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Pilot Study

Development and evaluation of QR code–based laboratory instructions using the ADDIE model: effects on students' practical performance

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Abstract

Background & Objective: The rapid spread of mobile technologies has opened new avenues for enriching laboratory education. Quick Response (QR) codes provide learners with immediate access to educational resources and may enhance the overall learning experience. This study set out to design QR code–based laboratory instructions using the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model and to test their effect on students' practical performance.

Materials & Methods: In this pilot quasi-experimental study (2024–2025), 20 third-semester Environmental Health Engineering students at Hamadan University of Medical Sciences were randomly allocated to an intervention group and a control group (n = 10 each). Students in the intervention group used QR code–based laboratory instructions, while those in the control group followed conventional teaching methods. Practical performance, ease of use, enjoyment, and perceived usefulness were measured before and after the intervention and compared using appropriate statistical tests.

Results: No significant baseline differences were observed between the two groups. After the intervention, the intervention group achieved higher practical performance scores and reported significantly greater ease of use, enjoyment, and perceived usefulness than the control group, which showed no meaningful change over the same period.

Conclusion: QR code–based laboratory instructions appear to offer real benefits for practical performance and student experience among environmental health students. Because this was a small pilot study, however, larger multicenter trials are needed before these preliminary findings can be generalized.

Keywords: QR codes; mobile learning; laboratory instruction; practical performance

Introduction

Education has been reshaped over the past two decades by the rise of digital technologies and the shift toward technology-mediated instruction. Smartphones, now nearly universal among students, have become integral to the way students access and engage with learning materials, and this shift has left a clear mark on modern pedagogy [1, 2]. Wider internet access and more capable mobile devices have pushed e-learning and mobile learning into the mainstream of higher education [3]. Compact wireless devices allow students to interact with course content wherever and whenever they choose, cutting down learning time and easing the transfer of concepts from instructor to learner [4]. Given a choice, learners tend to gravitate toward mobile-friendly material over other e-learning formats [5].

As smartphones have grown more capable, they have also found a place in the laboratory. Instructional videos and other multimedia content can build students' confidence, cut down on procedural mistakes, and sharpen practical performance [6]. Quick Response (QR) codes represent one of the more promising tools in this space: by linking directly to videos, guidelines, and other digital resources, they put information within a student's reach almost instantly. Universities already use them to point students toward electronic resources and support independent, hands-on learning—placing QR codes alongside library books, for instance, has been shown to raise students' awareness of available e-resources [7]. With most undergraduates now carrying internet-connected smartphones and possessing reasonable Information and Communication Technology (ICT) skills, QR-linked videos and multimedia are well positioned to complement, rather than replace, traditional teaching [8].

The value of sound instructional design in e-learning is well documented, and the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model—an iterative process built around continuous evaluation and revision—remains one of the most widely adopted frameworks for building educational programs [9].

Yet in Iran, uptake of these approaches has lagged, particularly where practical and laboratory skills are concerned, and only a handful of studies have looked at how QR codes affect students' hands-on performance. Students working with laboratory equipment often struggle in familiar ways: shaky confidence, forgotten steps, worry about damaging instruments, and a cognitive load that can overwhelm a novice user [8].

Motivated by the need to strengthen practical skills and bring portable technology into the laboratory setting, this study used the ADDIE framework to design, implement, and evaluate QR code–based laboratory instructions, through which students were linked to multimedia learning materials and step-by-step guidance. The primary aim was to determine whether these QR code–based laboratory instructions could improve students' practical performance when using laboratory instruments and equipment.

Materials & Methods

Design and setting(s)

This quasi-experimental study ran from September 22, 2024, to June 21, 2025 among third-semester Environmental Health Engineering students at Hamadan University of Medical Sciences, Hamadan, Iran. The intervention itself was built around the five phases of the ADDIE instructional design model—analysis, design, development, implementation, and evaluation [10]. Twenty eligible students participated in the study, split between an intervention group that received QR code–based laboratory instructions and a control group taught by conventional means (**Figure 1**).

Participants and sampling

All third-semester Environmental Health Engineering students were approached through census sampling; 20 met the eligibility criteria and agreed to take part. A simple randomization procedure—identification numbers assigned and allocated according to a computer-generated random sequence—placed 10 students in the intervention group and 10 in the control group. Demographic and academic information was gathered from all participants before the intervention began.

As a pilot investigation, this study did not include a formal sample size calculation or power analysis, and the results should be read as preliminary and exploratory rather than confirmatory.

