

ENHANCING LEARNER ENGAGEMENT IN DSA THROUGH ADAPTIVE LEARNING AND GAMIFICATION: THE NIRANTARA APPROACH

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Keywords:

Data Structures and Algorithms, Artificial Intelligence, Personalized hints, Progressive Dashboard, Gamification.

Introduction:

The proposed system aims to bridge this gap through intelligent feedback, gamification, and personalized learning. Data Structures and Algorithms (DSA) constitute the foundational pillars of computer science education, critical for fostering efficient problem-solving and algorithmic thinking skills that underpin software development and computational theory. Despite their importance, mastering DSA remains challenging due to the abstract nature of the concepts, the complexity of algorithmic logic, and the limitations inherent in conventional pedagogical methods. Traditional approaches largely rely on passive instruction and static problem sets, providing limited real-time, personalized feedback that is essential for deep comprehension and iterative learning. In recent years, the rise of educational technologies has introduced innovative tools such as artificial intelligence (AI)-driven tutoring, dynamic hint systems, and gamification, which have demonstrated considerable promise in addressing these gaps. These technologies facilitate adaptive learning environments that respond to individual learner needs, foster sustained motivation, and promote engagement. Nevertheless, most existing DSA platforms prioritize competitive coding metrics and lack seamless integration of diagnostic feedback, motivational scaffolds, and accessibility features necessary for holistic learning experiences. To overcome these challenges, this project proposes Nirantara, a comprehensive web-based learning platform that integrates real-time code evaluation, intelligent hint generation, and immersive gamification to transform DSA education. Nirantara provides learners with instant, contextual feedback on code submissions, enabling error diagnosis and targeted guidance that fosters reflective practice and mastery. Gamified elements, including daily streaks, achievements, and peer competitions, enhance learner engagement and consistency. The system design emphasizes modularity, scalability,

and inclusivity, offering multilingual support and analytics for personalized progress monitoring. By converging advanced pedagogical strategies with modern software engineering, Nirantara aspires to create a learner-centric ecosystem that empowers students to achieve sustained improvement, conceptual clarity, and confidence in DSA. This project not only addresses a critical educational need but also contributes to the broader landscape of adaptive learning technologies in computer science education.

Objectives:

1. To design and organize a structured DSA practice module with 100+ problems grouped by topic and difficulty, supported by roadmaps that guide learners from foundational to advanced levels in a logical progression.
2. To develop a multi-language coding environment with an integrated editor and sandboxed execution that provides adaptive, attempt-based hints and unlocks complete solutions only after repeated failures.
3. To enhance learner engagement by incorporating gamification elements such as timed challenges, streaks, badges, and real-time friend duels that encourage consistent practice.
4. To implement an analytics-driven progress tracking system that visualizes key performance metrics and recommends focus areas based on a learner's historical accuracy and problem-solving patterns.

Methodology:

The development of the Nirantara platform follows an iterative and agile methodology to ensure modularity, scalability, and continuous improvement. The process begins with requirement analysis based on challenges in DSA learning such as lack of structured practice, feedback, and engagement.

The system is designed as a full-stack web application consisting of a frontend (React), backend (FastAPI), and database (SQLite). The development is divided into multiple phases including design, implementation, testing, and deployment.

Initially, a user interface (UI) is developed to allow users to register, log in, select problems, and view progress dashboards. The frontend communicates with the backend through REST APIs. The Application Server acts as the central controller that manages requests and routes them to appropriate modules. The Authentication Module ensures secure login and user session handling.

A Code Evaluation Engine is implemented to compile and execute user code in a secure sandbox environment. It validates outputs against predefined test cases and returns results. The Hint Generation System provides adaptive, step-by-step hints based on user mistakes. It follows a three-level approach: conceptual hints, logical corrections, and final solution display after multiple failed attempts.

A Challenge Orchestrator organizes problems based on topic and difficulty, ensuring structured learning paths. The Progress Manager tracks user activity, streaks, and

performance metrics. Testing is performed using unit testing and integration testing to ensure accuracy of code execution and feedback mechanisms.

