QR CODE–ENABLED DIGITAL BADMINTON MODULES IN HIGHER PHYSICAL EDUCATION: DEVELOPMENT, USABILITY, LEARNING AUTONOMY, AND MOTOR SKILL OUTCOMES

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ABSTRACT
Practice-oriented badminton courses require students to translate technical explanations into rapid, coordinated movement, yet conventional printed modules cannot adequately represent temporal, spatial, and biomechanical features of strokes. This study developed and evaluated a QR code–enabled digital badminton module designed as an on-court visual learning assistant for physical education students. A research-and-development design using the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model involved 55 purposively selected students: 15 in a small-scale trial and 40 in a large-scale trial. Data were collected through content- and media-expert validation forms, student-response questionnaires, and observational motor-skill assessments. Expert validation indicated very high feasibility for content (88.00%), language and theoretical presentation (86.00%), graphic design (92.00%), and QR functionality (94.00%). In the large-scale trial, positive responses reached 90.50% for access ease, 88.20% for video clarity, 86.80% for independent practice, and 92.00% for learning motivation. Reported pre–post comparisons showed significant improvements in short serve (gain = 16.30, p = .002), clear lob (gain = 23.20, p = .001), and drop shot performance (gain = 19.50, p = .004). The findings indicate that a low-friction combination of concise printed guidance, cloud-hosted video, and instant QR access can support independent rehearsal and motor-skill learning in higher physical education. The study contributes a field-oriented hybrid-media design that minimizes navigation demands during physical practice. Future research should use multisite controlled trials, report effect sizes and retention outcomes, and test offline access and automated motion-feedback features.
Keywords: Badminton learning; Digital module; Motor skill performance; Physical education; QR code.

INTRODUCTION

In the past decade, much research has focused on the integration of digital technology into physical education because contemporary learners routinely move between physical, visual, and networked environments. Digital transformation in education is no longer limited to the substitution of printed pages with electronic documents; it increasingly involves the deliberate orchestration of video, mobile access, data, feedback, and learner autonomy. This shift is particularly relevant to higher physical education, where students are expected to acquire disciplinary knowledge, demonstrate technically correct performance, and develop the pedagogical capacity to teach movement to others. Indonesian scholarship similarly describes a transition toward technologically enriched sport pedagogy and more flexible digital media ecosystems (Ghazy et al., 2025; Yusdiantara, 2025). International reviews confirm that digital tools in physical education have expanded rapidly, although their instructional value depends on how they are aligned with pedagogical goals rather than on technological novelty alone (Calabuig-Moreno et al., 2020; Jastrow et al., 2022). Badminton provides a demanding context for this transformation. Effective performance depends on the coordination of grip, stance, footwork, timing, racket trajectory, impact point, and tactical placement within fractions of a second. Competitive analyses show that badminton combines high-intensity movement with repeated technical decisions, while biomechanical research increasingly uses sophisticated motion analysis to explain stroke production (Cabello Manrique & González-Badillo, 2003; Yang, 2026). For physical education students, the instructional challenge is therefore twofold: they must execute the movement and understand it sufficiently to diagnose and teach it. Conventional demonstrations remain indispensable, but a lecturer cannot remain beside every student during every repetition. Printed modules can standardize terminology and sequence, yet static photographs cannot fully communicate acceleration, joint sequencing, weight transfer, or the transition between preparation, impact, and recovery. Studies of badminton foot morphology, agility, and sport-specific training further indicate that performance is shaped by interrelated physical and technical factors that cannot be reduced to a single still image (Cahyo Setyaji, 2023; Kusuma, 2026; Li, Z., et al., 2025). Video-supported learning offers a plausible response because observation can provide a perceptual model of movement before, during, and after practice. Evidence from physical education demonstrates that video technology can improve student performance, self-assessment, and engagement when learners are able to inspect technically meaningful examples (Mödinger et al., 2022; Palao et al., 2015; Potdevin et al., 2018). Observation-based motor-learning theory explains that learners extract information about movement organization, outcomes, and error correction from models, particularly when demonstrations are paired with focused cues and opportunities for repetition (Ste-Marie et al., 2012). More recent experimental evidence also supports digital video feedback in complex gymnastic learning (Fauzi et al., 2026). The relevance to badminton is direct: slow-motion and multi-angle demonstrations can expose otherwise fleeting features such as racket preparation, forearm rotation, contact height, and follow-through. The pedagogical advantage of video, however, can be weakened by access friction. During an active practical session, students may need to unlock a device, search a platform, navigate menus, select a trustworthy clip, and relocate the exact segment that explains the current task. Each additional step interrupts physical practice and consumes attention. QR codes provide a simple bridge between a physical learning prompt and a specific digital resource. A printed code can direct a learner immediately to a designated video, animation, assessment rubric, or cloud resource without requiring a dedicated application. Research on QR-supported video learning has reported benefits for access and blended learning, while Indonesian work has highlighted the potential of QR-linked visual media for modern instruction (Ahmed & Zaneldin, 2020; Zahrah & Wardhana, 2025). The technology is inexpensive, device-agnostic, and compatible with modular updates because the destination content can be revised without changing the pedagogical logic of the printed guide. Two theoretical perspectives clarify why such a design may be useful. First, cognitive load theory argues that instructional design should reduce processing that is unrelated to the learning goal so that limited working-memory resources can be directed toward schema construction (Sweller, 1988). Multimedia learning research similarly recommends coherent signaling, segmenting, and the coordinated presentation of words and pictures rather than redundant or poorly organized information (Mayer & Moreno, 2003). For a novice badminton learner, a concise cue next to a QR-linked demonstration may reduce the extraneous demands associated with searching, interpreting dense prose, or mentally reconstructing motion from static images. Research with physical education students has shown that the form of visual presentation can affect technical performance, motivation, and cognitive load (H'mida et al., 2020). Indonesian discussions of Sweller's theory and multimodal learning reinforce the importance of controlling unnecessary processing, although the original manuscript's references to unrelated sensing and material technologies illustrate the need to distinguish pedagogical evidence from merely technological adjacency (Agarwal & Choudhary, 2025; Li, D., et al., 2026; Syagif, 2024). Second, technology acceptance research proposes that adoption is influenced by perceived usefulness and perceived ease of use (Davis, 1989; Venkatesh & Davis, 2000). In practical physical education, acceptance is not an abstract intention: it is visible in whether students actually scan the code between repetitions, replay the demonstration, and use the resource without abandoning the task. Indonesian studies applying the Technology Acceptance Model to higher education support the relevance of ease and utility for e-learning adoption (Akmal et al., 2025; Santi & Erdani, 2021). At the same time, research on online physical education warns that technology must be sensitive to infrastructure, teacher readiness, and the embodied nature of learning (Han, 2025). A QR-enabled module is therefore attractive not because it digitizes everything, but because it preserves face-to-face physical practice while inserting a limited, purposeful digital layer at the moment of need.

