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Innovative application of generating instrument operation videos using QR code technology in experimental teaching

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Abstract

Objectives: As an indispensable part of the higher education system, experimental teaching aims to cultivate students' practical skills, problem-solving capabilities, and innovative thinking. However, traditional models exhibit significant limitations, including uneven resource distribution, constrained operational demonstrations, and disparities in student comprehension. This study explores an innovative experimental teaching model employing Quick Response (QR) codes to enhance instructional efficacy and quality.
Methods: The proposed methodology employs QR codes to generate instructional videos for integration into experimental teaching. This approach transcends temporal and spatial constraints, enabling students to access instructional videos on demand.
Results: This technology-enhanced model facilitates mastery of instrument operation via on-demand video access, yielding the following outcomes: (1) improved efficacy and quality of experimental teaching; (2) flexible learning platform bridging theoretical knowledge and practical operations; (3) mitigation of issues of resource disparities and practice limitations inherent in traditional models; and (4) enhanced professional skills of students through self-paced repetition.
Conclusions: The study demonstrates that QR code technology drives innovation in experimental teaching reform. It effectively addresses traditional methodological constraints, improves instructional efficiency, and fosters optimal conditions for holistic student development.

Keywords: QR code technology; video of instrument operation; experimental teaching; innovative application

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Introduction

In the realm of educational innovation, the integration of technology into traditional pedagogical approaches has become increasingly pivotal, especially within experimental teaching contexts. As a cornerstone of science education, experimental teaching develops students' practical competencies, critical thinking, and problem-solving skills through hands-on learning [1]. However, traditional experimental teaching often encounters challenges such as resource limitations, high operational costs, and demands for personalized instruction. To address these challenges, educators are increasingly turning to technology, seeking innovative solutions that enhance the effectiveness and accessibility of experimental teaching. One such innovative application is the use of Quick Response (QR) codes technology to generate videos for instrument operation. QR code technology is renowned for its efficient data encoding/decoding capabilities and has been widely adopted in diverse fields, such as mobile payments, industry operations, and healthcare management [2–4]. Through in-depth analysis of QR code technology, we can identify its characteristics and advantages, such as large information storage capacity, wide coding range, strong fault tolerance, and low production costs. The incorporation of QR code technology in educational settings reflects current trends in technology-enhanced learning, specifically addressing key challenges related to accessibility, interactivity, and resource optimization. Recent studies have substantiated the pedagogical versatility of QR codes across diverse educational contexts. Onyeaka et al. [5] demonstrated that QR-linked pre-lab videos significantly improved procedural accuracy and reduced cognitive load among first-year engineering students, with 78 % of participants reporting enhanced confidence in complex tasks. Similarly, Lai et al. [6] implemented QR codes in forensic DNA training to standardize protocol dissemination, achieving a 22 % reduction in operational errors compared to traditional paper-based protocol dissemination. Collectively, these findings demonstrate QR codes' capacity to effectively bridge theoretical instruction and hands-on application, a critical need in experimental education. By leveraging these features, we can design a comprehensive process for producing and uploading videos of instrument operation, ensuring that students can easily access high-quality experimental teaching resources.

Traditional experimental teaching models present multiple challenges that affect both their learning experience and skill acquisition. First, when teachers personally demonstrate instrument operation in the classroom, due to limitations in vision and observation angles, it is often difficult to ensure that every student can have a clear and comprehensive observation experience [7]. In large classrooms, students in rear or peripheral positions frequently miss critical operational details due to visual obstructions, hindering comprehension and replication of procedures. Second, when students try to complete the experimental operation independently, remembering the steps becomes another common problem. Faced with a complex and multi-step experimental process, students are prone to miss certain key steps or confuse the order of operations under stress or excitement. Frequent instructor assistance requests disrupt both individual learning processes and overall class progress, compromising teaching efficacy. The technology's role in fostering self-regulated learning further resonates with the growing emphasis on flipped classroom models. Chen et al. [8] implemented QR code-embedded virtual labs in biochemistry courses, enabling students to access micro-lectures during experiments, which improved post-test scores by 15 %. This aligns with broader educational technology trends advocating for "just-in-time" learning resources to support individualized pacing.

