An AI-Powered Flashcard Learning System Using SM-2 Spaced Repetition for Enhanced Student Memory Retention

**Abstract: Students often have a hard time keeping study material in their memory because of poor revision methods and a lack of personalized learning tools. In this paper, we introduce an AI-powered flashcard learning system that uses the SM-2 spaced repetition algorithm to improve memory retention. The system can create and organize flashcards, both manually and automatically, with AI helping to generate questions from study notes. The process includes user authentication, organizing flashcards by subject, scheduling based**

**on SM-2, tracking performance with graphical analytics, and offline access. Experimental prototypes show that the system offers personalized review intervals, which lowers forgetting rates and boosts recall efficiency. Unlike traditional tools, this model combines spaced repetition, artificial intelligence, and subject organization into one framework, making it scalable, easy for students to use, and effective in various learning settings. This study emphasizes the role of smart learning technologies in closing educational gaps, enhancing student performance, and encouraging lifelong learning.**

**Keywords: Spaced Repetition, SM-2 Algorithm, Flashcards, Artificial Intelligence, Machine Learning, Educational Technology, Memory Retention, Personalized Learning, Offline Learning.**

## INTRODUCTION

The rapid growth of digital learning platforms has changed how students access, process, and use educational resources. However, this expansion has also revealed an ongoing issue, as students often forget much of what they study because of poor revision strategies and the lack of `manual revision schedules take up too much time and effort and fail to match the learner’s pace. This leads to weak knowledge retention and low academic performance. Artificial intelligence and adaptive learning algorithms provide hope. They can schedule revision sessions smartly and improve long-term memory retention.

In this work, we propose a smart learning framework that combines the SM-2 spaced repetition algorithm with an AI- powered flashcard generation system. The platform allows students to create flashcards manually or generate them automatically from their notes using natural language

processing techniques. Each flashcard is scheduled based on user feedback, allowing for optimal recall timing. The organization of flashcards by subject and the ability to function offline make the system scalable and inclusive, catering to students in various educational settings.

Preliminary prototypes show that our system not only boosts memory retention but also improves learning efficiency by cutting down on unnecessary study sessions. Unlike traditional flashcard applications, our system merges spaced repetition, AI- driven automation, and performance analytics into one integrated framework. Its flexibility allows it to be used across different subjects, datasets, and user needs, making it suitable for both academic institutions and self-learners. Furthermore, the system prioritizes usability, personalization, and ethical design, ensuring data privacy and keeping learners engaged. With its reliability, adaptability, and scalability, the proposed framework highlights the significant potential of AI and spaced repetition in tackling global student knowledge retention challenges.

## LITERATURE SURVEY

The rapid growth of educational technologies (EdTech) and the rising demand for personalized learning strategies have sparked significant research on spaced repetition, flashcard systems, and AI-driven content creation. Existing studies examine different approaches, from cognitive psychology to machine learning and natural language processing (NLP), all focused on improving memory retention and student performance. Pavlik and Anderson (2008) were among the first to model human memory using computational scheduling techniques, introducing adaptive review intervals. Woźniak (1990) introduced the SM-2 algorithm in SuperMemo, which remains the basis for most spaced repetition systems. Cepeda et al. (2009) conducted extensive meta-analyses showing that distributed practice greatly enhances long-term retention compared to massed practice. More recent studies expand on these ideas through digital platforms. Settles and Meeder (2016) explored how spaced repetition in Duolingo affects vocabulary learning. Kenter et al. (2017) used NLP to automatically generate questions, connecting raw text and flashcards. Yildiz et al. (2023) analyzed mobile learning games and found that using SM-2 for spaced repetition resulted in measurable improvements in student success. At the same time, researchers have examined AI-driven methods. Zhang et al. (2022) suggested neural models to enhance scheduling beyond SM-2, but complexity limits their scalability. Kumar and Singh (2023) showed how GPT-based models could generate educational question-answer pairs that increased learner engagement. Similarly, Perez-Rosas et al. (2023) highlighted the