Despite growing interest in digital physical education, it remains unclear how a lightweight QR-linked module can be designed specifically for on-court badminton learning in higher education and whether such a module is simultaneously feasible, usable, and associated with improved motor performance. Existing digital interventions frequently emphasize remote instruction, large standalone applications, general fitness tracking, or post-performance video review. These approaches are informative but do not fully solve the immediate problem faced by a student who needs an authoritative, curriculum-aligned visual reference within seconds while standing beside a badminton court. The practical niche is therefore not simply 'digital learning in sport'; it is the design of a low-friction hybrid resource that connects concise task cues to specific biomechanical demonstrations without displacing active practice. The source manuscript identified recurrent local problems: conventional modules were unable to represent fast movement adequately; lecturers had to repeat demonstrations for students who progressed at different rates; students lacked validated visual guidance during independent practice; and generic online videos did not necessarily match course expectations. These problems also expose a broader instructional contradiction. Students need rich visual information, but excessive device interaction can fragment practice. They require autonomy, but unguided autonomy may reinforce incorrect technique. They benefit from multimedia, but multimedia can increase rather than reduce cognitive load when it is cluttered or poorly sequenced. The general solution is consequently a structured hybrid system in which each QR code has a clear pedagogical purpose, each linked video is brief and technique-specific, and the printed module retains enough information to orient learning even before scanning.

The scientific literature suggests several design principles for such a solution. ADDIE offers a systematic framework for linking needs analysis, instructional design, product development, implementation, and evaluation, and remains widely used for iterative digital and blended learning development (Ranuharja et al., 2021; Shakeel et al., 2023; Spatioti et al., 2022). Within that framework, observational learning research supports the use of expert models, slow motion, repeated viewing, and cues that direct attention to critical features (Ste-Marie et al., 2012). Self-controlled combinations of video feedback and modeling can facilitate motor learning because learners can access information when it is most relevant to their perceived needs (Post et al., 2016). Feedback reviews also show that timing, specificity, learner level, and opportunities to act on feedback determine whether information produces durable skill change (Zhou et al., 2021). A field-oriented QR module can operationalize these principles by organizing content into discrete skill units: technical purpose, key movement cues, common errors, safety notes, QR-linked expert demonstration, and a short self-check. Visual production should privilege legibility, stable contrast, and meaningful camera angles rather than decorative complexity; graphic-design practice is relevant because poor layout can obstruct otherwise strong content (Wakla, 2023). Cloud-hosted resources and responsive web architecture can simplify content maintenance, although adjacent studies of booking systems, mobile applications, and integrated information systems should be treated as technical design references rather than direct evidence of motor learning (Daza et al., 2026; Masyitoh & Handayani, 2024; Prananingrum et al., 2025). Emerging movement technologies—including exoskeletons, motion sensing, electromyography, spiking neural networks, electronic skins, and concealed machine-readable tags—also demonstrate the expanding technical horizon, but they require a much higher level of infrastructure than a QR module (Agarwal & Choudhary, 2025; Kao & Wei, 2026; Li, D., et al., 2026; Liu et al., 2022; Melinda, 2025; Yotamornsunthorn, 2022).

The literature becomes progressively narrower at the intersection of four elements: higher physical education, badminton technique, instant QR access, and measured motor outcomes. QR studies commonly examine engagement, information access, or general learning outcomes; video-feedback studies typically focus on recorded learner performance and subsequent feedback; badminton technology studies increasingly emphasize biomechanical or artificial-intelligence analysis; and instructional-design studies often evaluate acceptance without testing sport-specific skill change. Darsi et al. (2025) developed a QR code–based physical education module for floor-gymnastics techniques and reported favorable feasibility, offering a close precedent. Nevertheless, the movement demands, equipment interaction, temporal structure, and tactical intent of badminton strokes differ from floor gymnastics. Yang's (2026) high-precision biomechanical analysis represents another relevant direction, but it addresses advanced analytical capability rather than an immediately scalable teaching resource. The unresolved gap concerns whether a simple, curriculum-embedded QR module can connect expert validation, student usability, independent practice, and badminton motor-skill outcomes in one development study. A second gap concerns evidentiary precision. Claims that a digital module 'reduces cognitive load' or 'increases technology acceptance' require direct measurement using validated instruments. The supplied study measured expert feasibility, student responses, and motor performance, but it did not report a dedicated cognitive-load scale or a full TAM model. Accordingly, cognitive load and technology acceptance are used here as explanatory frameworks rather than as directly tested dependent variables. This distinction is important for preventing theoretical interpretation from being misreported as measured causal evidence. Similarly, the increase from the small-scale to the large-scale response percentages should be interpreted as a product-development pattern across different groups after revision, not as a longitudinal gain within the same students.

