ENLIGHTENDS: ADVANCED TECHNOLOGIES FOR SKILL ENHANCEMENT AND TALENT RECOGNITION IN CHILDREN WITH DOWN SYNDROME

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Dissertation submitted in partial fulfillment of the requirements for the Bachelor of Science (Hons) in Information Technology

Department of Information Technology

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DECLARATION

I declare that this is my own work, and this dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. Also, I hereby grant to Sri Lanka Institute of Information Technology the non-exclusive right to reproduce and distribute my dissertation in whole or part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as article or books).

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ABSTRACT

Children with Down syndrome (DS) face significant cognitive challenges, particularly in the areas of memory, problem-solving, and mathematical learning. These difficulties often hinder their ability to acquire basic math skills, such as recognizing numbers, counting, and performing arithmetic operations. This study focuses on the development and evaluation of EnlightenDS, an adaptive educational platform designed to support the mathematical learning of children with DS, aged 5-15. The primary goal is to create a personalized and interactive learning environment that adjusts to the individual needs and progress of each child. The system incorporates adaptive quizzes, educational animations, and real-time performance tracking to tailor learning experiences. The quizzes adjust in difficulty across four arithmetic categories—addition, subtraction, multiplication, and division based on the child's performance. Visual animations help illustrate mathematical concepts, enhancing retention and engagement. Additionally, a feedback mechanism provides both children and parents with actionable insights into the child’s progress, highlighting strengths and areas for improvement. This research aims to demonstrate that personalized learning systems, when properly designed, can significantly enhance mathematical outcomes for children with Down syndrome (DS). The findings suggest that adaptive learning technologies, combined with targeted feedback and supportive parent involvement, can foster enhanced learning efficiency and engagement. However, the study also identifies areas for further development, such as improving system accessibility and expanding content personalization. Ultimately, EnlightenDS offers a promising approach to bridging educational gaps for children with DS and supports their mathematical growth in a tailored, supportive environment.

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LIST OF ABBREVIATIONS

DS	Down Syndrome
IQ	Intelligence quotient
TG	Training group
CG	Control group
WS	Williams syndrome
TD	Typically developing
ANCOVA	Analysis of covariance

1. INTRODUCTION

Down Syndrome (DS) is a genetic disorder that occurs by the presence of an additional chromosome 21 [1]. This disorder affects approximately 1 in 700 live births globally and results in characteristic physical characteristics and mental distinctions [1]. Individuals with DS typically possess distinct physical characteristics, including a flattened facial appearance, sloping eyes, and a single deep crease across the palm [2]. Their intellectual functioning varies, yet most of them have mild to moderate intellectual disability. The average IQ of individuals with DS is around 50, which is significantly lower than the average IQ of a normal person [3].

People with DS face many learning difficulties, especially in speech, language, memory, and attention [4]. Delays in speech and language can cause difficulties in focus and attention, reduced working memory capacity. They may also struggle with the conversion of word problems into equation format and the memorization of math facts, algorithms, or problem-solving procedures. Moreover, hyperactive children tend to have limited attention spans, making it hard for them to concentrate on tasks demanding prolonged attention, such as math problem-solving [5]. Math skills in DS children evolve more slowly compared to children developing typically. They struggle with number sense and basic math operations like counting, addition, subtraction, multiplication, and division. For example, recognition of numbers and counting are fundamental skills that set the stage for the students to learn mathematics. Numerical and social deficits could even limit their ability to perform even simple arithmetic activities [6].

Cognitive impairments in DS children render them more challenged to learn and memorize mathematical concepts. Mathematical facts such as addition or multiplication require repeated practice, which becomes an overwhelming task for them [7]. Transfer of learning to new problems also requires higher-order thinking, which is less developed in individuals with DS. They may struggle with switching between problems or breaking down a difficult problem into simple, smaller steps [8].