In addition, traditional experimental teaching predominantly relies on paper-based instructions, which lack intuitive and interactive elements in knowledge delivery, thereby failing to accommodate contemporary students' learning preferences and cognitive requirements. Paper instructions typically only provide static images and textual descriptions, lacking dynamic visualizations and instant feedback mechanisms, which hinders students' comprehension of complex instrument operation principles and methodologies. Especially for students with strong spatial imagination or visual learning ability, this teaching method limits their learning efficiency and is not conducive to their rapid and accurate grasp of experimental skills. Therefore, exploring and implementing more diversified, intuitive, and interactive experimental teaching modalities has become crucial for enhancing instructional quality and fostering students' experimental skills.

The teaching effectiveness of QR code technology can be systematically explained within the framework of educational psychology theory. The cognitive load theory proposed by John Sweller et al. [9] indicates that minimizing unnecessary cognitive load is the key to optimizing learning outcomes. This viewpoint provides a theoretical basis for the educational application of QR code technology. This technology provides procedural information on demand, enabling students to immediately access step-by-step guidance videos during key procedures such as instrument operation. This not only effectively reduces working memory burden but also decomposes complex experimental processes into more manageable modular segments, while supporting repeated viewing to strengthen the construction of procedural knowledge. A research practice of an online anesthesia education tool found that 81 % of patients stated that this tool improved their knowledge and understanding of anesthesia and reduced their cognitive burden [10]. Furthermore, QR code technology perfectly aligns with the multi-media learning principles proposed by Richard E. Mayer [11]: its dual encoding method integrating visual demonstrations and auditory explanations significantly enhances knowledge retention; and the flexible video control functions (pause, replay, etc.) implement the segmented learning principle, allowing students to adjust their learning progress according to individual differences. Research data based on standardized clinical skills teaching videos managed by QR codes applied in clinical teaching showed that the operating costs of the clinical skills center were significantly reduced, while the interns and teachers who received the videos demonstrated higher satisfaction than the traditional teaching mode, and their final exam scores for clinical skills were better, and the pass rate for the clinical training admission skills examination was higher [12]. This empirically confirms the advantages of multi-media teaching. These research findings collectively indicate that QR code technology provides effective technical support for experimental teaching by optimizing cognitive load and strengthening multi-media learning.

Two-dimensional barcodes (2D barcodes) encode data through geometric patterns arranged in a planar matrix according to standardized rules [13]. Common types of 2D barcodes include PDF417, QR codes, Hanxin codes, and color barcodes, with QR codes being the most widely used. QR codes can store a substantial amount of information in a compact space, with a capacity that far surpasses traditional one-dimensional barcodes. Specifically, they can hold up to

950 uppercase letters, 1,210 numbers, 560 bytes of binary data, or over 200 Chinese characters. This high-density encoding enables exceptionally efficient data transmission. Furthermore, QR code technology boasts a wide encoding range, capable of encoding diverse digital information such as images, sound, and text, and representing it in the form of barcodes. It also supports multiple languages and image data formats, significantly broadening its application scope. QR codes exhibit robust fault tolerance and error correction capabilities. Even if partially damaged due to perforation, smudging, or other factors, as long as the damage does not exceed 50 % of the code areas, the computer can still accurately identify and recover the encoded information, ensuring readability and stability in various environments. QR codes are cost-effective to produce and compatible with standard printing technologies across diverse media. Moreover, the size, shape, and proportion of the QR code symbols can be flexibly adjusted to suit specific applications, meeting diverse needs. Lastly, QR codes offer versatile reading methods. They can be scanned using laser or Charge Coupled Device (CCD) readers, as well as the camera function of smartphones, further enhancing their convenience and practicality [13].

In summary, implementing QR code technology for instrument operation videos represents significant progress in educational technology innovation. This exploration contributes to ongoing discourse on educational technology integration and stimulates further innovation in experimental pedagogy.

Methods

Experimental design

This study systematically evaluates the pedagogical efficacy of QR-code-generated instrument operation videos in experimental teaching. Given the unique demands of experimental teaching, a non-randomized controlled trial design was employed. The participants were second-year clinical students from Xi'an Jiaotong University Health Science Center. These students had commenced their clinical medicine curriculum, requiring mastery of various experimental operation skills that are closely related to the research topic. Additionally, participants' smartphone proficiency facilitated seamless QR code scanning and video viewing, ensuring efficient and reliable data acquisition.

