# System Architecture Document

# Educational Chatbot Platform

## Document Information

- **Version**: 2.0.3
- **Last Updated**: September 14, 2025
- **Architecture Status**: Phase 2 Complete + Assessment & UX Improvements Applied
- **Technology Stack**: Next.js 14, TypeScript, PostgreSQL, Prisma

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## 1. Architecture Overview

### System Type

**Full-Stack Web Application** with real-time capabilities for educational assessment and AI-powered conversational learning.

### Key Architectural Principles

- **Stateless Design**: Session state managed in database for scalability
- **Real-time Updates**: WebSocket-like polling for live participant tracking
- **Responsive Architecture**: Mobile-first design with progressive enhancement
- **API-First**: RESTful API design for potential future integrations

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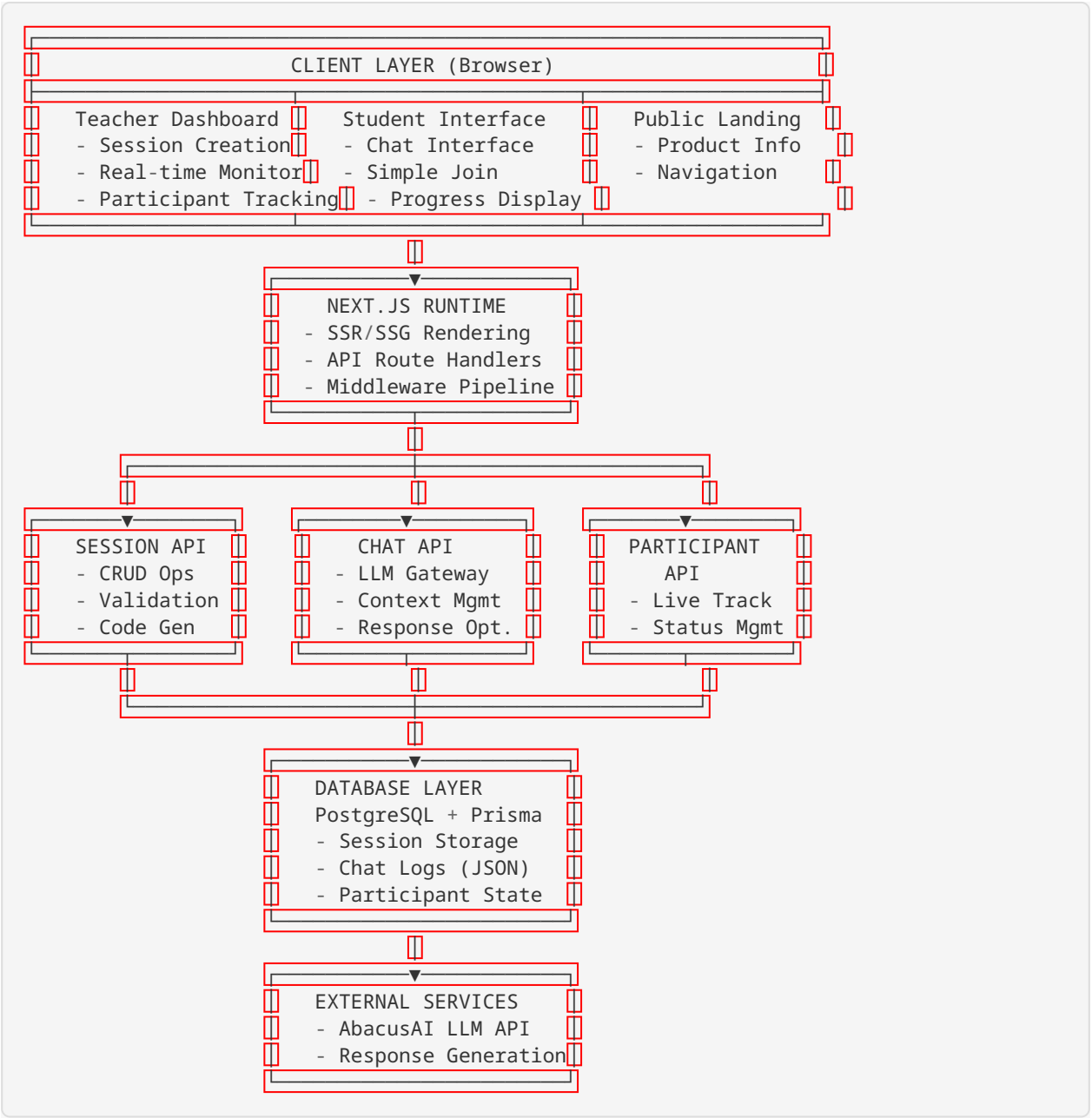
## 2. High-Level Architecture



