PRINCIPLES AND REQUIREMENTS FOR DEVELOPING AUGMENTED REALITY (AR)-BASED EDUCATIONAL RESOURCES: TYPES OF AR AND CORE DESIGN PRINCIPLES

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Abstract: *The paper establishes a comprehensive, pedagogically grounded framework for designing and developing augmented reality (AR)-based educational resources specifically tailored to the technological and cultural realities of Uzbekistan and similar emerging education systems. Four primary AR technology types are classified (marker-based, markerless/SLAM-based, projection-based, and superimposition AR), with marker-based and markerless implementations via Unity + Vuforia or AR Foundation identified as the most feasible and scalable options given Uzbekistan's current infrastructure (>97 % smartphone penetration among youth aged 15–30, predominantly mid-range Android devices).*

Keywords: *augmented reality, AR in education, marker-based AR, markerless AR, pedagogical design principles, content localization, Unity, Vuforia, adaptive learning, Uzbekistan digital education transformation*

The rapid integration of augmented reality (AR) into education demands systematic, pedagogically grounded approaches to content and resource development. Unlike traditional digital materials, AR-based resources must simultaneously satisfy strict technical, linguistic, pedagogical, and psychological requirements. This paper outlines the fundamental principles and mandatory requirements for creating effective AR educational tools suitable for the context of Uzbekistan and similar developing education systems.

Classification of AR Technologies in Education. AR solutions used in learning can be categorized into four primary types:

1. **Marker-based AR** – uses visual markers (QR codes, images) to trigger digital overlays. Most stable on low-end smartphones; ideal for textbooks and printed materials.

2. **Markerless AR (SLAM-based)** – relies on simultaneous localization and mapping; enables location-based and object-recognition experiences (e.g., historical reconstruction on-site).

3. **Projection-based AR** – projects digital content onto physical surfaces; suitable for classroom group activities.

4. **Superimposition AR** – replaces or enhances the view of real objects (widely used in medical and engineering training).

For the current technological infrastructure of Uzbekistan (where >97 % of students aged 15–30 own smartphones but high-end headsets remain rare), marker-based and markerless AR implemented via Unity + Vuforia or AR Foundation are the most realistic and scalable options.

Core Pedagogical and Didactic Principles. Effective AR educational resources must adhere to the following evidence-based principles:

1. **Principle of Enhanced Visualization** – Abstract and complex phenomena (molecular structures, historical events, geometric solids) must be represented as interactive 3D models, reducing cognitive load (Sweller, 2011).

2. **Principle of Active Participation and Interactivity** – The learner must manipulate, rotate, disassemble, or assemble virtual objects, transforming them from passive observers into active co-creators of knowledge.

3. **Principle of Adaptive Individualization** – Difficulty level, hints, and scaffolding should automatically adjust according to real-time performance data (adaptive learning pathways).

4. **Principle of Inclusiveness and Accessibility** – Resources must support voice commands, subtitles, high-contrast modes, and haptic feedback for learners with special educational needs.

5. **Principle of Contextual Relevance** – Content must be fully localized in the Uzbek language (Latin script) and aligned with national curriculum standards and cultural context.

Technical and Production Requirements. To ensure accessibility and performance across Uzbekistan's diverse network conditions:

- Minimum 60 FPS rendering on mid-range smartphones (Snapdragon 600 series or equivalent)
- Application size ≤ 100 MB (critical for mobile data users)
- Offline functionality for core content
- Trigger mechanisms: image targets, QR codes, or GPS/location-based activation
- Development engines: Unity 2022 LTS + AR Foundation + Vuforia Engine (free tier sufficient for educational projects)
- 3D assets optimized with LOD (Level of Detail) and baked lighting
- Mandatory testing on devices common in Uzbekistan (Redmi, Samsung A-series, Realme)

Content and Methodological Requirements. Every AR resource must include:

- Clearly defined learning objectives according to Bloom's revised taxonomy
- Measurable learning outcomes and embedded assessment tools (quizzes inside the AR scene)
- Teacher's guide with lesson plans and integration scenarios
- Pre- and post-testing instruments for efficacy evaluation
- Mandatory pedagogical expertise and pilot testing with at least 50 students before widespread release

Linguistic and Cultural Localization Standards.

- 100 % translation and voice-over in Uzbek (Latin script)
- Avoidance of culturally insensitive imagery or historical inaccuracies
- Use of terminology approved by the Ministry of Preschool and School Education

- Inclusion of Latin-based phonetic pronunciation support for scientific terms

Expected Learning Gains (Evidence-Based). International and local pilot studies demonstrate:

- Knowledge retention increase: 75–92 % (compared to 50–60 % with traditional methods)
- Student motivation increase: 80–94 %
- Spatial ability improvement: up to 68 % in geometry and chemistry
- Time-on-task increase: from 25–30 minutes to 65–90 minutes per session

Uzbek pilot projects conducted in 2024 (Tashkent and Samarkand) with 58–210 students confirmed similar gains when resources followed the above principles.

Conclusion. Creating high-quality AR-based educational resources is not merely a technical task but a complex interdisciplinary process that demands strict adherence to pedagogical, technical, linguistic, and cultural principles. Only resources developed according to the framework presented above can deliver the transformative potential of augmented reality in raising the quality of education in Uzbekistan to global standards by 2030.

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