Participants were recruited from the 2022 and 2023 cohorts of clinical medicine students at Xi'an Jiaotong University. The intervention group (Grade 2023, n=128) received QR code-integrated instruction, while the control group (Grade 2022, n=115) followed traditional teaching protocols. The inclusion criteria required that the biochemistry laboratory course be a mandatory subject for students, and they had no prior formal exposure to QR code-based learning tools. Students with incomplete attendance records were excluded. To ensure methodological rigor, the following variables were controlled: the participating teachers (n=28) were full-time lecturers with more than three years of experience in experimental teaching, ensuring consistency in teaching methods and evaluation criteria. The experiments were conducted in the same laboratory environment, using the same instruments and experimental materials to ensure stability in experimental conditions. The study subjects were all clinical medicine students with inherent similarities, thereby minimizing the impact of individual student differences on research outcomes.

Application of QR code technology in experimental teaching

Create an instrument operation video

Firstly, to ensure precise documentation of experimental instrument operations, professional screen recording software or high-definition digital cameras should be carefully selected and utilized. Selection criteria should prioritize tools capable of producing high-quality, real-time recordings that faithfully capture all procedural details without latency. Prior to recording, optimal parameters must be established, including appropriate resolution (recommended 1080 p at minimum), frame rate (≥30 fps), and standardized aspect ratios (typically 16:9 or 4:3) to ensure visual consistency. This approach streamlines video editing and post-production in the later stages, thereby avoiding problems such as image distortion or inconsistent proportions between different segments. Optimal lighting conditions must be maintained during recording, with uniform illumination of the experimental area to prevent quality degradation from shadows or reflections. Simultaneously, using a tripod or a fixed device can reduce jitter and make the video footage more stable. This video documentation approach enables accurate reproduction of experimental procedures, facilitates knowledge transfer, and generates valuable visual resources for both educational and research purposes.

Generate QR codes

The subsequent critical phase involves converting the video content into scannable QR codes using established generation tools. For this purpose, we can use popular online tools such as "QR Code Generator" and "Create QR Codes" to generate QR codes [14]. These tools combine user-friendly interfaces with reliable code generation capabilities, ensuring optimal scannability. After selecting a suitable QR code generation tool, we simply need to upload the video material and click the generate button. The system generates unique QR codes containing complete video metadata while maintaining optimal visual recognition characteristics.

The generated QR codes have multiple applications. First, we can print them out and attach them next to the experimental equipment. In this way, when the experimenter is performing the operation, they can immediately view the corresponding operation video by simply scanning it, greatly improving the efficiency and accuracy of the experiment. In addition, we can embed QR codes into laboratory manuals, so that students can easily scan and watch videos on their mobile devices during preview or review, thereby deepening their understanding of experimental steps and principles. In this way, we not only effectively integrate and utilize the video resources of experimental operations, but also enables rapid dissemination and widespread sharing of knowledge through the convenience of QR code technology.

Students scan codes to learn

During experiments, students can easily scan the QR codes attached to the laboratory equipment or embedded in the laboratory manuals by making full use of the convenience of modern technology on their mobile phones or tablet computers. This process facilitates immediate access to multimedia learning resources, allowing them to directly watch video tutorials pertinent to the operation of current experimental instruments. This approach significantly expands the scope of learning in terms of time and space, allowing students to no longer be limited by traditional classroom environments or fixed study times. Whether they are revising and previewing at home or encountering operational difficulties in the laboratory, they can scan the QR codes anytime and anywhere to obtain instant guidance and assistance. This approach supports personalized learning while enhancing both instructional efficiency and student autonomy. More importantly, the interactive and engaging nature of experimental teaching is significantly enhanced through the use of QR codes to view operation videos. During the process of watching the video, students can understand the experimental steps more intuitively, reduce the likelihood of experimental failure caused by improper operation, and thus enhance their confidence and interest in the experiment. At the same time, elements such as animated demonstrations and explanations of experimental principles that can be interspersed in the video make the learning process more vivid and engaging [5]. This diversified teaching method enriches students' learning experience.

In summary, using QR code technology to access videos of experimental instrument operation not only provides students with a convenient and efficient learning method, but also significantly p enhances the format and content of experimental instruction, thereby promoting the comprehensive improvement of students' practical skills.

Results

The application effect and advantages of QR code technology in experimental teaching

Improve teaching effectiveness

The meticulously produced instrument operation videos, facilitated by QR code technology, provide students with intuitive and dynamic learning resources. These videos employ visual demonstrations to guide students in mastering instrument operations, enhancing procedural comprehension and significantly improving instructional effectiveness, thereby optimizing knowledge transfer.

Save teaching cost

Compared with traditional experimental teaching, which relies on a large amount of experimental equipment and textbooks, QR code technology significantly reduces resource requirements through its innovative applications. By providing instructional videos of instrument operations, this approach not only reduces teaching expenditures but also offers novel perspectives on optimizing educational resource allocation, thereby maximizing cost-effectiveness.