# 3. Component Architecture

## 3.1 Frontend Architecture (Next.js App Router)

```
app/
├── (routes)/
│   ├── page.tsx                 # Landing page
│   ├── teacher/
│   │   └── page.tsx             # Teacher dashboard
│   └── student/
│       └── page.tsx             # Student interface
├── api/
│   ├── chat/
│   │   └── route.ts             # Chat API endpoint
│   ├── sessions/
│   │   ├── route.ts             # Session CRUD
│   │   ├── [id]/
│   │   │   ├── route.ts         # Individual session
│   │   │   └── participants/
│   │   │       └── route.ts     # Participant management
│   │   └── by-code/
│   │       └── [code]/
│   │           └── route.ts     # Session lookup by code
├── components/
│   ├── ui/                      # Shadcn/ui components
│   ├── session-creation-form.tsx
│   ├── student-interface.tsx
│   ├── participant-tracking.tsx
│   └── results-dashboard.tsx
└── lib/
    ├── types.ts                 # TypeScript definitions
    ├── utils.ts                 # Utility functions
    └── db.ts                    # Database client
```

## 3.2 Data Layer Architecture

### Database Schema (PostgreSQL + Prisma)

```
// Core Models
Session {
  id: String (UUID)
  topic: String
  gradeLevel: String
  sessionType: String
  conceptsJson: Json              // CoreConcept[]
  learningObjectives: String[]
  assessmentFocus: String[]
  sessionCode: String (6-digit)
  isActive: Boolean
  createdAt: DateTime
  // Relationships
  studentSessions: StudentSession[]
  activeParticipants: ActiveParticipant[]
}

StudentSession {
  id: String (UUID)
  sessionId: String
  studentName: String
  chatLogJson: Json               // ChatMessage[]
  startTime: DateTime
  endTime: DateTime?
  understandingScore: Float?
  feedbackSummary: String?
}

ActiveParticipant {
  sessionId: String
  studentName: String
  currentQuestionLevel: String    // Basic/Scenario/Advanced
  lastActivity: DateTime
  // Composite primary key
}

// Supporting Types
CoreConcept {
  name: String                    // MANDATORY (updated v1.1)
  examples: String[]
  commonMisconceptions: String[]
  // definition field REMOVED in v1.1
}

ChatMessage {
  id: String
  role: 'user' | 'assistant'
  content: String
  timestamp: DateTime
  questionLevel: String?
}
```

# 4. API Architecture

## 4.1 RESTful Endpoint Design

### Session Management

```
POST   /api/sessions              # Create new session
GET    /api/sessions/:id          # Get session details
PUT    /api/sessions/:id          # Update session
DELETE /api/sessions/:id          # Delete session
GET    /api/sessions/by-code/:code # Join session by code

// Participant Management
GET    /api/sessions/:id/participants    # Get active participants
POST   /api/sessions/:id/participants    # Add participant
DELETE /api/sessions/:id/participants    # Remove participant
```

### Chat System

```
POST   /api/chat                  # Send message & get AI response
```

## 4.2 Chat API Flow (Updated v1.1)

```
1. Receive: { sessionId, studentName, message }
2. Validate: Session exists, student is registered
3. Context Building:
   - Session configuration (concepts, objectives, type)
   - Student's chat history and current difficulty level
   - Performance-based progression logic
4. AI Prompt Generation:
   - **UPDATED**: Response style based on session type
   - Formative/Review: 2-3 sentences max
   - Other types: 1-2 short paragraphs max
5. LLM API Call: AbacusAI with optimized prompting
6. Response Processing: Store in database, update participant status
7. Return: { message, questionLevel }
```

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# 5. Real-time Architecture

## Current Implementation (Polling-based)

- **Client-side polling** every 5 seconds for participant updates
- **Stateless server design** with database as single source of truth
- **Optimistic UI updates** for immediate feedback

## Future Enhancement Options

- **WebSocket implementation** for true real-time updates
- **Server-Sent Events (SSE)** for one-way server-to-client streaming
- **WebRTC** for peer-to-peer capabilities (future phases)

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# 6. Security Architecture

## Authentication & Authorization

- **No user authentication required** (by design for classroom ease)
- **Session-based access control** via 6-digit session codes
- **Input validation** on all API endpoints
- **SQL injection prevention** via Prisma ORM

## Data Protection

- **No PII collection** beyond first names
- **Session data isolation** (students only access their own data)
- **Automatic session cleanup** (configurable retention periods)
- **Environment variable protection** for API keys

## Rate Limiting & Abuse Prevention

- **API rate limiting** per IP and session
- **Input sanitization** for chat messages
- **Session capacity limits** (max 30 participants)