The purpose of this study was to develop a QR code–enabled digital badminton module for physical education students and to evaluate its content and media feasibility, student-perceived usability and learning support, and associated changes in basic badminton skill performance. The novelty lies in the deliberate hybridization of a compact court-side module with technique-specific, cloud-hosted visual demonstrations that are accessible without installing a dedicated application. Unlike generic e-modules, the product was designed for interruption-sensitive physical practice: the learner scans a code, views a bounded demonstration, rehearses the movement, and returns to the task with minimal navigational delay. The study was guided by the expectation that a highly feasible and easily accessed module would receive positive student responses and that repeated access to validated visual models would be associated with higher post-test scores in short serve, clear lob, and drop shot performance. This expectation is theoretically justified by cognitive load, multimedia learning, observational learning, and technology acceptance research, but the design does not establish a definitive causal mechanism. The scope is limited to one higher-education physical education context, purposively sampled students, expert review, two stages of product trial, and a reported pre–post performance case study. It does not compare the module with a randomized control condition, test long-term retention, measure cognitive load directly, or evaluate advanced tactical decision making. These boundaries define the contribution as an evidence-informed product-development study and provide a clear agenda for subsequent controlled research.

METHOD

Research Design and Approach

This study used a research-and-development approach based on the ADDIE model: Analysis, Design, Development, Implementation, and Evaluation. ADDIE was selected because it provides a transparent sequence for translating an instructional problem into a testable educational product while retaining opportunities for revision at each stage (Ranuharja et al., 2021; Shakeel et al., 2023; Spatioti et al., 2022). The study integrated qualitative judgments from experts with descriptive and inferential quantitative evidence from student trials and motor-skill assessment. The resulting design was developmental rather than a randomized effectiveness trial; its primary purpose was to determine whether the product was sufficiently sound, usable, and promising to justify broader testing.

During Analysis, the developers examined the limitations of conventional printed badminton materials, the need for repeated visual modeling, and the practical constraints of accessing content in a sports hall. During Design, the module blueprint organized each skill around learning outcomes, concise movement cues, common errors, visual sequences, and a QR-linked demonstration. During Development, content and video links were integrated into the layout and submitted to material and media experts. Implementation consisted of a small-scale trial followed by revision and a large-scale trial. Evaluation synthesized expert feasibility, student responses, and reported pre–post motor-skill scores. Figure 1 summarizes the development logic, and Table 1 specifies the evidence generated at each stage.

Figure 1. ADDIE-based development and evaluation workflow.

Table 1. ADDIE development matrix and evidence sources.

Analysis	Identify learning constraints, user characteristics, access conditions, and target badminton skills.	Needs statement and product requirements.
Design	Map outcomes, technical cues, common errors, video sequence, layout, and QR destinations.	Module blueprint and assessment plan.
Development	Produce content and video, integrate QR codes, conduct expert validation, and revise.	Validated prototype and expert feasibility percentages.
Implementation	Conduct small-scale trial (n=15), revise, then conduct large-scale trial (n=40).	Student-response data and implementation observations.
Evaluation	Synthesize feasibility, responses, and reported pre–post motor performance.	Final product and evidence-informed revision priorities.

Participants

The target population comprised students in a Physical Education and Health program who were taking or had completed a practical badminton course during the relevant academic year. Purposive sampling was used because participants needed sufficient curricular exposure to judge the module's clarity, relevance, and field usability. A total of 55 students participated in product trials: 15 students in the small-scale trial and 40 students in the large-scale trial. The small-scale trial functioned as formative usability testing, whereas the large-scale trial assessed the revised module under a broader implementation condition.

The source manuscript also reported a motor-performance case study involving students with relatively low initial ability, but it did not specify the exact size or demographic composition of that subgroup. The present revision therefore preserves the reported means and p-values without inventing a sample size. Before journal submission, the authors should insert the number of participants in the motor assessment, age distribution, sex distribution where ethically and analytically appropriate, prior badminton experience, inclusion and exclusion criteria, and the institutional setting. These details are necessary for evaluating external validity and statistical power.

Data Collection Techniques and Instruments

Four instrument categories were used. First, a material-expert validation form evaluated alignment with course outcomes, technical correctness, sequencing, language, and theoretical presentation. Second, a media-expert validation form evaluated graphic design, readability, navigation, visual consistency, QR-code placement, scan reliability, and link functionality. Third, a structured student-response questionnaire assessed access ease, video clarity, support for independent practice, and learning motivation. These indicators are conceptually compatible with perceived ease, perceived usefulness, and learner engagement, although the questionnaire should not be described as a complete TAM instrument because the supplied manuscript did not report the full construct structure or validated TAM scales.

Fourth, an observational performance rubric was used to score short serve, clear lob, and drop shot technique. The rubric reportedly focused on process features grounded in badminton biomechanics, such as stance, racket preparation, contact, weight transfer, trajectory, and follow-through. Assessors recorded pre-test and post-test performance for the case-study subgroup after structured use of the module. The supplied document stated that the rubric had undergone expert validation, but it did not provide item-level specifications, inter-rater reliability, internal consistency coefficients, or evidence of criterion validity. Those data should be added from the original study records. Without them, the results can be interpreted as promising performance evidence but not as a fully documented standardized test.