Promote interaction between teachers and students

QR code technology serves not only as a medium for information transmission but also as a catalyst for enhancing interaction between teachers and students. Instructors can easily update operation videos of experimental instruments to ensure that teaching content remains current; students can provide immediate feedback on their learning questions and confusions, facilitating rapid problem resolution. This two-way interaction not only deepens communication and understanding between teachers and students but also significantly enhances the relevance and effectiveness of experimental teaching, making the learning journey smoother and more seamless.

Cultivate self-regulated learning ability

The videos of instrument operations generated by QR code technology create a flexible, self-paced learning environment for students. Learners can access these videos anytime and anywhere, progressing at their preferred pace and according to their individual interests. This personalized learning approach greatly stimulates students' enthusiasm for autonomous learning, cultivates independent thinking and problem-solving skills, and lays a robust foundation for lifelong learning.

Evaluation of the application of QR codes in experimental teaching

Questionnaire design and survey participants

With the rapid advancement of science and technology, the application of 2D code (QR code) technology in education has become increasingly prevalent. Especially in experimental teaching, QR code technology offers students more intuitive and accessible learning resources. This questionnaire survey aimed to investigate innovative applications of QR code technology in generating instructional videos in experimental teaching, as well as to collect feedback from both educators and students. The questionnaire assessed the current utilization of QR code technology in experimental teaching, its acceptance among educators and students, its effectiveness, and potential improvements. The survey primarily targeted instructors and students engaged in experimental teaching activities.

Survey results and analysis

The current application of QR code technology in experimental teaching

Quantitative analysis revealed divergent adoption patterns and perceptions between educators and students regarding QR code technology implementation. The results showed that implementation rates reached 88.5 % among instructors and 92.2 % among students for accessing instrument operation videos (Figure 1A). QR code technology is primarily utilized for providing operation instructions for experimental instruments, guiding experimental steps, and facilitating the submission of experimental reports. Among them, 65.5 % of teachers used this technology at least once a week to update teaching materials or simplify classroom management (Figure 1B). Educators reported a reduction in procedural explanations, enabling increased focus on individualized instruction and skill development. In contrast, students' interaction with QR codes focused on ease of use and self-paced learning. Survey results showed that