Tools/Instruments

A researcher-developed, self-administered questionnaire was used to collect data, covering demographic items alongside measures of ease of use, usefulness, enjoyment, and performance. Fifteen items, scored on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree), addressed ease of use, usefulness, and enjoyment; a further ten items measured performance on a five-point scale from "never" (0) to "always" (4).

Content validity was assessed through the Content Validity Ratio (CVR) and Content Validity Index (CVI). For ease of use, usefulness, and enjoyment, these values were 0.86 and 0.89, respectively; for performance, they were 0.85 and 0.87. Cronbach's alpha confirmed acceptable internal consistency across all four constructs: 0.90 for ease of use, 0.88 for usefulness, 0.91 for enjoyment, and 0.89 for performance.

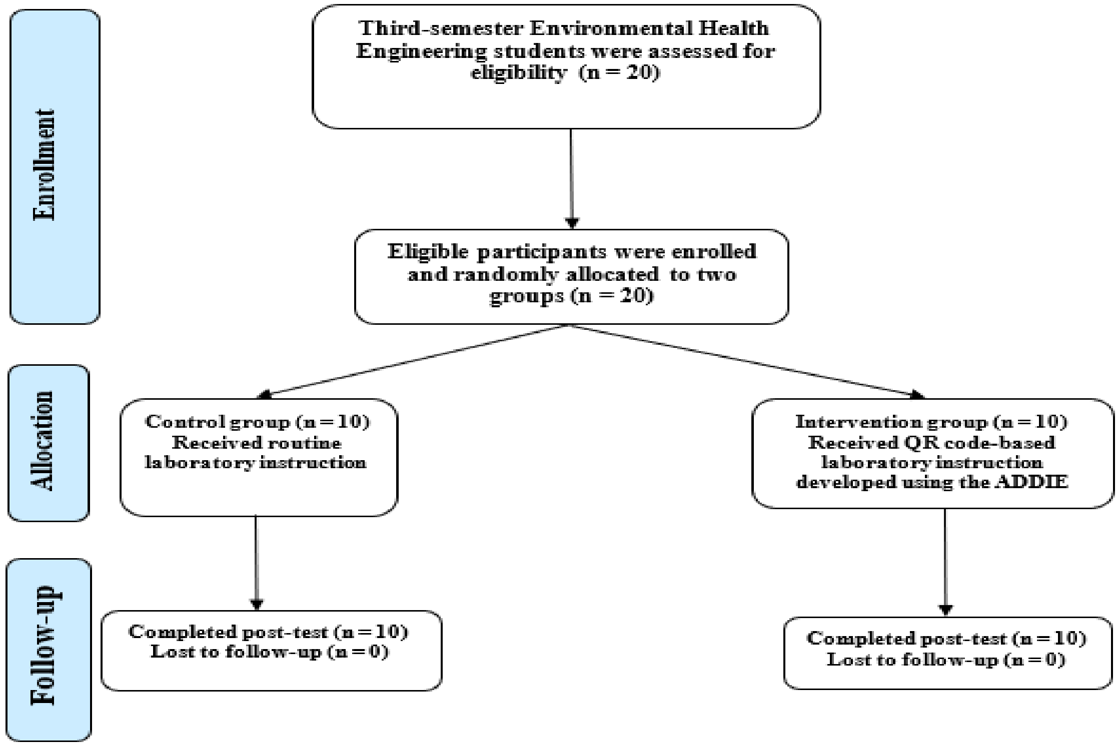

Figure 1. Flow diagram of participants in the study

Data collection methods

The intervention followed the five ADDIE phases in sequence.

Analysis phase: Demographic and academic characteristics, past laboratory performance, and standard laboratory checklists were reviewed to pinpoint educational needs around equipment use, experimental procedures, safety, data recording, and interpretation of results. This process surfaced specific weaknesses in students' handling of practical equipment.

Design phase: Learning objectives were set, and a framework for the QR-based instructional materials was drafted. Content included experimental procedures, equipment lists, data recording tables, and supporting scientific notes, alongside short one- to two-minute instructional videos and accompanying guide texts intended to encourage active, self-directed learning.

Development phase: Videos and written materials were produced and uploaded to a secure server, with QR codes linking to this content attached directly to laboratory equipment. Students could access the linked materials using any freely available QR scanner application. Materials covered a range of instruments and experiments, including spectrophotometers, flame photometers, Soxhlet extractors, reflux distillation, hardness testing, Most Probable Number (MPN) tests, and jar tests.

