QUANTUM RESONANCE LAB

App Blueprint Analysis

The universe is not continuous it is quantized.

Planck • Bohr • de Broglie • Schrödinger

M1	M2	M3	M4	M5	M6
Classical vs Quantum	Blackbody Radiation	Atomic Instability	Bohr Quantization	de Broglie Waves	Schrödinger Lab

Overview & Core Concept

Quantum Resonance Lab is a conceptually rigorous, interactive physics application designed to translate the foundational principles of quantum mechanics into real-time visualization and simulation. Unlike surface-level science apps, this blueprint targets advanced high-school students, undergraduates, engineers, and self-learners who want genuine mathematical and physical understanding.

What the App Aims to Demonstrate

- Why classical physics fails at the atomic and sub-atomic scale
- How quantization naturally resolves instability in atoms and radiation
- How standing waves with boundary conditions create discrete energy states
- How wavefunctions describe physical reality mathematically

Foundational Physicists

Physicist	Contribution to App
Max Planck	Energy quantization: $E = h\nu$. Resolves the ultraviolet catastrophe in blackbody radiation.
Niels Bohr	Angular momentum quantization $L = nh$. Stabilizes the electron orbit in hydrogen atoms.
Louis de Broglie	Matter waves: $\lambda = h/p$. Electrons have wave-like nature, creating standing wave conditions.

Physicist	Contribution to App
Erwin Schrödinger	Wave equation ψ(x). Predicts energy eigenvalues and probability density distributions.

CORE PHILOSOPHY	*Quantization is not arbitrary. It emerges when waves meet boundary conditions, energy must fit structure, and stability requires discrete states. From organ pipes to hydrogen atoms — the same mathematical principle.*

The Six App Modules

Module 1 Classical Continuum vs Quantized Systems

Standing Wave Simulator: showing quantization as a boundary condition constraint

What It Does

This opening module grounds the user in classical wave physics before introducing quantization. Users interact with resonating systems and immediately see that only specific frequencies are allowed. the first hint of discrete states.

Interactive Models

- Organ pipe with open and closed boundary conditions
- Guitar string with adjustable tension and length
- Circular orbit resonance model bridging waves and atoms

User Controls

- Adjust length, boundary conditions, and driving frequency in real time
- Toggle between allowed harmonics and disallowed frequencies

Live Visualization

- Only allowed harmonics appear and sustain
- Disallowed frequencies visually decay and disappear
- Equation display: $f_n = nv / 2L$ shown dynamically

LESSON	*Quantization is not a mysterious quantum invention. It is the same physics that governs organ pipes. Discrete states arise whenever waves must satisfy boundary*

conditions.

□ Module 2 — Blackbody Radiation Crisis

Planck Radiation Simulator: the birth of quantum theory

What It Does

This module recreates the historical crisis that launched quantum mechanics. Users directly compare the catastrophic classical prediction against Planck's corrected quantum model, seeing the data match in real time.

User Controls

- Temperature slider (100K – 10,000K)
- Toggle between Rayleigh–Jeans classical prediction and Planck quantum curve

Live Graph Output

- Classical prediction diverges to infinity at high frequencies (ultraviolet catastrophe)
- Planck curve fits observed experimental data precisely
- Peak wavelength shifts with temperature ($\lambda_{max} \propto 1/T$ Wien’s Law shown)

Model	Equation	Result
Rayleigh–Jeans (Classical)	$u(v) = 8\pi v^2 kT / c^3$	Diverges to infinity FAILS
Planck (Quantum)	$u(v) = 8\pi h v^3/c^3 \times 1/(e^{(hv/kT)} - 1)$	Matches experiment exactly — WORKS

LESSON *Energy must come in packets: E = hv. Planck’s constant h is not a mathematical trick. it is evidence that nature is fundamentally discrete at small scales.*

□ Module 3 Atomic Instability Crisis

The classical atom collapses in 10^{-9} seconds — an interactive demonstration

What It Does

Users witness the classical model's fatal prediction: an orbiting electron continuously radiates energy, spirals inward, and destroys the atom in under a nanosecond. This creates the problem that Module 4 solves.

Live Animation

- Electron orbits nucleus with classical electrodynamics
- Radiation emission shown as visible energy loss waves
- Orbit radius shrinks in real time with energy decay countdown
- System collapses at $t \approx 10^{-9}$ seconds

PROBLEM POSED	*Classical electrodynamics predicts atomic death. Every atom in the universe should have collapsed long ago. This is not a minor discrepancy. it is a complete failure of classical physics that demands a new theory.*

Module 4 Bohr Quantization Engine

Angular momentum restricted to discrete values — the atom stabilizes

What It Does

Users apply Bohr's quantization condition and watch the atom stabilize. Electron transitions between allowed orbits generate photon emissions with precise wavelengths matching real spectral line data.

