

ТЕОРИЯ И МЕТОДИКА ОБУЧЕНИЯ И ВОСПИТАНИЯ (ПО ОБЛАСТЯМ И УРОВНЯМ ОБРАЗОВАНИЯ)/THEORY AND METHODS OF TEACHING AND UPBRINGING (BY AREAS AND LEVELS OF EDUCATION)

DOI: https://doi.org/10.60797/IRJ.2026.166.29 EDN: IAHFDX

THEORETICAL VIEWS ON THE USAGE OF ELECTRONIC CODES WITH THE HELP OF COMPUTERS AT PHYSICS LESSONS

Research article

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Abstract

The digital transformation of education necessitates the integration of innovative technological tools into the pedagogical process. This article presents a theoretical examination of electronic code technologies—specifically QR codes and related machine-readable optical labels—as computer-assisted learning instruments in physics education. The study employs theoretical modeling and comparative analysis of existing pedagogical frameworks, including the Technological Pedagogical Content Knowledge (TPACK) model, to conceptualize the role of electronic codes in physics instruction. The analysis identifies four primary functional applications:

1) instant access to supplementary multimedia content;
2) organization of interactive quest-based learning activities;
3) facilitation of self-assessment and formative evaluation;
4) creation of virtual laboratory environments.

Theoretical findings indicate that electronic codes serve as effective bridging mechanisms between traditional textbooks and digital learning resources, potentially enhancing student engagement, self-directed learning capabilities, and conceptual understanding of physical phenomena. The article concludes that systematic integration of computer-generated electronic codes into physics lessons, grounded in established pedagogical theories, offers a viable pathway for modernizing science education while maintaining methodological rigor.

Keywords: electronic codes, QR codes, physics education, computer-assisted learning, TPACK framework, digital pedagogy, secondary education.

ТЕОРЕТИЧЕСКИЕ ВЗГЛЯДЫ НА ИСПОЛЬЗОВАНИЕ ЭЛЕКТРОННЫХ КОДОВ С ПОМОЩЬЮ КОМПЬЮТЕРОВ НА УРОКАХ ФИЗИКИ

Научная статья

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Аннотация

Цифровая трансформация образования требует интеграции инновационных технологических инструментов в педагогический процесс. В данной статье представлено теоретическое исследование технологий электронных кодов (в частности, QR-кодов и связанных с ними машиночитаемых оптических меток) как инструментов компьютерного обучения в преподавании физики. В исследовании используются теоретическое моделирование и сравнительный анализ существующих педагогических концепций, включая модель технологического педагогического содержательного знания (TPACK), для концептуализации роли электронных кодов в обучении физике. Анализ выявляет четыре основные функциональные области применения:

1) мгновенный доступ к дополнительному мультимедийному контенту;
2) организация интерактивных квестовых обучающих мероприятий;
3) обеспечение самопроверки и формирующего оценивания;
4) создание виртуальных лабораторных сред.

Теоретические результаты показывают, что электронные коды служат эффективными связующими механизмами между традиционными учебниками и цифровыми образовательными ресурсами, потенциально повышая вовлеченность учащихся, способности к самостоятельному обучению и концептуальное понимание физических явлений. В статье делается вывод о том, что систематическая интеграция генерируемых компьютером электронных кодов в уроки физики, основанная на устоявшихся педагогических теориях, предлагает жизнеспособный путь модернизации естественнонаучного образования при сохранении методологической строгости.

Ключевые слова: электронные коды, QR-коды, обучение физике, компьютерное обучение, модель TPACK, цифровая педагогика, среднее образование.

Introduction

The digitalization of educational environments has transformed the landscape of science teaching and learning over the past two decades. Physics, as a discipline that deals with both observable phenomena and abstract mathematical representations, presents unique challenges and opportunities for technology integration. Computer-assisted learning in physics has evolved from simple drill-and-practice programs to sophisticated simulation environments, yet the problem of seamlessly connecting physical learning materials (textbooks, laboratory equipment, worksheets) with digital resources persists. This disconnect creates what might be termed the "analog-digital divide" in physics classrooms, where students must manually navigate between printed materials and computer-based resources, interrupting the flow of inquiry and discovery [14, P. 34].