Implementation phase: One week before the laboratory sessions, intervention-group students installed a QR scanner application; during practical sessions, they scanned the codes to access instructional content, which they could revisit as often as needed, and consulted laboratory staff with any remaining questions. The control group, by contrast, relied on conventional instruction—face-to-face demonstrations, printed manuals, and verbal explanations from the instructor—with no QR codes or supplementary digital materials.

Evaluation phase: Performance, ease of use, usefulness, and enjoyment were assessed for all participants before and after the intervention, and the two groups were compared on each outcome.

Data analysis

Data were analyzed using IBM SPSS Statistics version 24 (IBM Corp., Armonk, NY, USA). Descriptive statistics, chi-square tests, independent-samples t-tests, and paired t-tests were used to evaluate the effects of the intervention.

Results

Age ($P = 0.088$), gender ($P = 0.213$), place of residence ($P = 0.063$), and grade point average ($P = 0.779$) did not differ significantly between the two groups, indicating comparable baseline characteristics (**Table 1**).

Table 1. Comparison of baseline demographic characteristics between intervention and control groups

Variables	Intervention (n = 10) n (%)	Control (n = 10) n (%)	Sig.
Age (years)			
≤ 19	6 (60%)	5 (50%)	X^2 = 2.90, df = 1, p = 0.088
≥ 20	4 (40%)	5 (50%)	
Gender			
Male	3 (30%)	2 (20%)	X^2 = 1.55, df = 1, p = 0.213
Female	7 (70%)	8 (80%)	
Place of residence			
Dormitory	6 (60%)	6 (60%)	X^2 = 3.46, df = 1, p = 0.063
Non-dormitory	4 (40%)	4 (40%)	
Grade point average (GPA)			
< 16	4 (40%)	3 (30%)	X^2 = 0.08, df = 1, p = 0.779
≥ 16	6 (60%)	7 (70%)	

Note: Chi-square test was used to compare all categorical variables between the two groups.
Abbreviations: n, number of participants; X^2, Chi-square test; df, degrees of freedom; Sig., statistical significance; p, probability value.

Mean practical performance scores were similar between groups before the intervention (P = 0.469). Afterward, the intervention group scored significantly higher than the control group (P = 0.001). Looking within groups, the intervention group improved significantly following the intervention, while the control group showed no such change (**Table 2**). The independent t-test confirmed no baseline difference in practical performance (P = 0.469) but a clear post-intervention difference (P = 0.001); the paired t-test likewise showed a significant improvement in the intervention group over time (P = 0.001) (**Table 2**). Ease of use, enjoyment, and perceived usefulness likewise showed no between-group differences at baseline. After the intervention, the intervention group scored significantly higher on all three measures, and within-group comparisons confirmed significant gains in this group alone; the control group again showed no meaningful change (**Table 3**).

Table 2. Comparison of practical performance scores before and after intervention between groups

Group	Time Point	Mean ± SD	Sig.
Intervention (n = 10)	Before	4.72 ± 1.19	t = 9.84, df = 9, p = 0.001*
	After	7.78 ± 0.42	
Control (n = 10)	Before	4.61 ± 1.13	t = 1.83, df = 9, p = 0.097
	After	4.90 ± 0.99	
Between-group comparison	Before		t = 0.74, df = 18, p = 0.469
	After		t = 3.91, df = 18, p = 0.001*

Note: Paired t-test was used to compare pre- and post-intervention scores within each group. Independent t-test was employed to compare scores between groups at each time point. * Statistically significant at p < 0.05.
Abbreviations: n, number of participants; SD, standard deviation; t, independent/paired t-test; df, degrees of freedom; Sig., statistical significance; p, probability value.

Table 3. Comparison of ease of use, enjoyment, and perceived usefulness scores before and after intervention between groups