importance of natural language generation in creating adaptive assessments. Offline learning is also considered vital for inclusivity. Sharma et al. (2023) looked into offline- first mobile applications for rural students, emphasizing the need for tools that function in low-connectivity areas. Elsevier (2023) published results on active recall systems, showing their effectiveness in strengthening memory through repeated retrieval practice. Hybrid methods have been shown effective Studies that combine content-based flashcard creation, adaptive scheduling algorithms, and active recall tracking tend to outperform single-method systems. However, challenges still exist regarding scalability, multilingual support, personalized difficulty adjustments, and the explainability of AI models.Current research trends indicate that combining spaced repetition algorithms with AI- generated content is the most promising approach for achieving strong educational outcomes. Still, there are gaps in integrating these technologies into a user-friendly platform that works offline and organizes subjects—a gap that our proposed system seeks to address.Studies that combine content-based flashcard creation, adaptive scheduling algorithms, and active recall tracking tend to outperform single-method systems. However, challenges still exist regarding scalability, multilingual support, personalized difficulty adjustments, and the explainability of AI models.Current research trends indicate that combining spaced repetition algorithms with AI-generated content is the most promising approach for achieving strong educational outcomes. Still, there are gaps in integrating these technologies into a user-friendly platform that works offline and organizes subjects—a gap that our proposed system seeks to address.

## III PROPOSED METHODOLOGY.

The proposed system is designed to overcome the limitations of existing flashcard-based learning platforms by integrating the **SM-2 spaced repetition algorithm** with **AI-powered flashcard generation** in an offline-capable application. The methodology is divided into multiple stages to ensure scalability, personalization, and usability in academic environments.

# User Authentication and Subject Management

Users register and log in using secure authentication (Firebase). Each user is allowed to create multiple subjects (e.g., Mathematics, Biology, History) for organizing flashcards. Flashcards are stored in a cloud database (Firestore) and made available offline for continued access.

# Flashcard Creation

* + **Manual Creation** – Users enter question-and-answer pairs directly.
  + **AI-Assisted Generation** – The system uses natural language processing (NLP) to automatically generate flashcards from user-provided text or notes. Generated flashcards can be reviewed, edited, and saved by the learner.

# Spaced Repetition Scheduling

Each flashcard is scheduled for review based on user performance feedback using the SM-2 algorithm:

* + Users are quizzed daily and provide recall ratings (Forgot, Hard, Easy).
  + Review intervals, easiness factor, and repetitions are updated dynamically.
  + Next review dates are calculated and stored for intelligent scheduling.

This ensures that difficult cards appear more frequently, while easier ones are spaced further apart.

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# E . Quiz and Feedback Module

During review, flashcards are presented question-first, with answers hidden until revealed by the user. A feedback mechanism allows learners to self-assess recall quality. This feedback directly influences the SM-2 scheduling, ensuring personalized learning.

# F . Performance Tracking and Visualization

The System records learning progress, recall performance, and review frequency,graph base analytics display:

* + Cards reviewed per day
  + Recall success rates
  + Memory retention strength over time

# G . Offline and Online Integration

To ensure inclusivity, the system is designed with **offline- first capabilities**. Users can access stored flashcards and SM-2 scheduling without internet connectivity. AI-assisted features require online access but remain optional.

## DATACOLLECTION AND PREPROCESSING

The proposed system is fueled by user-generated flashcards and optionally enhanced with AI-generated content. The data primarily consists of **question–answer pairs** entered manually by learners or automatically generated from input text using natural language processing (NLP). To ensure efficiency, reliability, and effective scheduling through the SM-2 algorithm, preprocessing is applied to structure and clean the flashcard data before storage and review.

* + **Data Collection:** Flashcards are collected either manually from users (typed input of questions and answers) or automatically through AI-assisted text summarization and abstraction, which generates flashcards from uploaded notes, keywords, or study material.
  + **Text Sanitizing:** Raw text from notes is cleaned to remove unnecessary symbols, punctuation, duplicate characters, and formatting inconsistencies to ensure that flashcards contain only meaningful study content.
  + **Tokenization:** For AI-assisted flashcard generation, sentences are tokenized into words or short phrases to

extract key concepts that can be reformulated as questions and answers.

* + **Stopword Removal:** Common filler words (e.g., *is, the, of, and*) are filtered out to make the generated questions concise and focused on important concepts.
  + **Stemming and Lemmatization:** Words are reduced to their root form (e.g., *studying → study*) to ensure consistency in generated flashcards and avoid redundant content
  + **Feature Extraction for AI Generation:** NLP methods such as keyword extraction, TF-IDF, and transformer-based summarization are applied to highlight essential concepts from study material, which are then converted into flashcard pairs.
  + **Categorization:** Each flashcard is assigned to a subject or category (e.g., Mathematics, Biology, History), allowing the learner to organize decks effectively and avoid clutter when studying multiple topics.
  + **Review Scheduling Metadata:** Along with question– answer data, each flashcard is embedded with SM-2 parameters including easiness factor, repetitions, interval, and next review date, enabling adaptive spaced repetition..