Electronic codes — particularly Quick Response (QR) codes, which are two-dimensional barcodes capable of storing up to several thousand alphanumeric characters — offer a potential solution to this divide. First developed in 1994 by the Japanese corporation Denso Wave for automotive parts tracking, QR codes have since found applications in marketing, logistics, and more recently, education. When scanned with a computer webcam or mobile device camera, a QR code can trigger a variety of actions: opening a URL, displaying text, sending an email, or connecting to a Wi-Fi network. In educational contexts, these capabilities translate into the ability to transform static printed materials into interactive gateways to digital content [1], [9].

Early research on educational applications of QR codes, such as the work by Buzko, Bonk, and Tron (2025) [7], identified several promising use cases in physics instruction, including physical quests, web-based quests, interactive games, quizzes, polls, virtual exhibitions, and computer-based modeling of physical phenomena [2], [3]. However, this research has largely been descriptive and exploratory, lacking a strong theoretical foundation that would explain why and under what conditions electronic codes might enhance physics learning. The present article addresses this gap by developing a theoretically grounded account of electronic codes as pedagogical tools in physics education.

The main purpose of the article is to develop a comprehensive theoretical framework for understanding the integration of computer-generated electronic codes into physics instruction, identifying their pedagogical functions, cognitive affordances, and limitations within contemporary science education contexts.

The genesis of the article arises from the confluence of three observable trends in modern education:

a) the accelerating digitization of secondary science curricula globally;

b) the proliferation of mobile computing devices in classroom settings;

c) the persistent challenge of effectively bridging traditional textbook-based instruction with interactive digital learning resources.

Despite the widespread adoption of information and communication technologies in education, the specific pedagogical role of electronic codes — machine-readable optical labels that store encoded data — remains undertheorized in the physics education literature.

The functions of the article are threefold. First, it synthesizes existing theoretical perspectives on technology integration in physics education, particularly drawing upon the Technological Pedagogical Content Knowledge (TPACK) framework [5], [6], to position electronic codes within established pedagogical discourse. Second, it articulates a typology of electronic code applications specific to physics instruction. Third, it identifies research gaps and proposes testable theoretical propositions to guide future empirical investigations.

Research Methods

This study employs theoretical methodology appropriate to its conceptual aims. The approach integrates three complementary methods:

1) systematic literature synthesis;

2) comparative case analysis;

3) conceptual modeling.

2.1. Systematic Literature Review: Methodological Transparency

A systematic literature review was conducted following PRISMA-inspired guidelines for theoretical syntheses. The review encompassed peer-reviewed journal articles, conference proceedings, and book chapters published several years.

2.2. Analytical Framework: The TPACK Model

The primary analytical lens employed is the Technological Pedagogical Content Knowledge (TPACK) framework [11, P. 1017], [8, P. 227]. The framework posits that effective technology integration requires teachers to possess knowledge at the intersection of content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK).

2.3. Comparative Case Analysis: Specific Cases and Coding Procedure

To develop the typology presented in Section 3, this study analyzed documented implementations of code-based learning activities in physics and related STEM disciplines. From the 47 sources identified in the systematic review, ten cases were selected based on two criteria:

a) explicit description of pedagogical procedures;

b) relevance to physics topics.

Each selected case was analyzed according to five dimensions:

1) the type of electronic code used;

2) the physics content addressed;

3) the pedagogical strategy employed;

4) the role of computer technology;

5) reported outcomes.