Development and Implementation Procedures

Content development began with the mapping of course competencies to modular units. Each unit was designed to contain a brief conceptual explanation, stepwise technical cues, common errors, and a QR code linked to a specific video rather than to a general channel or search page. Videos were intended to show the movement from useful angles and to permit replay or slow-motion inspection. The QR images were generated at high resolution and placed against a high-contrast background so that they could be scanned under variable indoor lighting. This low-friction access principle was consistent with QR-supported video learning and multimedia-segmentation recommendations (Ahmed & Zaneldin, 2020; Mayer & Moreno, 2003).

After expert review, the development team revised content, language, layout, camera perspectives, and technical access. The small-scale trial was then conducted with 15 students to identify navigation problems and ambiguous instructions. Feedback informed the revision of link organization and QR presentation. The revised product was implemented with 40 students in the large-scale trial during practical badminton learning. Students accessed the module with their own smartphones, reviewed designated demonstrations, practiced the target techniques, and completed the response questionnaire. Motor performance was assessed before and after module-supported practice in the reported case-study subgroup. Because exact exposure duration, number of sessions, and instructor-to-student ratio were not included in the source document, these variables must be verified and added before submission.

Data Analysis Procedures

Expert ratings and student-response data were converted into percentages using the ratio of obtained scores to maximum possible scores. The source manuscript classified percentages above 85% as ‘very feasible’ for expert review. Descriptive analysis summarized the small-scale and large-scale response percentages for each indicator. For motor performance, mean pre-test scores, mean post-test scores, absolute gains, relative gains, and reported significance values were tabulated. Relative gain was calculated in this revision as the absolute gain divided by the pre-test mean and multiplied by 100%; it is presented only as a descriptive index, not as a normalized gain or effect size.

The source manuscript reported p-values of .002, .001, and .004 for short serve, clear lob, and drop shot, respectively, using an alpha level of .05, but it did not name the inferential test, report test statistics, provide confidence intervals, or supply participant-level data. No attempt was made to reconstruct those missing statistics. The final submitted paper should state whether a paired-samples t test, Wilcoxon signed-rank test, or another procedure was used; document assumption checks; and report an appropriate effect size with confidence intervals. This correction is essential because p-values alone do not communicate the magnitude or precision of an educational effect.

Validity, Reliability, and Ethical Considerations

Content validity was addressed through expert review of both substantive and media components, followed by revision before field testing. Practical validity was examined through two sequential student trials. Reliability of QR access was supported descriptively by the high expert score for functionality and the large-scale response for access ease. Nevertheless, psychometric reliability and inter-rater reliability were not reported in the supplied manuscript. The authors should provide Cronbach’s alpha or omega for the student questionnaire, agreement or intraclass correlation for motor assessors, and the number and qualifications of experts.

The study should also report informed-consent procedures, voluntary participation, confidentiality safeguards, and the relevant institutional ethics approval or exemption number. These details were absent from the source manuscript and cannot be ethically inferred. The module’s video content should use materials owned by the authors or appropriately licensed, and links should avoid collecting unnecessary personal data. During on-court smartphone use, safety procedures should require students to move outside the active playing area before scanning or viewing a video

RESULTS AND DISCUSSION

The development process produced a hybrid learning resource in which concise badminton explanations were paired with QR codes that opened technique-specific visual demonstrations. The product was designed to remain usable at the edge of the court: students could consult a cue, scan a code, replay a bounded movement sequence, and return to practice. Expert review, student-response data, and motor-performance results provided three complementary forms of evidence. Expert review addressed whether the module was conceptually and technically defensible; student responses addressed whether it functioned acceptably for intended users; and motor assessment examined whether performance changed after module-supported practice.

Expert validation results were uniformly high. Content feasibility reached 88.00%, language and theoretical presentation reached 86.00%, graphic design reached 92.00%, and QR functionality reached 94.00%. The strongest result was therefore the technical operation of the QR system, followed by graphic design. These findings indicate that the product met the source study's 'very feasible' criterion across all evaluated components. The relatively lower, although still high, language/theory score suggests that conceptual clarity required more attention than scan mechanics. Expert comments reported in the source manuscript included the need for multi-angle views of the smash and more explicit visualization of shoulder and wrist action. The revision of camera perspective was pedagogically important because movement information is viewpoint-dependent; a technically accurate demonstration can remain difficult to learn if the critical joint action is visually occluded.

Table 2. Expert validation results for the digital badminton module.

Content / material	88	100	88.00%	Very feasible
Language and theoretical presentation	43	50	86.00%	Very feasible
Graphic design	92	100	92.00%	Very feasible
QR-code functionality	47	50	94.00%	Very feasible