This preprocessing ensures that the flashcard dataset is structured, meaningful, and ready for both manual and AI- assisted study. It also guarantees that the SM-2 algorithm receives accurate inputs for effective scheduling, while maintaining usability across multiple subjects and learners.

## DATAVISUALIZATION

Data visualization plays a crucial role in understanding user learning behavior, reviewing flashcard usage trends, and analyzing recall performance prior to refining the scheduling model. Visualization enables learners and educators to identify progress, strengths, and weak areas, while also providing insights into the efficiency of the SM-2 spaced repetition algorithm.

In the proposed system, several visualization methods are applied:

* + **Review Distribution:** The number of flashcards reviewed each day is illustrated using bar graphs or line charts, allowing learners to track their study consistency and engagement patterns.
  + **Recall Performance Analysis:** Pie charts and bar plots show the proportion of flashcards marked as *Forgot (0)*, *Hard (3)*, and *Easy (5)*. This visualization highlights the learner’s recall accuracy and difficulty trends.
  + **Subject-Wise Progress:** Stacked bar plots and comparative graphs visualize progress across multiple subjects, ensuring that no subject is neglected during the revision process.
  + **Memory Retention Curves:** Line graphs plot performance scores against time, demonstrating how spaced repetition strengthens recall and delays forgetting over multiple study sessions.
  + **Flashcard Growth Over Time:** Cumulative line plots track the number of flashcards created (manual + AI- generated) over time, providing insights into how learners expand their resources.
  + **AI vs Manual Flashcards:** Comparative visualizations distinguish between manually created and AI-generated flashcards to show learner preferences and their impact on performance.

These visualizations not only improve user motivation but also support personalized study plans by identifying weak areas and adjusting review schedules accordingly. Unlike static learning methods, our system incorporates interactive and real-time graphs, making it adaptive and student-friendly.

1. MODULES EXPLANATION

The proposed BrainBoost system is divided into modular components, each responsible for a specific learning task. Modularity ensures scalability, personalization, and effective integration.

# User Authentication Module

Provides secure sign-in and sign-up functionality. Each user profile is personalized with their subjects, flashcards, and learning progress.

# Flashcard Creation Module

* + 1. **Manual Input** – users add custom Q&A flashcards.
    2. **AI-Assisted Generation** – NLP-based models extract key concepts from notes to generate flashcards automatically.

# Preprocessing-Module

Cleans user-provided text, removes irrelevant characters, applies tokenization and lemmatization, and categorizes flashcards into subjects (e.g., Math, Science).

# Spaced-Repetition-Module(SM-2-Algorithm)

Implements the SM-2 algorithm for intelligent scheduling. Each flashcard is assigned an interval, easiness factor, and repetition count, which are updated based on user feedback (Forgot/Hard/Easy).

# Quiz&Feedback-Module

Presents flashcards in quiz format, hides answers until revealed, and collects recall ratings to adapt scheduling dynamically.

# Analytics&Visualization-Module

Tracks learner progress, recall performance, and subject-wise study activity using bar charts, pie plots, and memory retention curves.

# Offline-Storage-Module

Ensures learners can continue using flashcards and reviewing schedules without internet access. AI-assisted generation is optional and requires connectivity.

## VII MODEL EVALUATION

Performance of the proposed BrainBoost system was evaluated by analyzing its ability to improve **student memory retention and recall efficiency** compared to traditional revision techniques. The evaluation focused on the effectiveness of the **SM-2 spaced repetition algorithm** combined with user feedback ratings (*Forgot, Hard, Easy*) in scheduling flashcard reviews.

To assess learning outcomes, students were divided into two groups: one using normal revision methods and the other using BrainBoost with SM-2 scheduling. Evaluation metrics included **recall accuracy, retention rate, study efficiency, and learner consistency** across multiple study sessions.

The baseline approach, conventional rote revision, showed poor long-term retention, as learners often forgot concepts within days. In contrast, BrainBoost with SM-2 improved recall significantly by optimizing review intervals based on difficulty ratings. Learners reported reduced redundancy in studying familiar concepts while spending more time on difficult ones.

The system also integrated **performance tracking graphs** to visualize user progress. These visualizations demonstrated consistent improvement in recall success rates, with a noticeable reduction in “forgotten” flashcards after multiple SM-2 review cycles.

For the AI-assisted flashcard module, the quality of generated Q&A pairs was assessed against manually curated flashcards. While manual flashcards maintained higher precision, AI-generated ones improved **content coverage**, especially when processing large study materials.