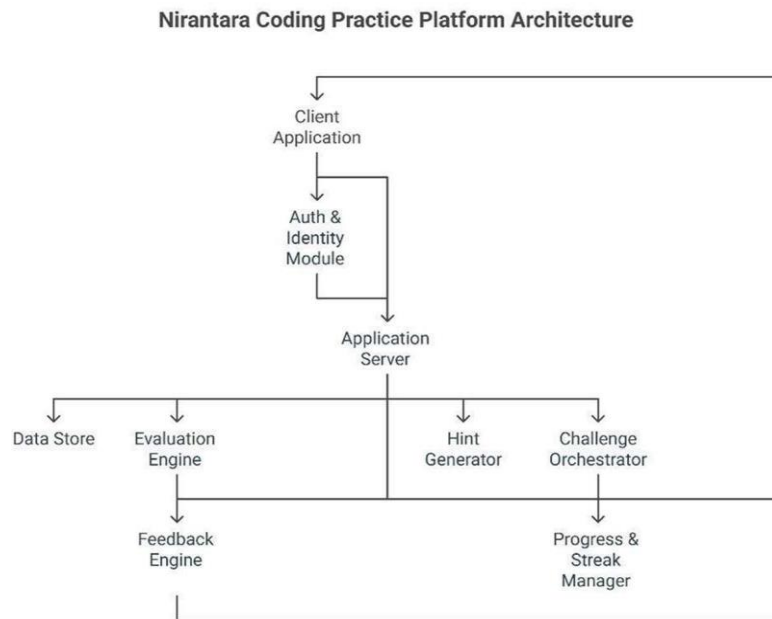


Figure 1: System Architecture

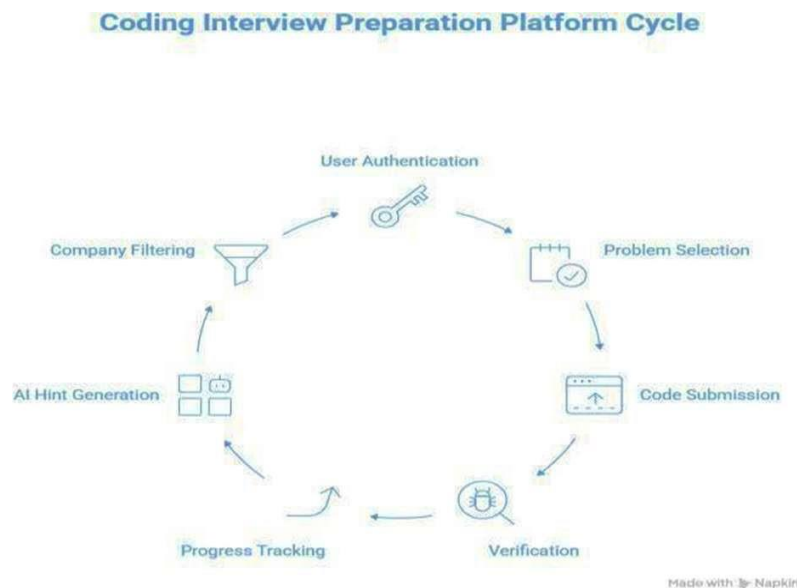


Figure 2: Data Flow

Result and Conclusion:

The Nirantara platform successfully demonstrates an effective improvement in DSA learning through structured practice, adaptive feedback, and gamification. The system provides a collection of 400+ categorized DSA problems organized by topic and difficulty levels (Easy, Medium, Hard). Users can solve problems using a multi-language editor supporting Python, Java, C++, and C.

The implementation of real-time code execution and validation enables users to receive immediate feedback on their solutions. The adaptive hint system significantly improves learning by guiding users step-by-step instead of directly revealing answers.

The progress dashboard visualizes user performance, highlighting strengths and areas needing improvement. Gamification features such as streaks and goals encourage consistent practice.

Snapshots from the system (Homepage, Code Editor, Dashboard) demonstrate smooth navigation, usability, and integration of features.

The results indicate that Nirantara effectively bridges the gap between theoretical learning and practical problem-solving required for technical interviews.

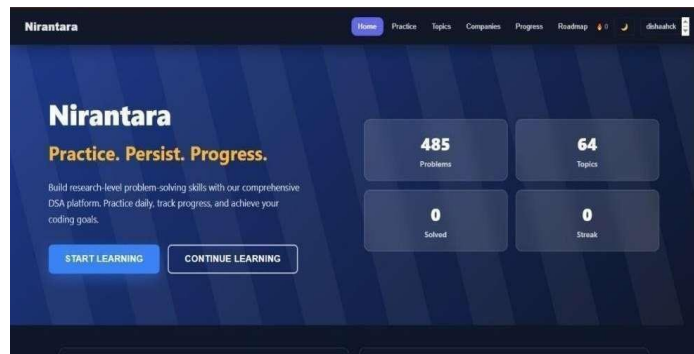


Figure 3: Home page

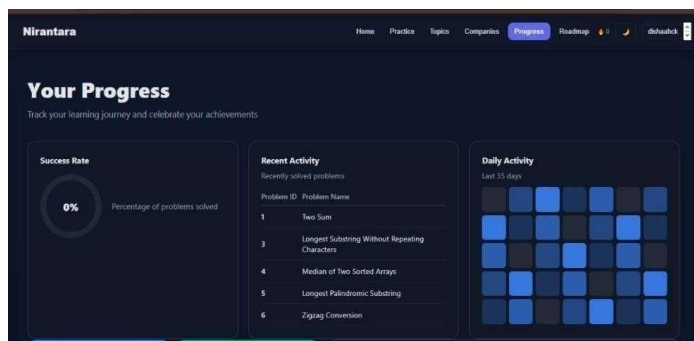
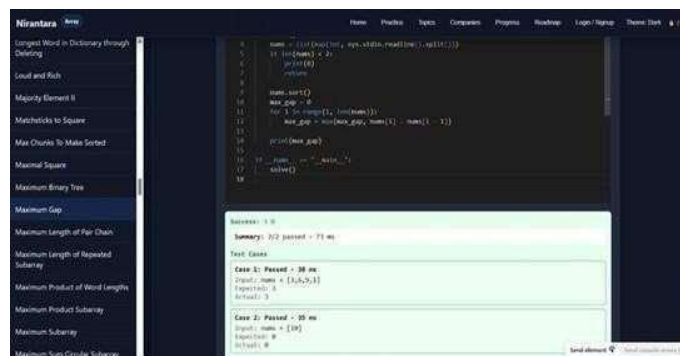