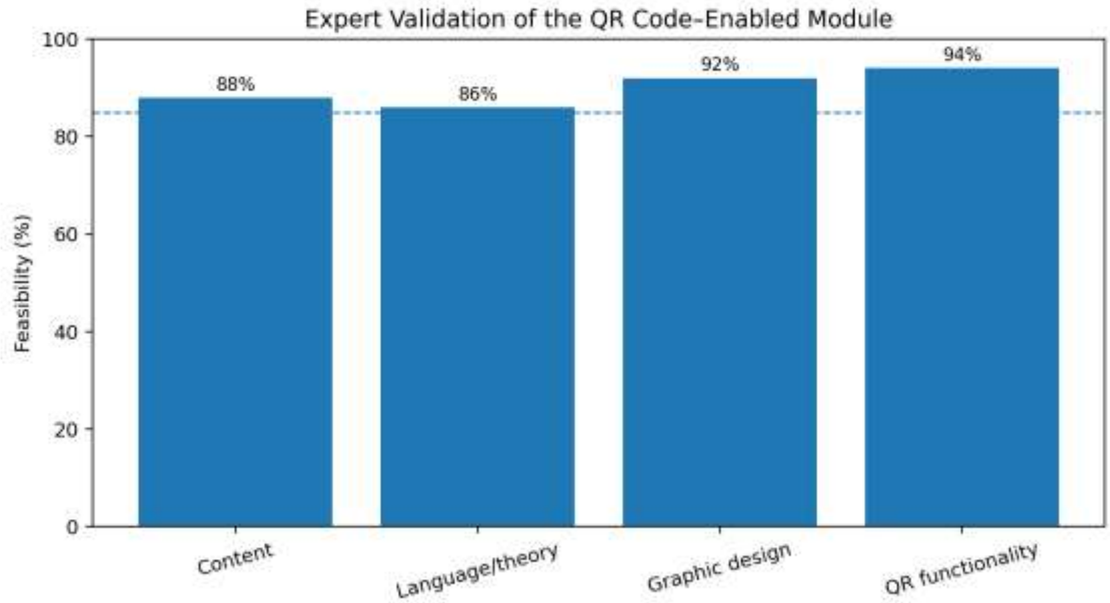

Figure 2. Expert feasibility percentages; the dashed line marks the 85% benchmark reported in the source study.

Student responses also favored the module. In the small-scale trial, positive responses were 82.40% for access ease, 80.00% for video clarity, 78.50% for independent practice, and 85.00% for motivation. In the large-scale trial, the corresponding values were 90.50%, 88.20%, 86.80%, and 92.00%. Across the two groups, average positive responses were 86.45%, 84.10%, 82.65%, and 88.50%, respectively. Motivation was the highest average indicator, whereas independent practice was the lowest. The pattern is meaningful: students were enthusiastic and able to access the material, but autonomous correction is a more demanding outcome than enjoyment or successful scanning. Autonomy requires learners to identify an error, select the relevant cue, compare their action with a model, and implement a correction; a QR code can support this process but cannot guarantee it.

Table 3. Student responses in the small-scale and large-scale trials.

Access ease	82.40%	90.50%	86.45%
Video clarity	80.00%	88.20%	84.10%
Independent practice	78.50%	86.80%	82.65%
Learning motivation	85.00%	92.00%	88.50%

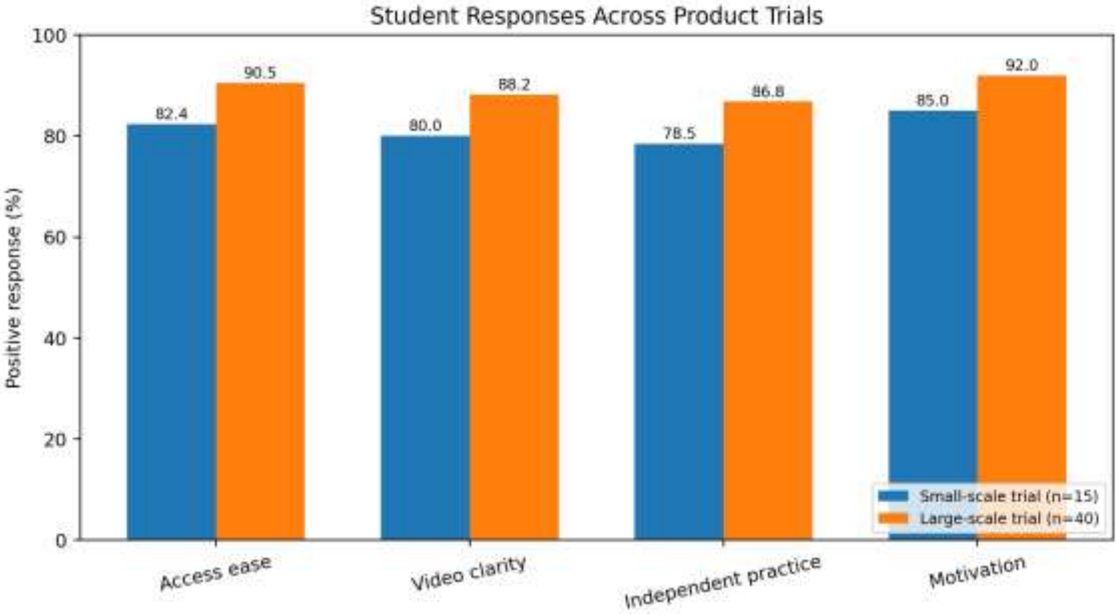

Figure 3. Positive student responses across the two sequential product trials.

The higher large-scale percentages should not be treated as a repeated-measures improvement because the two trials involved different groups and the product was revised between stages. They instead indicate that the revised module was received more positively under the later implementation. The absolute differences were 8.10 percentage points for access ease, 8.20 for video clarity, 8.30 for independent practice, and 7.00 for motivation. The consistency of these differences suggests that revisions may have improved the overall user experience, but group composition, prior digital familiarity, instructor support, device quality, and network conditions are alternative explanations. A stronger future design would track the same users across versions or randomly assign different versions within a controlled usability study.

