TECHNICAL PLATFORMS AND TOOLS FOR DEVELOPING AUGMENTED REALITY (AR)-BASED EDUCATIONAL RESOURCES: CURRENT LANDSCAPE AND RECOMMENDATIONS FOR UZBEKISTAN

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Abstract: *The article presents a comprehensive analysis of contemporary technical platforms and tools for developing augmented reality (AR)-based educational resources. AR significantly enriches the learning process by overlaying virtual objects and information onto the real environment, thereby transforming traditional lessons into highly interactive and visually engaging experiences. Scientific evidence confirms that AR substantially increases students' motivation, cognitive engagement, and long-term knowledge retention.*

Keywords: *Augmented Reality, AR in education, Unity AR Foundation, Vuforia, ARCore, ARKit, WebAR, AR.js, MindAR, no-code AR authoring, digital pedagogy, Uzbekistan*

Augmented Reality (AR) has evolved from a novel visualization aid into a fully-fledged pedagogical technology that significantly enhances motivation, knowledge retention, spatial reasoning, and practical skill acquisition. The creation of effective AR-based educational resources requires careful selection of technical platforms that balance performance, accessibility, development complexity, and compatibility with the existing technological infrastructure of the target educational system.

Core Technical Platforms and Their Educational Affordances.

Unity remains the dominant game engine and AR development environment worldwide. The AR Foundation module abstracts Apple's ARKit and Google's ARCore into a single API, enabling developers to write one codebase that deploys to both iOS and Android with minimal modification. Key advantages for education:

- Full support for marker-based, markerless (SLAM), plane detection, light estimation, occlusion, and physics-based interactions
- Rich ecosystem of free and commercial 3D assets (Unity Asset Store)
- Offline functionality and high performance even on mid-range smartphones common in Uzbekistan (Redmi, Samsung A-series)
- Proven in large-scale educational projects in South Korea, Singapore, and the EU

Vuforia continues to lead in image/target recognition accuracy and robustness. It excels at "book augmentation" — turning static textbook pages, posters, or laboratory diagrams into interactive 3D experiences. Educational relevance:

- Model targets and cylindrical targets allow real laboratory equipment to trigger digital overlays
- Cloud recognition service for thousands of targets without increasing app size
- Seamless integration with Unity
- **ARKit (Apple)**: LiDAR-enabled depth sensing, people occlusion, and facial tracking make it ideal for anatomy, architecture, and collaborative scenarios.
- **ARCore (Google)**: Depth API, lightweight augmented images, and excellent performance on budget Android devices — the most relevant platform for Uzbekistan's smartphone market (≈ 85 % Android in 2025).

WebAR Solutions (Zero-Installation AR). WebAR eliminates the need for app installation, dramatically lowering the barrier to adoption in schools with limited IT support:

- **AR.js + A-Frame / Three.js**: Open-source, marker-based, runs on any modern browser.
- **MindAR**: Neural-network-powered image & face tracking without markers; supports complex natural feature tracking.
- **8th Wall**: Commercial but highly robust; used by National Geographic and many universities. Advantage for Uzbekistan: a teacher can share a single link or QR code; students instantly access the experience via Chrome or Safari on any smartphone.

A significant portion of educators lack programming skills. The following platforms enable non-technical users to create AR content in minutes:

- CoSpaces Edu – widely adopted in European and Asian schools; block-based and drag-and-drop interface.
- Zappar / Zapworks Studio – visual scripting, rich template library.
- Blippar Education – focused on curriculum-aligned content.
- Merge EDU + Object Viewer – physical "Merge Cube" combined with digital platform; extremely popular for science subjects.
- HP Reveal (formerly Aurasma) – simple image-trigger overlays.

These tools democratize AR content creation and are essential for rapid prototyping and teacher-led innovation.

Comparative Analysis for the Uzbek Context (2025–2030)

Platform Category	Development Skill Required	Performance	Accessibility (no app needed)	Cost (educational licenses)	Recommended Phase in Uzbekistan
Unity + AR Foundation	High (C#)	★★★★★	No	Free tier + assets	Phase 2–3 (2027+)
Vuforia	Medium-High	★★★★★	No	Free for <1,000 recognitions	Phase 2
ARCore / ARKit	High	★★★★★	No	Free	Phase 2–3
WebAR (AR.js, MindAR)	Low–Medium (HTML/JS)	★★★★	Yes	Completely free	Phase 1 (2025–2027)
No-code tools (CoSpaces, Zappar, Merge)	None	★★★–★★★★	Yes (some) / minimal app	$50–300/year per school	Phase 1–2 (immediate rollout)

Recommended Implementation Roadmap for Uzbekistan. Phase 1 (2025–2027): Prioritize WebAR and no-code platforms (AR.js, MindAR, CoSpaces Edu, Merge EDU). Train 5,000+ teachers via short online courses; create 500+ localized experiences linked to national textbooks via QR codes. Phase 2 (2027–2030): Establish regional AR development hubs using Unity + Vuforia/ARCore; produce complex laboratory simulations (chemistry, physics, anatomy, engineering). Phase 3 (2030+): Full integration of markerless location-based and collaborative multi-user AR in universities and flagship schools.

Conclusion. The current ecosystem offers solutions for every level of technical capacity and budget. For Uzbekistan to achieve widespread, sustainable adoption of AR in education, a dual-track strategy is optimal: immediate large-scale deployment of WebAR and no-code tools to build teacher confidence and student exposure, combined with parallel investment in Unity-based professional development to create high-fidelity, curriculum-specific content. This balanced approach will position Uzbekistan among regional leaders in digital pedagogy by 2030.The combination of accessible WebAR, teacher-friendly authoring tools, and the power of Unity/AR Foundation provides a complete technical continuum capable of transforming abstract concepts into tangible, interactive learning experiences across the entire national curriculum.

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