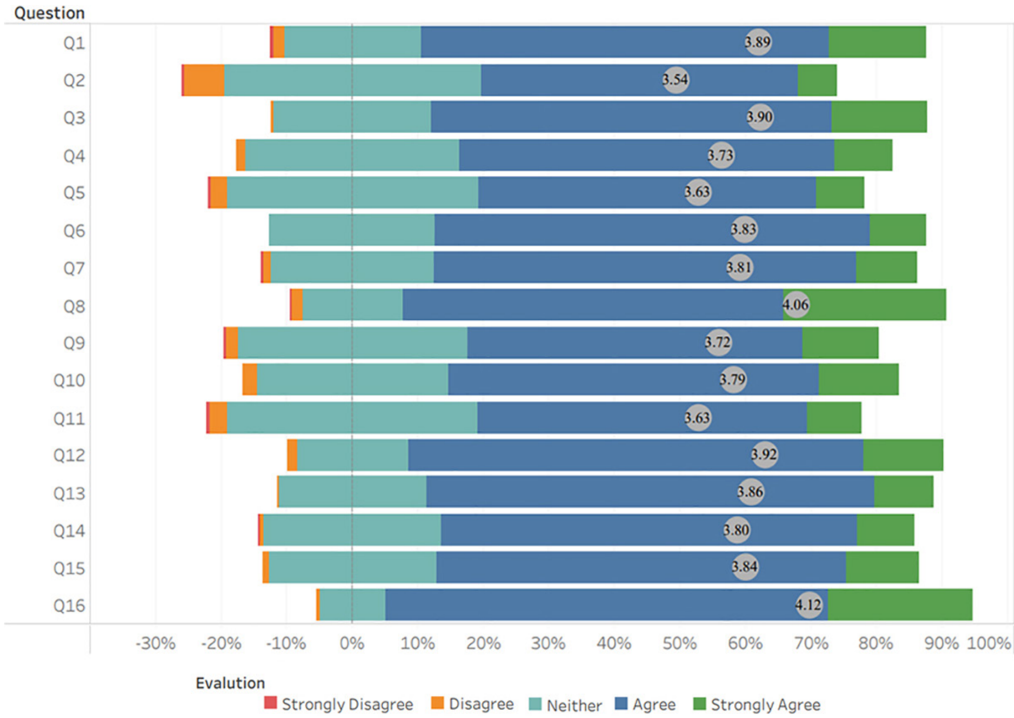

Fig. 7. Results of the distribution of the percentage of students' satisfaction at all levels

According to the first set of questions (Q1–Q3), students expressed their perceptions about the potential of information technology to enhance the learning process as a teaching aid in the smart classroom. The statistical results show that students are satisfied with both device access (item 1) and multi-screen content presentation (item 3) (3.89 ± 0.672 and 3.90 ± 0.624). This indicates that the integration of mobile devices into their learning process is highly suitable and that the use of the MSILS effectively lowers the cognitive load of students. However, there is still some deviation (3.54 ± 0.72) from our expected resource access (item 2). Many students perceived that they could not access and share high-quality learning resources, even though our education cloud platform already has a vast collection of digital learning resources. Therefore, the design of future smart classrooms should prioritize the convenience of accessing various learning resources. This will enable students to easily access resources through the Internet and smart devices.

In terms of pedagogy (Q4–Q7), four indicators were used to measure students' actual feelings about the teaching methods employed. These indicators included human interaction, human-technology interaction, teaching activities, and learning support. The focus was on determining whether classroom interaction was promoted. The survey results show that, with the exception of a low mean score (3.63) for human-technology interaction (item 5), students generally agreed that the smart classroom enhanced other interactions in the classroom (item 4), such as interaction with resources and interaction between teachers and students (66% agreed or strongly agreed). This finding indicates that the interaction with the device or system interface is not very user-friendly. It also suggests that there are still many aspects of the supporting technology and teaching platform in the smart classroom that require further improvement. However, 59.0% of students agreed or strongly agreed that technology should be used in the classroom to enhance interactions (item 5). The fact that 66.5% of students were satisfied with the teaching style (item 6) and 8.4% were very satisfied with it, with no students objecting, indicates that they are successfully adapting to and integrating into the new learning environment. Additionally, 73.8% of the students agreed or strongly agreed that they could receive learning support in the smart classroom. Overall, this finding suggests that it is very appropriate to apply teaching methods that combine M-learning and multi-display technology to the teaching and learning process.

Regarding perceived value (Q8–Q11), the main focus was on whether smart classrooms were designed to enhance student learning and foster engagement in the learning process. As shown in Table 1 and Figure 7, there were significant differences in students' perceptions of the overall value of smart classrooms. 82.8% of students indicated that smart classrooms provide a better learning experience than traditional classrooms (Q8 mean score: 4.06 ± 0.691). Additionally, students reported believing that this new learning environment has changed the traditional lecture-based teaching method and given rise to new and diverse teaching methods (Q10 mean score: 3.79 ± 0.672). These findings align with the statistical results of the students' learning experience in the smart classroom. Many students agreed or strongly agreed that the smart classroom helped them understand and master course concepts, improving their learning (item 9). However, approximately 38.2% of students remained neutral on the question of learning effectiveness, and their score on the question of learning effectiveness was the lowest (3.63 ± 0.696). This suggests that teachers need to make more efforts to enhance students' professionalism and overall competence.