Variable	Group	Time Point	Mean ± SD	Sig.
Ease of use	Intervention (n = 10)	Before	1.52 ± 0.39	t = 16.12, df = 9, p = 0.001*
		After	4.08 ± 0.32	
	Control (n = 10)	Before	1.73 ± 0.43	t = 1.67, df = 9, p = 0.126
		After	1.74 ± 0.25	
	Between-group	Before		t = 1.22, df = 18, p = 0.236
		After		t = 4.23, df = 18, p = 0.001*
Enjoyment	Intervention (n = 10)	Before	1.22 ± 0.14	t = 16.89, df = 9, p = 0.001*
		After	4.25 ± 0.21	
	Control (n = 10)	Before	1.13 ± 0.18	t = 1.34, df = 9, p = 0.205
		After	1.06 ± 0.19	
	Between-group	Before		t = 0.97, df = 18, p = 0.345
		After		t = 4.56, df = 18, p = 0.001*
Perceived usefulness	Intervention (n = 10)	Before	1.02 ± 0.17	t = 15.23, df = 9, p = 0.001*
		After	4.51 ± 0.17	
	Control (n = 10)	Before	1.55 ± 0.10	t = 1.08, df = 9, p = 0.301
		After	2.07 ± 0.22	
	Between-group	Before		t = 0.66, df = 18, p = 0.521
		After		t = 4.89, df = 18, p = 0.001*

Note: Paired t-test was used to compare pre- and post-intervention scores within each group. Independent t-test was employed to compare scores between groups at each time point. * Statistically significant at p < 0.05.
Abbreviations: n, number of participants; SD, standard deviation; t, independent/paired t-test; df, degrees of freedom; Sig., statistical significance; p, probability value.

Discussion

Taken together, these pilot findings point to several ways in which QR code–based laboratory instructions might have boosted students' practical performance. By delivering standardized instructions quickly and conveniently, QR codes may cut down on confusion and help students carry out procedures correctly [11]. Access to guidance exactly when it is needed also lends itself to just-in-time learning, which has been linked to better retention and more durable skill acquisition [12]. A more straightforward explanation is that when students spend less time hunting through scattered resources, they can devote more attention to the task at hand, which in turn may sharpen performance [13]. QR codes also carry an obvious advantage in their capacity to deliver multimedia—videos, images, visual checklists—that can support the development of psychomotor skills while fostering independence and self-assurance in learners [14]. Viewed in this light, the stronger post-intervention performance seen in the intervention group is consistent with previous studies on educational technology [15]. Still, given the small sample and exploratory design of this pilot, these results call for a measure of caution and should be confirmed in larger studies before being taken as conclusive. There are also signs that QR code–based instruction made learning more enjoyable. Blending traditional and digital resources appears to have produced a livelier, more interactive learning environment—multimedia content and chances for active participation have previously been tied to greater intrinsic motivation and less monotony and stress [16]. This mirrors earlier findings in which students responded favorably to the enjoyment and motivational pull of QR-supported learning [17]. Perceptions of ease of use and usefulness improved as well. Scanning a QR code with a smartphone requires minimal effort, and the near-instant access to learning materials that follows seems to lower technical barriers and make learning more efficient [18], a pattern consistent with prior reports on the practicality of QR codes in educational contexts [19]. Some limitations deserve mention. The sample was small—just 20 participants—and no formal power calculation guided its size. The study was carried out at a single institution, which limits how far the results can be generalized, and the follow-up period was fairly short. For these reasons, the findings are best treated as preliminary. Confirming them, and building a stronger evidence base for QR code–based laboratory instruction, will require multicenter studies with larger, adequately powered samples.

Conclusion

QR code–based laboratory instructions show real potential for improving practical performance, ease of use, enjoyment, and perceived usefulness among environmental health students.

Because these findings come from a small pilot sample at a single institution, they should be treated as preliminary until confirmed by larger multicenter studies with adequate statistical power.

Ethical considerations

This study was approved by the Ethics Committee of Hamadan University of Medical Sciences and Health Services (Ethical code: IR.UMSHA.REC.1404.602). All participants gave written informed consent before enrollment, participation was voluntary throughout, and participant confidentiality was maintained at every stage.

Artificial intelligence utilization for article writing

No artificial intelligence tools were used in designing this study, collecting or analyzing its data, or writing this manuscript. The authors confirm that all interpretations, analyses, and written content reflect their own scholarly effort.

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Conflict of interest statement

The authors declare no conflict of interest.

Author contributions

MRS conceived and designed the study, interpreted the findings, drafted the original manuscript, and led project administration; he also contributed to reviewing and editing.

ZT contributed to methodology, data collection, and manuscript review and editing. MA oversaw data collection, supervision, and validation, and contributed to review and editing. MMG, HZN, MR, MR, and AS carried out data collection and delivered the intervention. SM and RNV were responsible for data analysis and data curation.

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Data availability statement

The data underlying this study are not publicly available, owing to participant confidentiality, but can be obtained from the corresponding author upon reasonable request and with appropriate ethical approval.

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