Reported motor-performance outcomes showed higher post-test means for all three skills. Short serve increased from 62.50 to 78.80, an absolute gain of 16.30 points and a relative descriptive increase of 26.08% ($p = .002$). Clear lob increased from 58.20 to 81.40, an absolute gain of 23.20 points and a relative increase of 39.86% ($p = .001$). Drop shot increased from 55.00 to 74.50, an absolute gain of 19.50 points and a relative increase of 35.45% ($p = .004$). Clear lob showed both the largest absolute and relative increase. All reported p-values were below .05, supporting the source manuscript's conclusion that pre–post differences were statistically significant. However, the unnamed statistical test, unspecified subgroup size, and absence of effect sizes require cautious interpretation.

Table 4. Reported pre-test and post-test badminton motor performance.

Short serve	62.50	78.80	16.30	26.08%	.002
Clear lob	58.20	81.40	23.20	39.86%	.001
Drop shot	55.00	74.50	19.50	35.45%	.004

**Relative gain = absolute gain / pre-test mean × 100. This is a descriptive percentage, not a standardized effect size. The source manuscript did not identify the statistical test or motor-assessment subgroup size.*

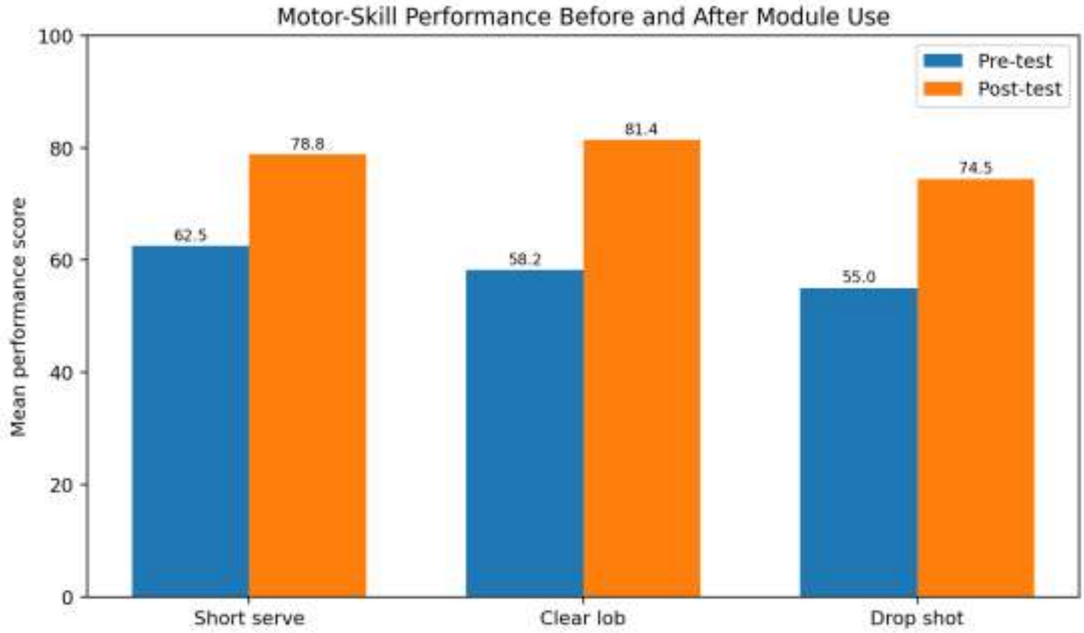

Figure 4. Reported mean motor-skill scores before and after module-supported practice.

The feasibility results align with research showing that QR codes can effectively connect conventional learning materials with focused multimedia resources. Ahmed and Zaneldin (2020) found that blending QR codes with video can strengthen access and learning in a foundation-level context. Darsi et al. (2025) similarly reported a feasible QR-based physical education module for floor gymnastics. The present study extends that logic to higher-education badminton and to an on-court context where time, movement, device handling, and safety constrain media use. The high functionality score is therefore not a trivial technical result. A code that fails under gym lighting, directs users to the wrong segment, or loads too slowly can break the instructional sequence and discourage repeated use. The strong student response for motivation is consistent with studies in which video and digital feedback increased situational interest, engagement, or perceived usefulness. Potdevin et al. (2018) reported that video feedback can support motor learning, self-assessment, and motivation in novice gymnastics. Palao et al. (2015) also demonstrated a positive impact of video technology on performance in physical education. The present finding differs in an important respect: students were not merely shown video by the instructor; they could retrieve a designated model through a physical code embedded in their own module. This self-initiated access may contribute to agency, although the study did not separately manipulate self-control and instructor control. Post et al. (2016) found that self-control over combined modeling and feedback can facilitate motor learning, suggesting a mechanism worth directly testing in future QR-module research. The motor improvements are compatible with the broader evidence base on observation and feedback. Mödinger et al. (2022) concluded that video-based visual feedback can enhance motor learning in physical education, while Zhou et al. (2021) emphasized that effective feedback depends on the learner, task, timing, and feedback design. Fauzi et al. (2026) provided recent evidence that digital video feedback improves roundoff learning in gymnastics. The current badminton results fit this pattern, particularly for clear lob and drop shot, in which timing and coordinated racket motion are difficult to communicate through text alone. However, the study did not record the learners' own performance for side-by-side feedback. It primarily provided model-based visual guidance. The mechanism is thus closer to observational modeling and guided rehearsal than to full video feedback, and terminology should reflect that distinction. The findings also support, but do not prove, explanations from cognitive load and multimedia learning. H'mida et al. (2020) showed that video and static pictures can differentially influence technical performance, motivation, and cognitive load among physical education students. Mayer and Moreno (2003) argued that segmentation and coherence can reduce unnecessary multimedia processing. In the present design, the QR code may have reduced search and navigation demands, and the short linked clips may have segmented complex movement. Nevertheless, cognitive load was not directly measured. It would therefore be inappropriate to state that the intervention ‘scientifically proved’ a reduction in extraneous cognitive load. The defensible claim is that the product was designed according to load-reduction principles and that the observed usability and performance pattern is theoretically consistent with those principles. Technology acceptance findings show a similar boundary. Access ease and perceived usefulness were strongly represented in student responses, aligning with Davis (1989), Venkatesh and Davis (2000), and Akmal et al. (2025). Yet a four-indicator satisfaction questionnaire is not equivalent to a validated structural TAM analysis. Behavioral intention, actual use frequency, social influence, and facilitating conditions were not modeled. The module’s acceptance should thus be described in terms of positive usability and learning-support responses rather than as confirmation of the entire TAM. This more precise interpretation strengthens rather than weakens the contribution because it distinguishes observed data from theoretical inference.