User Interaction

- Press "Apply Quantization" button electron immediately stabilizes
- Select principal quantum number n = 1, 2, 3... to choose orbital
- Trigger electron transitions to generate photon emission or absorption

Live Output

- Discrete orbital rings appear at calculated Bohr radii
- Angular momentum display: $L = n\hbar$
- Transition animation with emitted photon wavelength shown
- Spectral line generated in real time and added to spectrum display

Quantum Number n	Energy Level	Orbit Radius
n = 1 (Ground state)	E_1 = −13.6 eV	r_1 = 0.529 Å (Bohr radius)
n = 2	E_2 = −3.4 eV	r_2 = 2.12 Å

Quantum Number n	Energy Level	Orbit Radius
n = 3	E_3 = −1.51 eV	r_3 = 4.76 Å
n = ∞ (Ionized)	E = 0 eV (free electron)	r = ∞

LESSON *By restricting angular momentum to $L = n\hbar$, electrons can only occupy specific orbits. Between orbits there is nothing no gradual transition. This is the quantum jump.*

□ Module 5 de Broglie Standing Wave Condition

Electrons as waves: only integer wavelengths fit stable orbits

What It Does

This module provides the physical explanation for why Bohr's quantization works. Users watch electron waves wrap around orbits and observe that non-integer wavelength fits produce destructive interference and therefore cannot exist.

User Controls

- Momentum slider wavelength updates via λ = h/p in real time
- Adjust orbital radius to test integer and non-integer fits
- Toggle constructive vs destructive interference visualization

Live Visualization

- Electron displayed as a wave wrapping around the circular orbit
- Integer fits: wave reinforces itself stable orbit glows and persists
- Non-integer fits: wave destructively interferes orbit fades and dissolves

LESSON *The de Broglie relation λ = h/p is not metaphorical electrons genuinely behave as waves. Bohr's discrete orbits are the only orbits where the electron's own wave does not cancel itself out.*

□ Module 6 Schrödinger Wavefunction Lab

Numerically solving the wave equation: energy eigenvalues emerge naturally

What It Does

The most advanced module. The app numerically solves the time-independent Schrödinger equation for three potential well configurations. Users observe discrete energy levels emerging as a direct mathematical consequence of the wave equation no additional assumptions required.

Potential Wells Available

- Infinite square well simplest case, exact analytical solution for comparison
- Quantum harmonic oscillator equally spaced energy levels, foundational for field theory
- Simplified hydrogen atom (1D radial) real atomic physics

Live Outputs

- Wavefunction ψ(x) plotted in real time
- Probability density $|\psi|^2$ shown as a glowing probability cloud
- Energy eigenvalues E_n displayed for each allowed state
- Nodes in wavefunction correspond directly to quantum number n

Potential	Energy Formula	Key Feature
Infinite Square Well	$E_n = n^2\pi^2\hbar^2 / 2mL^2$	Quadratic energy spacing
Harmonic Oscillator	$E_n = (n + ½)\hbar\omega$	Equal energy spacing
Hydrogen (1D radial)	$E_n = -13.6$ eV / n^2	Inverse-square spacing

LESSON *Discrete energy levels are not imposed on the Schrödinger equation — they fall out of it automatically. Quantization is a mathematical necessity, not a physical assumption.*

Quantum vs Classical Toggle Universal Feature

Every module includes a master switch allowing users to toggle between Classical Prediction and Quantum Correction. This feature is the single most important pedagogical element of the entire app.

Module	Classical Mode Shows	Quantum Mode Shows
M1: Standing Waves	Any frequency allowed	Only harmonic integers survive

Module	Classical Mode Shows	Quantum Mode Shows
M2: Blackbody	Ultraviolet catastrophe divergence	Planck curve fits real data
M3: Atom	Electron spirals in, atom collapses	Stable discrete orbits persist
M4: Bohr	Continuous energy — all orbits allowed	Only n = 1, 2, 3... orbits exist
M5: de Broglie	Particle with definite position	Wave only survives integer orbit fit
M6: Schrödinger	Continuous energy spectrum	Discrete eigenvalue spectrum

Real-Time Collaborative Features

Three advanced social and collaborative layers transform this from a solo learning tool into a live shared physics environment.

Feature	Description	Technical Need
Global Quantum Classroom	Instructor controls shared simulation parameters. Students observe synchronized graphs in real time.	WebSockets, server sync
Quantum Debate Room	Live philosophical discussions: Is reality wave-like? Is quantization epistemic or ontic?	Chat + voting system
Spectral Database	Overlay theoretical spectral lines against real experimental data for H, He, and other atoms.	NIST spectral API or dataset

Technology Stack

The stack is chosen to balance real-time physics computation, 3D rendering quality, and broad browser accessibility without requiring a native install.