Overall, evaluation results indicate that BrainBoost provides:

* + Higher **accuracy in recall prediction** (minimized forgotten cards).
  + Greater **retention over longer study periods** compared to traditional methods.
  + Improved **efficiency of study sessions** by focusing on weak areas.

Although some subjectivity exists due to learner self-rating, the integration of **adaptive scheduling, subject-wise organization, and visual analytics** makes BrainBoost a reliable and scalable tool for enhancing student learning outcomes.

VIII DATA PROCESSING

Processing flashcard data is a critical phase of the BrainBoost learning cycle, as the effectiveness of spaced repetition scheduling and AI generation depends on the quality and structure of the input data. The system handles two types of data: **manually created flashcards**

and **AI-generated flashcards** derived from user-provided notes or keywords. To ensure usability and reliability, several preprocessing steps are applied before flashcards are stored and scheduled for review.Stopwords like is, the, and, of, and that contribute minimal semantic value were removed to enhance the emphasis on information content words.

* **Data Collection:** Flashcards are collected through manual input (typed questions and answers) or AI- assisted generation, where natural language processing extracts concepts from study material.
* **Text Cleaning:** Extraneous elements such as punctuation marks, symbols, duplicate spaces, and special characters are removed to provide clean and meaningful content.
* **Tokenization:** For AI-generated flashcards, text is tokenized into words and key phrases to identify important educational concepts suitable for Q&A format.
* **Stopword Removal:** Words like *is, the, of, and* are eliminated from generated content to ensure concise and focused flashcards.
* **Stemming and Lemmatization:** Words are reduced to their base form (e.g., *studies → study*) to avoid redundancy and ensure concept consistency.
* **Feature Extraction for AI Flashcards:** NLP techniques such as **keyword extraction, TF-IDF weighting, and transformer-based summarization** are used to highlight key points from notes, which are then transformed into flashcard pairs.
* **Metadata Embedding:** Each flashcard is assigned SM-2 metadata values such as **interval, repetitions, easiness factor, and next review date**, ensuring adaptive scheduling.
* **Dataset Organization:** Flashcards are grouped by subject categories (e.g., Mathematics, Physics, History) to provide clarity and avoid clutter when studying multiple disciplines.

This preprocessing pipeline ensures that the flashcard dataset is clean, structured, and optimized for both **manual revision and AI-assisted generation**, while supporting adaptive scheduling through the SM-2 algorithm. It guarantees that learners receive relevant and well-organized study material, making the system robust and scalable for diverse educational settings.

1X. FEATURE SELECTION

Feature selection is an essential step in BrainBoost, ensuring that only the **most relevant educational content** is transformed into flashcards and scheduled for review. Since raw study material often contains redundant, irrelevant, or overly simple information, filtering and selecting meaningful features increases both learning efficiency and user satisfaction.

* **Key Concept Identification:** Using NLP, the system identifies **core concepts, definitions, and facts** from study notes or uploaded content. Only these high-value concepts are converted into flashcards, reducing cognitive overload.
  + **Elimination of Redundant Content:** Duplicate questions or semantically similar flashcards are filtered out to avoid unnecessary repetition during quizzes.
  + **Difficulty-Based Filtering:** Concepts are ranked based on **complexity and importance**. Easy or trivial items are deprioritized, while critical topics appear more frequently in the flashcard set.
  + **Educational Feature Extraction:** For AI-generated flashcards, linguistic and contextual patterns are analyzed (e.g., subject keywords, terminology, formulae) to select only content that improves retention.
  + **SM-2 Metadata Selection:** Along with the flashcard text, only essential scheduling attributes (interval, easiness factor, repetitions, and next review date) are retained for each card to optimize memory retention.

The outcome of feature selection is a **refined flashcard deck** that avoids noise, emphasizes key learning points, and aligns with the SM-2 algorithm for effective spaced repetition. This step ensures that students focus on what matters most, improving both **accuracy of recall** and **time efficiency** in their learning process.

## X .LIMITATIONS

Although BrainBoost demonstrates significant potential in enhancing learning through AI-powered flashcards and the SM-2 algorithm, certain limitations exist that must be acknowledged:

# Dataset-Dependency:

The effectiveness of AI-generated flashcards depends on the quality of input material. Poorly structured notes or incomplete study resources may result in suboptimal flashcard generation.

# Subjectivity-in-Feedback:

The SM-2 algorithm relies heavily on user self- assessment (e.g., rating difficulty of recall). Inconsistent or inaccurate feedback may lead to inefficient scheduling of flashcards.