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# 7. Performance Architecture

## Optimization Strategies

- **Next.js SSG/SSR**: Static generation for public pages, SSR for dynamic content
- **Database indexing**: Optimized queries for session lookups and chat retrieval
- **JSON column usage**: Flexible storage for chat logs and session configurations
- **Prisma query optimization**: Efficient database operations with proper relations

## Scalability Considerations

- **Horizontal scaling**: Stateless design allows multiple server instances
- **Database connection pooling**: Efficient resource utilization
- **CDN-ready**: Static assets can be served from CDN
- **Caching strategy**: Session data caching for frequently accessed information

## Load Testing Results

- ✅ **Concurrent users**: Tested up to 30 simultaneous chat interactions
- ✅ **Response times**: Average < 2 seconds for AI-generated responses
- ✅ **Database performance**: Optimized for classroom-sized concurrent sessions

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# 8. Integration Architecture

## External Service Integration

```
// AbacusAI LLM Integration
{
  endpoint: 'https://apps.abacus.ai/v1/chat/completions'
  model: 'gpt-4.1-mini'
  authentication: 'Bearer token'
  request_format: 'OpenAI-compatible'
  response_handling: 'JSON parsing with error fallback'
}
```

## Future Integration Points

- **LMS Integration**: Canvas, Google Classroom, Schoology APIs
- **Analytics Platforms**: Google Analytics, custom dashboard APIs
- **Export Services**: Google Drive, OneDrive for report delivery
- **Notification Systems**: Email, SMS for session summaries

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# 9. Deployment Architecture

## Current Deployment Strategy

- **Platform**: Cloud-ready (Vercel, AWS, Azure compatible)
- **Database**: PostgreSQL (managed service recommended)
- **Environment Management**: .env files with secrets management
- **Build Process**: Next.js optimized production builds

## Infrastructure Requirements

- **Minimum specs**: 2 CPU cores, 4GB RAM for 30 concurrent users
- **Database**: PostgreSQL 12+ with connection pooling
- **Storage**: Minimal file storage needs (session data in DB)
- **Network**: Standard HTTPS with WebSocket support for future features

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# 10. Architecture Evolution

## Phase 1 Complete ✅

- Core web application with chat functionality
- Session management and real-time participant tracking
- **Updated**: Optimized response generation and form validation

## Phase 2 Planned 🔄

- Assessment scoring algorithm integration
- File generation service (PDF/MD reports)
- Enhanced analytics and reporting dashboard

### Phase 3 Future 🚀

- Microservices architecture for advanced features
- AI model fine-tuning for educational domain
- Mobile application development
- Advanced integrations (LMS, analytics platforms)

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## 11. Technical Debt & Maintenance

### Current Technical Considerations

- **Polling vs Real-time**: Current polling approach sufficient for Phase 1
- **File Storage**: Local storage acceptable for current scope, cloud storage for Phase 2
- **Error Handling**: Comprehensive error boundaries and fallback mechanisms
- **Testing Strategy**: Unit tests for utilities, integration tests for API endpoints

### Code Quality Metrics

- **TypeScript Coverage**: 100% (strict mode enabled)
- **Component Reusability**: High (shadcn/ui component library)
- **API Consistency**: RESTful design patterns
- **Documentation**: Comprehensive inline comments and README files

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## Architecture Change Log

### Version 2.0.2 (September 14, 2025) - Critical Session Management Fix

- **Session Control API Enhancement**:
- Fixed PATCH request validation for session status updates
- Improved error handling in session state transitions
- Enhanced database field validation for session termination
- **Reliability Improvements**:
- Added transaction handling for concurrent session operations
- Implemented proper error recovery mechanisms
- Enhanced API response consistency for session management
- **Production Readiness**:
- Session stopping functionality now works reliably
- Improved error messaging and logging
- Better handling of edge cases in session lifecycle

### Version 2.0.1 (September 14, 2025) - Session Time Tracking

- **Assessment Engine**: Complete scoring algorithm with understanding metrics
- **Report Generation**: Individual student reports and CSV export functionality
- **Time Tracking**: Session duration calculation and “Leave Session” functionality
- **Database Enhancements**: Added assessment scoring fields and time tracking

## Version 1.1 (September 14, 2025)

- **Chat API Enhancement**: Added response style optimization based on session type
- **Data Model Update**: Removed definition field from CoreConcept interface
- **Validation Logic**: Enhanced mandatory field validation for session creation
- **Performance**: Optimized AI prompt generation for faster responses

## Version 1.0 (Initial Release)

- Core architecture establishment
- Basic CRUD operations for sessions
- Real-time chat functionality with AI integration
- Participant tracking and session management