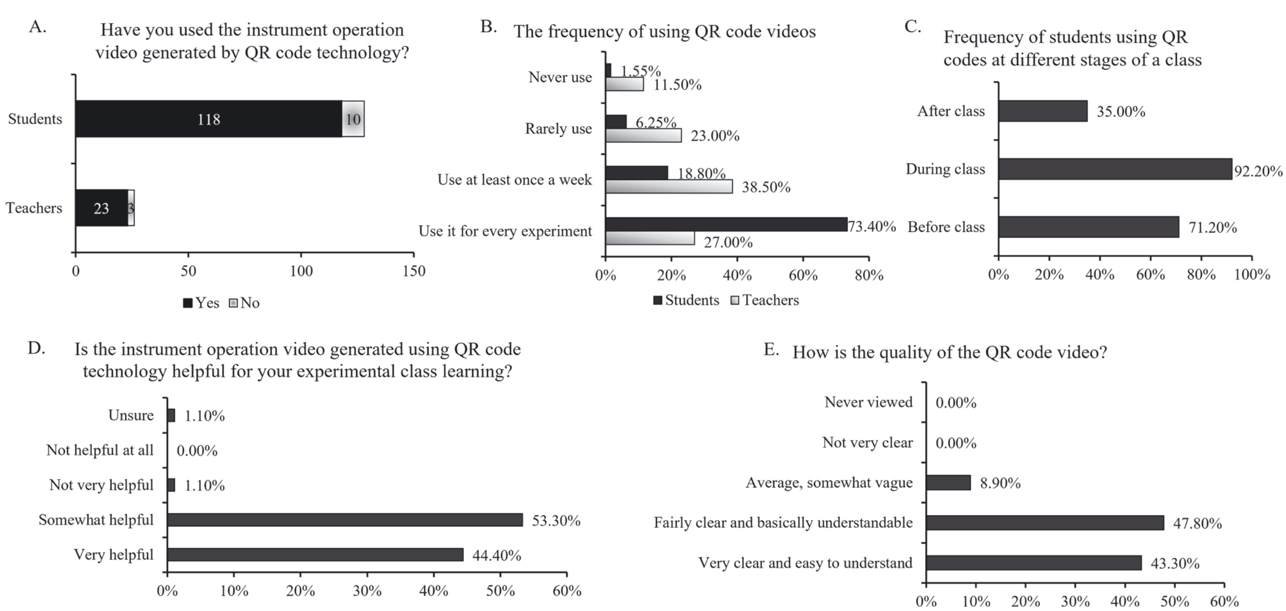

Figure 1: Survey analysis on the application of QR code technology in experimental teaching. (A) and (B) The willingness and frequency of teachers and students to utilize QR code technology. (C) The frequency of students' use of QR codes at different stages of the experimental course. (D) Feedback on the accessibility of QR code-generated videos for students. (E) Students' feedback on the video quality of QR code-based materials.

71.2 % of students scanned QR codes during pre-lab preparation, while 92.2 % accessed videos for in-lab troubleshooting (Figure 1C), and an additional 35.0 % for post-lab review (Figure 1C), which offered the convenience of reviewing complex steps post-lesson. QR codes facilitated on-demand access to experimental videos, transcending temporal and spatial constraints, enhancing their understanding of the experimental content (Figure 1D). Simultaneously, on-demand video access significantly reduced their anxiety about operational errors.

Students placed high value on video quality and availability, with 91.1 % rating the clarity of the videos linked by QR codes as "excellent" or "good" (Figure 1E), making the instrument operation steps easy to understand and thus facilitating their learning process. However, a minority of students mentioned occasional technical challenges, such as unstable internet connections affecting video loading times. These findings highlight the differences in priorities between teachers and students, with teachers valuing the role of QR codes in improving teaching efficiency and resource standardization, while students appreciating their role in fostering autonomy, reducing cognitive load, and enabling flexible learning. Addressing these complementary needs can further optimize the impact of this experimental technology in education.

Acceptance of QR code technology by teachers and students

Educators widely perceived QR code technology as an innovative pedagogical tool that enhances instructional efficiency and fosters students' learner autonomy based on survey responses. This technology simplified the teaching process and encouraged students to explore independently. Similarly, students had shown great interest in QR code technology, finding it novel and engaging. They enjoyed scanning QR codes to access learning resources and participated in classroom activities, believing that this technology provided them with a more convenient way to learn. They could scan the QR codes anytime and anywhere to obtain the required learning materials or complete their assignments, making knowledge easier to acquire and the learning experience more enjoyable.

Application effect and improvement suggestions of QR code technology

The results of this questionnaire survey revealed that the innovative application of QR code technology in experimental teaching had achieved remarkable results and gained widespread acceptance among both teachers and students. Teachers reported notable improvement in students' experimental operation skills following the adoption of QR code technology. This technology also reduced the time teachers spent explaining procedures in the classroom, enabling them to focus more on observing and guiding students' practical work. Students had expressed that scanning QR codes to view operational videos helped them grasp experimental steps more quickly and reduced operational errors.

The survey further indicated that some teachers suggested expanding the functionality of QR code technology, such as by developing more interactive features to enhance student engagement. Additionally, students hope that QR code technology could be applied to a wider range of experimental courses, offering them even more diverse learning resources. Moreover, both teachers and students had proposed enhancing the security of QR code technology to protect against the spread of malicious software and viruses. These suggestions underscored the ongoing potential for improvement and refinement in the application of QR code technology in experimental teaching.

Comparison of experimental results

The class participating in this teaching reform consisted of the Grade 2023 clinical medicine students, whose average experimental course score was (96.25 ± 0.79). This score was significantly higher ($p<0.01$) than that of the Grade 2022 clinical medicine students, which was (94.52 ± 0.81), as shown in Figure 2. The Grade 2023 clinical medicine students demonstrated operational proficiency through on-demand video access of instrument operation and analyze test results by scanning the QR codes. Additionally, video learning provided convenient conditions for students to preview before

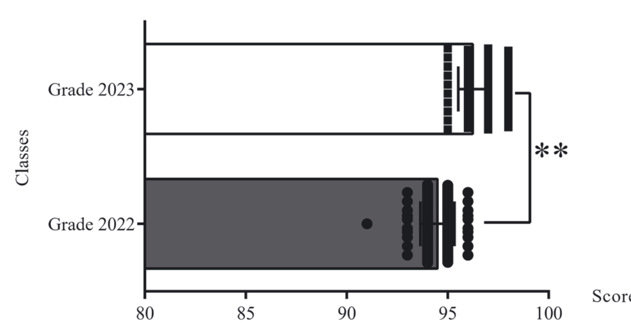

Figure 2: Comparative analysis of experimental course scores. The experimental scores of clinical medicine students from the Grade 2023 and Grade 2022 classes were analyzed. The results indicated that students' experimental scores significantly improved through watching videos of instrument operation accessed via QR codes. Quantitative data are presented as the mean ± standard deviation (SD). Multiple group comparisons were conducted using ANOVA Post Hoc Tests (Bonferroni) with *StatView* software (version 2.15). A p-value of less than 0.01 was considered statistically significant. $^{**}p<0.01$.