The most important pattern is the convergence of technical feasibility, positive user response, and skill improvement. The expert and student data suggest that the design was not only operational but also instructionally meaningful. QR functionality received 94.00%, and access ease in the large-scale trial reached 90.50%. This correspondence indicates that technical quality was visible to end users. In instructional technology, such alignment matters because usability is a precondition for learning opportunity: students cannot benefit from a model they cannot reliably reach. The product appears to have removed a specific form of friction—the gap between recognizing a need for help and locating an authoritative demonstration. Clear lob produced the largest gain, which can be interpreted through task visibility. The skill involves a comparatively large movement sequence: preparation, weight transfer, upward-forward racket acceleration, high contact, and recovery. These features may be easier to segment visually than the subtle force control of a short serve. The source manuscript attributed improvement to clearer visualization of the impact point and transfer of body weight, a plausible explanation consistent with motor modeling. Drop shot also improved substantially because video can reveal the similarity of preparation to an attacking stroke and the late deceleration or softer contact that changes shuttle trajectory. Short serve improved less in absolute terms, possibly because fine control, consistency, and pressure regulation depend on kinesthetic calibration that observation alone cannot supply. This pattern suggests that QR video may be most powerful when critical movement relationships are visually discriminable but difficult to describe verbally. Alternative explanations must also be considered. Students may have improved through repeated practice, instructor feedback, peer observation, familiarity with the assessment, or regression toward the mean, independent of the module. Motivation may have increased because the technology was new, creating a novelty effect that could decline over time. Students with better phones or network access may have benefited more. The large-scale group may also have differed from the small-scale group in digital experience or initial motivation. A controlled study should therefore compare QR-supported instruction with an equivalent printed module, instructor demonstration only, and perhaps a direct-link or learning-management-system condition. Such a design would isolate whether the benefit comes from video, from the QR access pathway, from self-control, or from the combined hybrid system.

From a motor-learning perspective, the module may contribute to the interaction of enhanced expectancies, autonomy support, and external focus described in the OPTIMAL theory (Wulf & Lewthwaite, 2016). Allowing students to decide when to scan and replay a demonstration may create a limited but meaningful form of choice. Clear visual goals can also strengthen expectancies by making success criteria observable. However, cue wording must avoid directing excessive attention toward internal body mechanics during execution, because an overly internal focus can interfere with automatic control. Future module versions should distinguish between analytic cues used during observation and concise external-focus cues used during performance, such as shuttle trajectory, target zone, or racket-path outcome. The general literature on motor learning confirms that practice structure, feedback, attentional focus, and motivation interact rather than operate in isolation (Wulf et al., 2010). The study contributes to theory by proposing ‘access friction’ as an instructional-design variable in embodied learning. Traditional cognitive-load discussions often focus on what appears within a multimedia presentation. In a sports hall, however, the learner also expends time and attention reaching the presentation. Searching for a clip, judging its credibility, or scrolling to the relevant moment creates pre-content processing that can disrupt the perception–action cycle. A QR code placed next to a specific cue reduces this distance between physical task and digital explanation. The contribution is not a new cognitive-load theory, but a contextual extension: in mobile and embodied learning, interface steps outside the media itself may function as extraneous demands. The hybrid design also advances the literature on cybernetic learning. Cope and Kalantzis (2022) describe learning systems in terms of recursive information and feedback. Indonesian cybernetic-learning discussions similarly emphasize information processing and learner interaction with the instructional system (Kalifah et al., 2022). In the present module, the loop can be represented as observe–attempt–compare–adjust–repeat. The QR resource supplies a stable external model, but the quality of self-correction depends on learners' capacity to detect discrepancies. This explains why independent-practice responses, although high, were lower than motivation. To strengthen the loop, future modules should add a short error-diagnosis checklist, peer-observation protocol, or learner-recorded comparison rather than relying on model viewing alone. Practical implications are substantial for lecturers. A validated QR module can redistribute instructional time: lecturers may spend less time repeating identical demonstrations and more time diagnosing individual errors, designing constraints, and giving tactical feedback. The module can support flipped preparation before class, just-in-time reference during class, and review after class. It can also standardize demonstrations across multiple groups and assistant instructors. Yet it should not be treated as a replacement for professional observation. Complex errors, pain, unsafe loading, and individualized adaptations require direct supervision. The module is best understood as an instructional assistant that increases the number of high-quality visual contacts available to each learner. For curriculum and policy, the findings support an approach to digitalization that begins with pedagogical bottlenecks rather than large technology purchases. A QR system can be implemented with low-cost printing and existing smartphones, but institutions must still ensure wireless coverage, device inclusion, accessibility, data privacy, and content maintenance. Han (2025) noted broader opportunities and constraints in online physical education, and the same caution applies here: infrastructure is an equity issue. A module should offer downloadable or locally cached videos where connectivity is unstable, provide shared devices for students without compatible phones, include captions or transcripts, and maintain a non-digital fallback. Cloud and application studies demonstrate the importance of stable architecture, scheduling, and interface consistency, although they are not themselves evidence of learning effectiveness (Daza et al., 2026; Masyitoh & Handayani, 2024; Prananingrum et al., 2025).