Finally, regarding the last block (Q12Q15) on learning satisfaction, the results show an overall mean score of 3.86 with a standard deviation of 0.59. The mean scores for all questions were very close and not low, indicating that the learning experience for students was effective. A total of 81.6% of students felt that the experience in the smart classroom had the desired effect (item 12). Regarding whether smart classrooms promote higher levels of motivation and engagement (item 15), 73.6% of students felt that the spatial layout (including tables, chairs, and multi-screen layout), physical environment, and variety of interactions in smart classrooms motivated and engaged them. These factors, in turn, influenced their motivation to learn. Only 0.8% of students disagreed, and there were no negative comments. This finding indicates that the use of smart classrooms promotes complete student engagement.

Along with the 15 items in Table 1, the final item (Q16) was utilized to assess students' ongoing willingness to utilize smart classrooms. The responses reveal that students' attitudes toward the use of smart classrooms are generally very positive (4.12 ± 0.57). Almost 90% of students (89.7%) are willing to continue taking classes through smart classrooms, with 22.3% expressing a strong desire to continue using them. In general, the students expressed their sincere gratitude for the use of the smart classroom system and conveyed their desire to utilize it in other subjects of their curriculum.

To determine if there is a significant difference between the students' satisfaction with the proposed system and the general value of "3", a single-sample t-test was conducted. The results showed that the mean values of the items were all higher than 3, which was statistically significant ($p < 0.05$). This indicates that, overall, the students were relatively satisfied with the proposed system and expected that teachers would continue to apply it in future teaching.

From the results of the survey, it is clear that smart classrooms meet the teaching and learning needs of teachers and students. They increase teaching interaction, promote and support course teaching, and, to a certain extent, promote the reform of classroom teaching methods and modes.

5 DISCUSSION AND CONCLUSION

Many studies have already demonstrated that the integration of mobile and multi-display technologies in education can foster student engagement and motivation. This integration also provides considerable benefits by building and supporting creative, collaborative, and interactive capabilities within learning environments [26, 43, 44]. The inclusion of these technologies enhances the teaching and learning process at universities, providing students with an efficient and interactive learner-centered multi-screen learning environment [28, 45].

This research was conducted with the objective of designing and evaluating the impact of the proposed smart classroom architecture, which is based on the MSILS, on the teaching and learning of traditional science and engineering courses. In this paper, we propose a new smart classroom architecture that combines M-learning and multi-display technologies to address the challenges encountered in traditional classrooms. We implemented and deployed the system for real classroom learning. Students' evaluations were collected, and their experience of using the system was analyzed in four aspects: information technology, pedagogy, perceived value, and learning satisfaction. The experimental results demonstrate that the smart classroom system proposed in this paper effectively enables engineering students to actively participate in the classroom, enhancing their learning interaction and satisfaction. The multi-screen display significantly reduces cognitive load and improves learning efficiency. The results observed in this research mirror those of the previous literature [5, 29] that examined the effect of introducing a multi-screen learning environment in both secondary schools and higher education institutions. One of the important implications of this finding is that the implementation of a smart classroom can enhance students' motivation and classroom interaction, improve their understanding and mastery of course content in the target subject, and foster the development of their independent learning skills, creative thinking, and analytical and problem-solving abilities. Moreover, different pedagogies require different learning environments [46, 47]. Technology-equipped physics classroom environments are designed to assist students and teachers in understanding course content using various learning and teaching methods. This has contributed, to some extent, to the reform and innovation of classroom teaching methods and pedagogical models [48].

Another noteworthy fact is that students found the system to be highly effective for learning and that it increased their satisfaction in the classroom. Approximately 90% of students expressed a desire to continue using the system in future courses.

Overall, the use of the proposed system had a highly positive impact on students. We recommend integrating such a learning environment into almost all science and engineering courses. The system will be promoted in schools and continuously improved as we receive more user feedback.

Despite the positive aspects identified in the present research, there are still some shortcomings. First, despite the use of mobile devices in every class, a significant number of students still faced challenges accessing digital learning resources and sharing them with their peers. This finding reveals that students are still not familiar with the operations that the MSILS offers due to insufficient descriptions or user-friendly interfaces while using the system. Therefore, there is a need to continuously optimize interactive teaching systems in the future to meet the needs of learners [49]. Pedagogical adaptability should be a key consideration for smart classroom applications. Second, the gender ratio of the collected sample is not well balanced between men and women, which may have an impact on the final data analysis results to some extent. Future studies should take this into consideration. Finally, this paper only investigated students' satisfaction with this smart classroom system and their feedback regarding interaction. However, no comparative experiments were conducted to explore the impact of this system on learning performance. Future studies may consider using traditional multimedia classrooms as a control group for comparative studies on learning.

The construction and application of smart classrooms are still in the early stages, and the exploration of smart classroom teaching is a relatively new topic for both theoretical research and practical application. Future research should avoid excessive focus on information technology and instead prioritize the actual needs of teaching reform. The goal should be to create a smart teaching environment that caters to the diverse application needs of teaching modes in colleges and universities. Subsequently, the investigation should delve into the patterns of teaching and learning activities in smart classrooms, with the aim of aligning technology, teaching, and learning spaces. In this way, the true potential value of the smart classroom as a new learning environment can be realized.

The main contributions of the study include the following: (1) The proposed architecture is a smart classroom architecture based on the MSILS. The study evaluates the impact of the system on the learning of science and engineering students in four dimensions: information technology, pedagogy, perceived value, and learning satisfaction. (2) The results reveal the significant benefits that integrating mobile device technology and multi-display technology into the proposed system can provide for university education, including flexibility, convenience, accessibility, immediacy, and interactivity. (3) Multi-screen displays have great potential for teaching and learning processes, as our initial experiments initially verified. (4) The use of ICTs for the instructional design of engineering courses can create a student-centered and smart learning environment. This environment encourages researchers to develop innovative systems for classroom learning environments and promotes changes in classroom teaching models, leading to a deeper integration of ICTs and classroom teaching.

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