class and review repeatedly after class, which may be one of the factors contributing to the improvement in the experimental course scores of the Grade 2023 clinical medicine students.

Discussion

The strategic integration of QR code technology into experimental teaching, coupled with high-quality video tutorials, has significantly enhanced instructional quality while reducing costs. Additionally, it fosters teacher-student interaction and cultivates independent learning skills. In light of these benefits, we should make every effort to promote and apply QR code technology, injecting vitality and a strong impetus into experimental teaching.

Currently, this technology has been applied in experimental teaching of various disciplines such as biomedicine, agriculture [15], physics, and engineering [16]. This indicates that the QR code technology has already demonstrated certain teaching value in experimental teaching. In the future, we can also improve and perfect this technology to better serve the experimental teaching. While QR code technology shares the broader goal of enhancing experimental instruction with other digital tools like augmented reality (AR) manuals and virtual simulation platforms, its pedagogical value lies in distinct practical advantages. Compared to AR-based systems, which require specialized hardware and high development costs, QR codes leverage ubiquitous smartphones, ensuring low-cost scalability. Similarly, virtual labs excel at simulating hazardous scenarios but lack tactile feedback for physical instrument handling, a gap addressed by QR-linked videos that bridge virtual guidance with hands-on practice. For instance, in chemistry experiments, linking QR codes to standardized instructional videos for hazardous reagents can substantially improve experimental safety. In engineering training, dynamic videos illustrating the assembly and disassembly processes of complex equipment can reduce operational challenges. Moreover, this technology could be adapted for non-traditional laboratory environments, including field internships and clinical skill training, offering students with “on-demand guidance” and overcoming the spatial and temporal limitations of conventional teaching. Furthermore, by integrating AR and virtual reality (VR) technologies, QR codes can serve as portals to hybrid virtual-physical environments. For instance, after scanning a QR code, students can not only access instructional videos but also engage with virtual instrument models via AR interfaces, simulating troubleshooting or parameter adjustment procedures to strengthen practical skills. Naturally, the successful implementation of this technology necessitates comprehensive teacher training. Workshops, micro-certification courses, and similar initiatives can enhance educators’ proficiency in video production, QR code management, and data-driven instruction. Simultaneously, experimental classroom design should be reconceptualized – the role of instructors transitions from “operational demonstrators” to “learning facilitators,” with increased class time allocated to higher-order cognitive tasks (e.g., experimental design, data analysis). Meanwhile, foundational operational skills can be acquired through pre-class self-study via QR code scanning, facilitating a “flipped classroom” approach. This approach significantly improves the efficiency of experimental teaching.

This study deeply explores the innovative application of QR code technology for generating instrument operation videos in experimental instruction. By carefully analyzing the unique advantages of QR codes and integrating them with video production and uploading process, we have proposed specific strategies to enhance experimental teaching efficacy. Looking ahead, in experimental teaching activities, we can further explore the potential of QR codes. Beyond the existing instrument operation guides and experimental step-by-step instructions, we can also investigate the use of QR code technology for recording experimental data, sharing experimental results, and other purposes. Simultaneously, we are committed to developing more interactive features, such as online question and answer (Q&A) and real-time feedback, allowing students to ask questions and participate in discussions while watching the videos, thereby deepening their learning engagement and stimulating their interest in learning. Furthermore, we must also strengthen the security management of QR code technology to ensure that the sources of the QR codes scanned by students are credible and to prevent the infiltration of malicious software and viruses.

In summary, the innovative application of QR code technology for generating instructional videos in experimental teaching has brought numerous unprecedented conveniences and significant advantages. This approach has significantly improved students’ learning efficiency and procedural mastery while offering scalable, sustainable solutions, and provided novel methods for the innovation and development of experimental teaching. We confidently anticipate that QR code technology will play an even more pivotal role in future educational practice.

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Data availability: All data supporting the reported results were showed in figures included in the present manusctipt.

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