2.4. Conceptual Modeling Procedure

The conceptual model presented in Section 3.3 was developed through an iterative process of theoretical integration. First, cognitive principles from multimedia learning theory [10] and self-determination theory [8] were identified as relevant to code-based instruction. Second, these principles were mapped onto the functional affordances of electronic codes (instant access, interactivity, personalization, feedback). Third, theoretical propositions linking code affordances to learning mechanisms were formulated. Fourth, these propositions were reviewed against counterexamples and edge cases identified in the literature to refine their scope and conditions.

Main results

The theoretical analysis yielded three major results:

1) a functional typology of electronic code applications in physics instruction;

2) an articulation of the mechanisms by which electronic codes may support physics learning;

3) a set of testable theoretical propositions [4].

3.1. Functional Typology of Electronic Codes in Physics Instruction

Analysis of documented implementations revealed four primary functional categories of electronic code use in physics education:

Category 1: Content Delivery and Access. The most basic application involves using QR codes to provide immediate access to supplementary digital content. When studying kinematics, for example, a textbook diagram of projectile motion might include a QR code linking to an animated simulation showing parabolic trajectories. Similarly, a laboratory worksheet might contain codes linking to video demonstrations of experimental procedures. This function addresses the logistical challenge of distributing digital resources in classrooms with limited learning management system infrastructure.

Category 2: Interactive Learning Activities (Quests and Scavenger Hunts). Several studies describe the use of QR codes to organize location-based or document-based learning activities. In a "physics quest," students move between stations, each marked with a QR code that presents a problem or question. Solving the problem reveals a clue directing students to the next station. This approach gamifies learning and incorporates physical movement, which may be particularly appropriate for topics in mechanics and waves that involve spatial reasoning.

Category 3: Formative Assessment and Self-Testing. Electronic codes can be embedded in worksheets or flashcards, with each code linking to solution explanations, worked examples, or video tutorials. This application supports self-paced learning, allowing students to check their understanding immediately and access remediation when needed. The low-cost nature of QR code generation makes this feasible even in resource-constrained settings.

Category 4: Augmented Laboratory Experiences. In laboratory settings, QR codes placed on equipment can link to operating instructions, safety information, or data collection templates. More sophisticated applications involve codes that trigger data logging or sensor calibration routines, effectively transforming standard equipment into "smart" laboratory instruments [12].

3.2. Mechanisms of Pedagogical Action

The analysis suggests that electronic codes support physics learning through four primary mechanisms:

Mechanism 1: Reduction of Cognitive Load. By providing just-in-time access to relevant information, electronic codes reduce the working memory demands associated with searching for resources. A student who encounters an unfamiliar term in a physics problem can scan a code for immediate definition, rather than interrupting problem-solving to consult a dictionary or internet search.

Mechanism 2: Scaffolding of Inquiry. Codes can provide graduated assistance, offering hints at increasing levels of specificity. This scaffolding function aligns with Vygotskian principles of learning within the zone of proximal development.

Mechanism 3: Increased Engagement Through Autonomy. The interactive nature of code scanning, combined with the ability to choose which codes to access, supports student autonomy. According to self-determination theory, autonomy support enhances intrinsic motivation and persistence with challenging tasks.

Mechanism 4: Bridging Representations. Physics learning requires students to move between multiple representations: verbal descriptions, mathematical equations, graphs, diagrams, and real-world phenomena. Electronic codes can link these representations, allowing students to, for example, scan a graph to see a video of the physical motion it represents.

3.3. Theoretical Model of Code-Integrated Physics Instruction

Synthesizing the functional typology and mechanisms yields an integrated theoretical model. The model posits that the effectiveness of electronic codes in physics instruction depends on three interacting factors:

1) the alignment between code function and learning objective;

2) the quality of the digital content accessed via codes;

3) the teacher's TPACK capabilities in designing code-integrated activities.

The model further distinguishes between substitutive uses of codes (replacing existing resources with digital equivalents) and transformative uses (enabling learning activities not possible without codes). Transformative uses — such as creating interactive quests that blend physical and digital spaces — are theoretically predicted to yield greater learning gains than substitutive uses, though this proposition awaits empirical testing [15].