Figure 4: Progress Dashboard



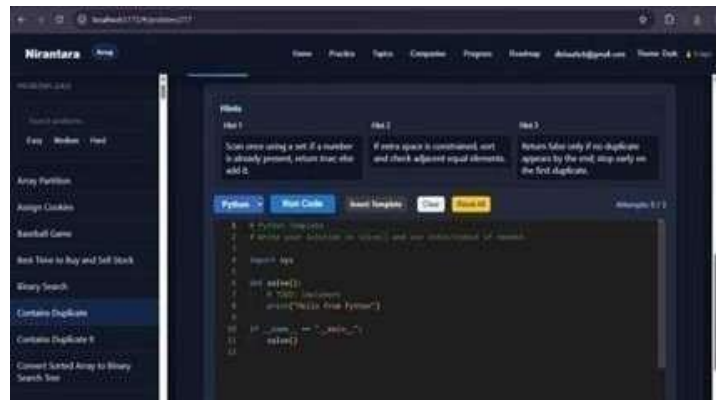


Figure 5: Code Editor

In conclusion, the proposed system enhances learner engagement, improves problem-solving skills, and provides a scalable, user-friendly platform for DSA practice. It proves to be an efficient and cost-effective alternative to existing platforms by integrating adaptive learning and gamification in a unified system.

Project outcome & Industry relevance:

The Nirantara platform delivers a practical and scalable solution for enhancing DSA learning through adaptive and interactive techniques. The project outcome includes a fully functional web-based system capable of real-time code execution, intelligent feedback, and performance tracking.

From an industry perspective, the platform is highly relevant as Data Structures and Algorithms form the foundation for technical interviews and software development roles. The inclusion of company-specific problem sets prepares students for real-world recruitment processes.

The adaptive hint system and analytics-based progress tracking align with modern EdTech trends, where personalized learning is becoming essential.

The system can be extended for use in:

- Educational institutions for structured DSA learning
- Online learning platforms (EdTech companies)
- Corporate training programs for skill development

Additionally, the use of scalable technologies like FastAPI and React makes the platform suitable for large-scale deployment. Overall, the project contributes to bridging the gap between academic learning and industry requirements by providing an intelligent, engaging, and accessible learning environment.

Working Model vs Simulation/Study

The proposed system is a fully functional working web-based application. It integrates real-time code execution, adaptive hint generation, user authentication, and progress tracking features.

Users can write, compile, and execute code in multiple programming languages within a secure sandbox environment. The system provides immediate feedback and personalized hints based on user performance.

Hence, the project is not a simulation or theoretical study, but a complete working model implemented as a full-stack application.

Project Outcomes and Learnings

The project resulted in the successful development of an interactive and user-centric platform designed to enhance the learning of Data Structures and Algorithms through adaptive learning techniques and gamification. The system effectively addresses the limitations of traditional learning methods by providing structured problem-solving approaches, real-time feedback, and personalized guidance. By integrating intelligent hint generation and performance tracking, the platform ensures continuous learner engagement and improvement. The inclusion of gamification elements further motivates users to practice consistently, making the learning process more engaging, efficient, and outcome-driven.

Key outcomes include:

- Development of a full-stack web application
- Implementation of a multi-language code execution system
- Design of an adaptive hint generation mechanism
- Integration of gamification features such as streak tracking and progress monitoring
- Creation of a structured roadmap for systematic DSA learning

Key learnings include:

- Hands-on experience in frontend and backend development
- Understanding of adaptive learning and AI-based assistance
- Knowledge of secure code execution systems
- Experience in database management and API integration
- Improved teamwork, problem-solving, and project planning skills

Future Scope

The future scope of this project includes:

- The Nirantara platform can be further enhanced by integrating advanced AI technologies such as Large Language Models (LLMs) to provide more intelligent and context-aware hints.
- In the future, interactive features such as friend-based coding challenges can be introduced, where users can invite their peers and participate in real-time problemsolving competitions. This will improve engagement, collaboration, and healthy competition among learners.

- The platform can also be expanded by adding a larger and more diverse problem set, covering a wide range of topics and difficulty levels to support continuous learning.
- Additionally, interview preparation modules can be incorporated, including companyspecific questions, mock coding rounds, and guided practice sessions to help students prepare effectively for technical interviews.
- The inclusion of aptitude training modules covering logical reasoning, quantitative aptitude, and verbal ability can further make the platform comprehensive for placement preparation.
- Advanced analytics and recommendation systems can be added to provide deeper insights into user performance and personalized learning paths.
- The platform can also be extended for institutional use, where colleges and universities can adopt it as a structured learning and assessment tool for students. Faculty can monitor student progress, assign practice sets, and track performance through analytics dashboards, making it useful for academic evaluation and training programs.