Layer	Technology	Purpose
Frontend UI	React	Component architecture, state management, module routing
3D Rendering	Three.js	Orbital animations, 3D wavefunction clouds, atom models
Wave Simulation	WebGL	GPU-accelerated real-time wave interference

Layer	Technology	Purpose
		rendering
Math Equations	KaTeX or MathJax	LaTeX-quality equation rendering in the browser
Backend	Node.js	API layer, session management, WebSocket server
Numerics	Python microservice	Finite difference Schrödinger solver, eigenvalue computation
Real-time Collab	WebSockets	Synchronized classroom simulations, live parameter sharing
Optional GPU	GPU.js or CUDA (Python)	Accelerated wavefunction computation for complex potentials

Design System

The visual language must feel like a scientific instrument precise, elegant, and immersive. Every design choice serves physics communication, not decoration.

Design Element	Specification	Rationale
Background	Deep cosmic navy #0B132B	Reduces eye strain for long study sessions; evokes the cosmos
Primary Accent	Electric cyan #00D9FF	High contrast for wave animations and active state indicators
Secondary Accent	Photon gold #FFD166	Highlights energy quanta, photon emissions, key equations
Quantum States	Purple glow effect	Discrete states distinguished from continuum backgrounds
Typography	LaTeX rendering via KaTeX	All equations displayed with mathematical precision
Grid Layout	Clean minimal grid	Reduces distraction; keeps focus on physics content
Animations	Smooth wave interference + probability cloud pulse	Physics made visible without being cartoonish

Pedagogical Architecture

The app serves four distinct audiences through a difficulty mode system that scales from conceptual intuition to full mathematical derivation without changing the underlying content.

Difficulty Mode	Audience	Content Level
Conceptual	Advanced high school / curious non-physicists	Intuition, analogies, visual-only. Minimal equations.
Mathematical	Undergraduate physics / engineering students	Core equations shown and used. Numerical results explored.
Full Derivation	Advanced undergraduates / self-learners	Complete derivations, numerical solvers, historical context.

Integrity Features

- All equations cited with source (Planck 1900, Bohr 1913, de Broglie 1924, Schrödinger 1926)
- Historical context panels accompanying every module
- Strict physics: no pseudoscience, no mysticism, no quantum woo
- Experimental data overlays to validate theoretical predictions against reality
- Citations section with primary literature references

Future Expansion Roadmap

Feature	Description	Priority
Path Integral Visualization	Feynman path integral approach — all paths summed, only constructive ones survive	High
Quantum Field Mode	Field operators, creation/annihilation, particle number states	Medium
Solid-State Band Structure	Bloch waves, band gaps, semiconductor physics. Same standing wave principle.	High
Real Experimental Data	Live overlay of NIST spectral data against app predictions	High
VR Orbital Immersion	WebXR mode: stand inside the probability cloud of a hydrogen atom	Low (future)
Multi-Electron Atoms	Extend beyond hydrogen: Pauli exclusion, electron configuration, periodic table	Medium

Strengths & Implementation Challenges

Strengths

- Conceptually unified: one principle (boundary conditions) explains all six modules
- Historical framing builds genuine understanding, not just formula memorisation
- Classical vs Quantum toggle is a powerful pedagogical device
- Three difficulty modes make it accessible to a wide audience
- Integrity commitment separates it from pseudoscience apps
- Expansion roadmap shows a clear 2-3 year development path

Implementation Challenges

- Python microservice Schrödinger solver requires careful numerical stability (finite differences)
- Three.js 3D orbital rendering is performance-intensive on low-end devices
- WebSocket synchronization for classroom mode needs robust error handling
- KaTeX real-time equation rendering adds frontend bundle complexity
- Cross-browser WebGL support still varies; fallback rendering needed
- Maintaining scientific accuracy across all difficulty levels requires expert review

Final Verdict

This is a serious, well-structured physics app blueprint.

The conceptual architecture is coherent and the pedagogical progression is genuinely rigorous. The decision to unify all six modules under a single principle quantization from boundary conditions is the blueprint's greatest strength. If built faithfully, with the Schrödinger solver working correctly and the Classical vs Quantum toggle implemented in every module, this could become a landmark physics education tool.

- Module progression: Excellent builds logically from waves to full quantum mechanics
- Pedagogical framing: Excellent problem-first, then solution structure works perfectly
- Tech stack: Appropriate all choices are well-matched to requirements
- Design vision: Strong scientific instrument aesthetic is the right call
- Collaborative features: Ambitious but achievable WebSocket classroom mode is realistic
- Biggest risk: Python microservice Schrödinger solver performance at scale