3.4. Practical aspects

Teacher TPACK required Low (technical only) High (integration of content, pedagogy, technology)

Specific examples from physics:

Substitutive (example S1): A QR code on a worksheet that replaces a printed answer key. The student scans to check answers. Learning outcome: Same as using the printed key; only access mode changes.

Substitutive (example S2): A QR code in a textbook linking to a PDF of the same text. Learning outcome: Redundancy, no pedagogical gain.

Transformative (example T1 — Mechanics): A QR code affixed to a physical pendulum. Scanning opens a real-time data visualization showing angular displacement, velocity, and acceleration graphs synchronized with the pendulum's motion. Students can compare theoretical sinusoidal curves with empirical data instantaneously. Learning outcome: Students develop representational competence by directly linking physical motion to abstract graphs — an activity impossible without the code-mediated link.

Transformative (example T2 — Optics): A QR code on a concave mirror stand. Scanning launches an augmented reality overlay showing principal rays (parallel, focal, center) and their reflections. Students can rotate the mirror physically and see the ray diagram update in real time. Learning outcome: Students connect physical manipulation to geometric optics principles without mental translation delays.

Transformative (example T3 — Thermodynamics): A QR code on a gas syringe in a pressure-volume experiment. Scanning triggers a data logging interface that automatically records pressure and volume values, calculates the product PV, and plots P vs. 1/V in real time. Learning outcome: Students focus on interpreting Boyle's law relationships rather than manual data entry, enabling discovery of the inverse relationship through immediate visual feedback.

Transformative (example T4 — Electromagnetism): A QR code on an electromagnet setup. Scanning opens a simulation where students can vary current, number of turns, and core material, seeing the magnetic field strength change in a virtual magnetometer. Learning outcome: Students explore parameters that cannot be varied safely or easily in a standard lab (e.g., very high currents, different core alloys).

Discussion

The theoretical findings presented above have several implications for research and practice in physics education. This section discusses these implications, situates the findings within broader conversations about technology integration in science education, and acknowledges the limitations of the present analysis [13].

4.1. Interpretation of Findings

The functional typology developed in Section 3.1 extends earlier descriptive accounts of QR code use in physics education by providing a systematic classification grounded in pedagogical purpose rather than technological feature. This typology has practical utility for teachers designing code-integrated lessons and for researchers developing coding schemes for observational studies of technology-enhanced instruction.

The identification of four mechanisms (reduction of cognitive load, scaffolding of inquiry, increased engagement through autonomy, bridging representations) represents a theoretical contribution to understanding how electronic codes might support learning. These mechanisms are not mutually exclusive and may operate simultaneously. For instance, a well-designed code-integrated laboratory activity might simultaneously reduce cognitive load (by providing just-in-time access to procedural information), support autonomy (by allowing students to choose when to access hints), and bridge representations (by linking equipment readings to theoretical graphs).

The distinction between substitutive and transformative uses of electronic codes has practical significance for professional development. Many early adopters of educational technology focus on substitution — replacing paper worksheets with digital versions accessed via QR codes. While this may offer convenience benefits, it does not leverage the unique affordances of code technology. Transformative uses, which fundamentally alter the nature of learning activities, require more sophisticated teacher knowledge but are theoretically predicted to yield greater educational benefits [14].

4.2. Comparison with Previous Research

The present findings align with and extend the TPACK-based analysis of QR code integration reported by Oktasari and colleagues. Their empirical study of 95 Indonesian high school students demonstrated that QR code-integrated physics instruction, designed within the TPACK framework, produced a large effect size (Cohen's f = 0.33) on students' ICT literacy compared to conventional instruction. The present theoretical analysis suggests that this effect may be mediated by the mechanisms identified above, though direct mediation analysis was beyond the scope of the original study.