The results also have implications for physical education teacher preparation. Students are future teachers, not merely learners of badminton. Experiencing a well-designed module can help them understand how to select models, segment skills, create QR pathways, and evaluate media feasibility. This technological-pedagogical competence is increasingly important as digital and physical environments converge (Calabuig-Moreno et al., 2020; Jastrow et al., 2022). The module may therefore contribute to both immediate sport skill and professional design literacy. A follow-up assessment should examine whether students can transfer the design principles to another movement unit, such as volleyball serving, tennis strokes, gymnastics, or traditional games. The study's technical choices also clarify what should not be prioritized prematurely. Advanced systems based on motion sensing, electromyography, dynamic exoskeletons, spiking neural networks, electronic skins, artificial intelligence, and hidden tags may eventually support automated feedback (Agarwal & Choudhary, 2025; Kao & Wei, 2026; Li, D., et al., 2026; Liu et al., 2022; Melinda, 2025; Yotamornsunthorn, 2022). Yang (2026) demonstrates the potential of high-precision biomechanical stroke analysis. Nevertheless, the present results show that a comparatively simple access technology can already address a meaningful instructional problem. Innovation should be staged: first establish reliable content, clear cues, and effective use; then add automated analysis only when it improves feedback validity and remains feasible in the intended context. Several findings were unexpected or deserve further attention. Graphic design scored higher than content and language, suggesting that the module's visual shell may have matured faster than its conceptual precision. This is common in educational product development: attractive layout can be achieved before the language of technical correction has been optimized. The next revision should therefore prioritize content micro-analysis, such as separating essential cues from optional detail, checking terminology against coaching standards, and ensuring that each video shows the exact cue described in print. Wakla (2023) provides a relevant graphic-content perspective, but visual quality must remain subordinate to movement accuracy and instructional coherence. The inclusion of broad or adjacent technological sources in the original reference list also reveals a scholarly limitation. Works on hydrogel electronic skins, medical-record systems, sports-facility booking, and motion-sensing games demonstrate technological possibilities but do not directly establish the effectiveness of a badminton module. In the revised argument, these studies are used only to frame infrastructure or future development, not as primary evidence for motor learning. The central claims are instead anchored in systematic reviews and empirical studies of digital physical education, video feedback, observational learning, motor learning, and QR-supported instruction. This reweighting improves construct validity and provides a clearer scientific lineage for the intervention. Reliability and validity constraints remain material. High percentages do not reveal how many experts participated, whether they agreed consistently, or whether questionnaire items formed coherent scales. The motor scores do not indicate assessor agreement, score distributions, confidence intervals, or ceiling effects. The exact inferential test is unknown, and the motor subgroup size was omitted. These limitations prevent a definitive estimate of causal effect. They do not invalidate the development evidence, but they change the level of conclusion: the module is highly feasible, positively received, and associated with improved performance in the reported sample; it is not yet proven superior to alternatives across institutions. Future research should proceed in three stages. First, a measurement study should publish the complete module blueprint, item content, expert qualifications, questionnaire validation, and motor-rubric reliability. Second, a randomized or quasi-experimental multisite study should compare equivalent conditions, report baseline equivalence, effect sizes, confidence intervals, fidelity, and missing data, and include a delayed retention test. Third, design-based research should examine how students actually use the codes: scan frequency, replay patterns, time away from active practice, errors selected for review, and the relationship between usage and performance. Offline-first delivery and adaptive linking should be tested before more resource-intensive artificial-intelligence motion tracking is introduced. Overall, the importance of the study lies in its fit between technological scale and pedagogical need. The product did not attempt to virtualize badminton or replace embodied instruction. It inserted a reliable visual reference into the physical learning environment at the exact point where printed media and one-to-many demonstration were insufficient. This fit explains the high feasibility and response scores and provides a plausible context for the observed skill gains. The module's scientific value will be strengthened by more complete reporting and controlled evidence, but its design logic offers a credible and transferable model for instructional technology in practical higher education.

CONCLUSION

This study aimed to develop and evaluate a QR code–enabled digital badminton module for physical education students by examining expert feasibility, student responses, and reported motor-skill outcomes. The module achieved very high expert ratings for content, language and theory, graphic design, and QR functionality; received strong large-scale responses for access ease, video clarity, independent practice, and motivation; and was associated with significant pre–post improvements in short serve, clear lob, and drop shot performance, with the largest gain in clear lob. The study contributes a field-oriented hybrid-media model that connects concise printed cues to validated, technique-specific visual demonstrations with minimal access friction, thereby extending digital-learning design into an embodied higher-education context. In practice, the module can support independent rehearsal and allow lecturers to redirect time toward individualized diagnosis and tactical instruction; at policy level, it illustrates a low-cost pathway for purposeful digitalization while emphasizing connectivity, inclusion, safety, and content governance. Because the study lacked a control group, complete psychometric reporting, a specified inferential test, and long-term retention evidence, future research should conduct multisite controlled trials, report effect sizes and reliability indices, analyze actual QR-use behavior, and evaluate offline delivery and automated motion-feedback extensions.

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