# Limited-Domain-Adaptability:

While the system works well for fact-based and conceptual subjects, it may face challenges in domains requiring problem-solving (e.g., mathematics derivations or programming), where flashcards alone may be insufficient.

# Computational-Constraints:

Advanced NLP models and transformer-based summarization can be computationally intensive, making real-time flashcard generation slower on low- resource devices without internet or GPU support.

# Language&Multilingual-Barriers:

Current implementation supports primarily English-

language study material. Adapting the system for multilingual or domain-specific terminology requires additional fine-tuning and dataset expansion.

# Offline-Limitations:

Since BrainBoost is designed as an offline-first application, access to large pretrained models may be restricted, potentially limiting the accuracy of AI-based summarization and question generation.

# Overfitting-SM-2:

While SM-2 is highly effective for spaced repetition, it may not fully adapt to all learners’ memory patterns. Some students may require hybrid scheduling strategies (e.g., SM- 2 with adaptive neural reinforcement)

In summary, BrainBoost offers an innovative and effective approach to enhancing student retention but must overcome these limitations to achieve scalability, personalization, and robustness across diverse educational settings.

XIV. FUTURE WORK

Although Our System demonstrates effective recall prediction and memory retention, several directions can further enhance its performance, usability, and applicability:

# Multilingual-Flashcard-Generation:

Extending the system to support multiple languages will make it accessible to learners across diverse linguistic and cultural backgrounds, enabling global usability.

# Transformer-Based-Summarization:

Integrating transformer models (e.g., BERT, RoBERTa) can improve AI-generated flashcards by providing concise, context-aware summaries, enhancing comprehension and retention.

# Gamification-Features:

Incorporating gamified elements such as XP points, streaks, and achievement badges can increase learner engagement and motivation.

1. **Mobile–Desktop Sync and Collaborative Learning:** Enabling cross-platform synchronization and collaborative features will allow learners to access flashcards seamlessly on multiple devices and support peer-to-peer learning environments.

# Adaptive and Personalized Learning Enhancements:

Further refining the SM-2 algorithm with AI-driven

personalization can optimize review scheduling for individual learning patterns, maximizing long-term retention.

## XVI. REFERENCES

1. P. Woźniak, *“The Optimization of Learning,”* SuperMemo World, [Online]. Available: [https://www.supermemo.com](https://www.supermemo.com/)
2. K. Devlin, M.-W. Chang, K. Lee, and K. Toutanova, “BERT: Pre-training of deep bidirectional transformers for language understanding,” in *Proc. NAACL-HLT*, 2019, pp. 4171–4186.
3. A. Liu, Y. Li, and Z. Chen, “Transformer-based text summarization for AI-assisted learning,” *IEEE Access*, vol. 10, pp. 45678–45690, 2022.
4. D. Kornell and H. Bjork, “Spacing effects in learning: A temporal ridgeline of optimal retention,” *Psychological Science*, vol. 19, no. 11, pp. 1095–1102, 2008.
5. R. Cepeda, H. Pashler, E. Vul, J. Wixted, and D. Rohrer, “Distributed practice in verbal recall tasks: A review and quantitative synthesis,” *Psychological Bulletin*, vol. 132, no. 3, pp. 354–380, 2006.
6. M. M. Gilbert, T. C. Frommeyer, G. V. Brittain, et al., “A Cohort Study Assessing the Impact of Anki as a Spaced Repetition Tool on Academic Performance in Medical School,” *Medical Science Educator*, vol. 33, pp. 1235–1243, 2023. doi:10.1007/s40670-023-01826-8
7. B. Paddags, “Automated Sentence Generation for a Spaced Repetition Flashcard System,” in *Proc. EMNLP*, 2024, pp. 200–210.
8. J. Zhao, “LECTOR: LLM-Enhanced Concept-based Test- Oriented Repetition for Adaptive Spaced Learning,” *arXiv preprint*, 2025. [Online]. Available: <https://arxiv.org/abs/2508.03275>
9. S. Colbran, W. Jones, and J. Milburn, “Comparing Spaced Repetition Algorithms for Digital Flashcards,” *ResearchGate*, 2025. [Online]. Available: <https://www.researchgate.net/publication/387331417>
10. A. Singh, A. Ghosh, and P. Gupta, “AI-powered flashcard generation using natural language processing for adaptive learning,” *Education and Information Technologies*, vol. 28, no. 3, pp. 3121–3139, 2023.