Bakri and colleagues developed QR code-assisted physics textbooks for 12th-grade students, reporting positive student responses to the multimedia-enriched format. Their research and development approach demonstrated the feasibility of code-integrated materials but did not isolate the specific contributions of codes versus other instructional elements. The present analysis suggests that the effectiveness of such materials likely depends on the quality of the linked content and the alignment between code functions and learning objectives [4], [5].

4.3. Practical Implications for Physics Teachers

For physics educators, the theoretical framework developed here suggests several practical guidelines. First, codes should be used intentionally, with clear pedagogical purposes aligned to specific learning objectives, rather than added indiscriminately as technological novelty. Second, the digital content accessed via codes must be carefully curated or created; low-quality content undermines any potential benefits. Third, teachers should consider the infrastructure available in their contexts — reliable internet access, student devices, printing capabilities — when designing code-integrated activities.

Professional development programs for physics teachers should address not only the technical skills of generating and printing QR codes but also the pedagogical knowledge required to design transformative learning activities. The TPACK framework provides a useful structure for such professional development.

4.4. Limitations and Future Research Directions

This theoretical article has several limitations. First, the analysis is necessarily speculative in the absence of a robust empirical literature on electronic codes in physics education. Second, the functional typology and mechanisms derived may not exhaust all possible applications or explanatory pathways. Third, the article does not address potential drawbacks or risks of code integration, such as increased screen time, digital distraction, or equity concerns related to device access.

Future research should pursue several directions. Empirical studies employing experimental or quasi-experimental designs are needed to test the theoretical propositions articulated in Section 3.3. Specifically, research should compare learning outcomes between conditions with substitutive code use, transformative code use, and no code use, while controlling for content quality and instructional time. Mediation analyses could test whether the proposed mechanisms (cognitive load reduction, autonomy support, etc.) account for observed effects.

Design-based research approaches, in which researchers collaborate with teachers to iteratively develop and refine code-integrated physics curricula, would generate both practical design principles and theoretical insights. Longitudinal studies could examine whether code-integrated instruction produces sustained changes in students' self-directed learning behaviors or attitudes toward physics.

Finally, comparative studies across different educational contexts (primary versus secondary, general versus specialized physics tracks, high-resource versus low-resource settings) would clarify the boundary conditions for effective code integration.

Conclusion

This article has presented a theoretical examination of electronic code technologies as computer-assisted learning instruments in physics education. Drawing upon the TPACK framework and synthesizing existing literature, the analysis yielded a functional typology of code applications (content delivery, interactive quests, formative assessment, augmented laboratories) and identified four mechanisms by which codes may support learning (cognitive load reduction, inquiry scaffolding, autonomy-driven engagement, and representational bridging).

The theoretical model proposed suggests that transformative uses of electronic codes — those that enable learning activities not possible without them — hold greater educational promise than substitutive uses. However, realizing this potential requires physics teachers to develop integrated technological, pedagogical, and content knowledge, and requires researchers to subject theoretical claims to rigorous empirical testing.

As physics education continues to evolve in response to digital transformation, electronic codes represent a modest but potentially valuable tool for bridging the analog-digital divide. Their low cost, ease of implementation, and compatibility with existing mobile infrastructure make them accessible even in resource-constrained settings. Whether they fulfill their pedagogical potential will depend on the intentionality of their use, the quality of the content they access, and the theoretical grounding of their integration into physics instruction.

The findings of this article contribute to the ongoing scholarly conversation about technology integration in science education by providing a theoretically grounded account of one specific technological tool. Future empirical work building upon this theoretical foundation will determine which of its propositions withstand empirical scrutiny and which require revision or rejection.

Конфликт интересов

Не указан.

Рецензия

Все статьи проходят рецензирование. Но рецензент или автор статьи предпочли не публиковать рецензию к этой статье в открытом доступе. Рецензия может быть предоставлена компетентным органам по запросу.

Conflict of Interest

None declared.

Review

All articles are peer-reviewed. But the reviewer or the author of the article chose not to publish a review of this article in the public domain. The review can be provided to the competent authorities upon request.

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