During early childhood, these children with DS will focus on problem-solving with their hands and simple pattern recognition. A slow processing speed and problems with memory, however, may limit them from processing information. Teaching methods like visual support, hands-on experience, and repetition can maximize these skills.

From 8 to 11 years, kids begin to develop higher-level reasoning abilities, such as understanding cause-and-effect and multi-step problem-solving. Difficulty with abstract thinking and generalization may still be experienced, however. Breaking tasks down into smaller steps and using concrete examples will help them learn [9].

By adolescence (ages 12-15), some children with DS gain stronger reasoning skills, allowing them to apply logic and develop solutions. However, they may still need assistance with abstract thinking and complex cognitive tasks. Personalized learning tools, adaptive quizzes, and customized educational strategies can be highly beneficial in strengthening their skills through targeted practice and feedback.

Though DS children learn more slowly, their cognitive and analytical skills can be developed with the appropriate type of assistance. Structured teaching techniques that address their specific learning needs can improve their academic performance. Through proper guidance and personalized teaching techniques, DS children can develop their mathematical abilities and achieve better learning results [10]

1.1. Background Literature

Children with DS typically have problems with mathematics. To address these challenges, various instructional methods have been specifically designed to help children with Down syndrome develop counting skills and understand numbers more effectively. These methods have already been implemented in some child centers, yet most parents and caregivers are still unaware of them. The purpose of creating this system is to present these successful strategies to parents and caregivers while, in the process, integrating them into a novel learning platform [11].

There exist two predominant instructional methods designed to support numeracy development among children with DS,

1. Kumon Approach

This approach emphasizes repetitive practice and stepwise progression in levels of difficulty. Students acquire basic arithmetic operations in a stepwise, progressive manner before advancing to more advanced material [12]. The primary pedagogical resource utilized in this approach is an ordered collection of worksheets. These worksheets are planned to move from easy to increasingly complex tasks, thereby enabling students to develop their self-confidence and learn concepts at their own learning rates [13] [12]. The Kumon approach facilitates independent learning and enhances problem-solving capabilities. It enables children to learn at their own pace, thereby developing a stronger foundation for mathematical concepts [11] [12].

2. The Stern and Numicon Approaches

This method uses tangible objects and visual aids to represent numerical values and their relationships. By making abstract mathematical concepts more concrete, it makes children comprehend mathematical ideas more effectively [5] [12]. The Numicon approach uses colorful, removable number shapes that children can calculate to investigate fundamental mathematical concepts like addition, subtraction, and number value. This method works best with visual and kinesthetic learners. Calculating materials make abstract concepts more tangible, which is beneficial for young children and students with learning disabilities.

Each approach has its strengths, and the two approaches together offer a complete way of teaching numeracy. Using both methods guarantees a more enriched learning experience that will suit various learning styles.

The following are the essential principles that must be grasped to teach counting effectively to the learners. Here is an overview of the principles: [12]

- One-to-One Correspondence: Each object in a group must be given a different number while counting. For example, five apples must be counted one at a time so that there are no omissions or repetitions.
- Stability: Numbers must be counted in the correct order (1, 2, 3, 4, 5) so that children know the specific order to be followed by the numbers.
- Cardinal Principle: The last number said in counting tells how many objects there actually are. For example, counting five blocks and saying "five" for the last block thus acknowledges these five blocks as the total.
- Order Irrelevance Principle: The order in which objects are counted does not affect the total. The count continues whether it is done front-to-back, back-to-front, or in any other configuration; the sum remains constant.
- Abstraction Principle: Counting is not restricted to tangible objects; children may also count sounds, actions, or hypothetical entities.

With these principles in play during counting activities, children can develop strong number bonding, which is very necessary as a prerequisite for learning higher math.

Of this whole concept of numbering, we have a number system based on 10, It is important to introduce the combinations that add up to 10. A teaching method called "Rainbow Facts to 10" involves coordinating these number pairs in children's minds using colors and patterns. This method of linking number combinations with visual reminders strengthens early arithmetic skills.

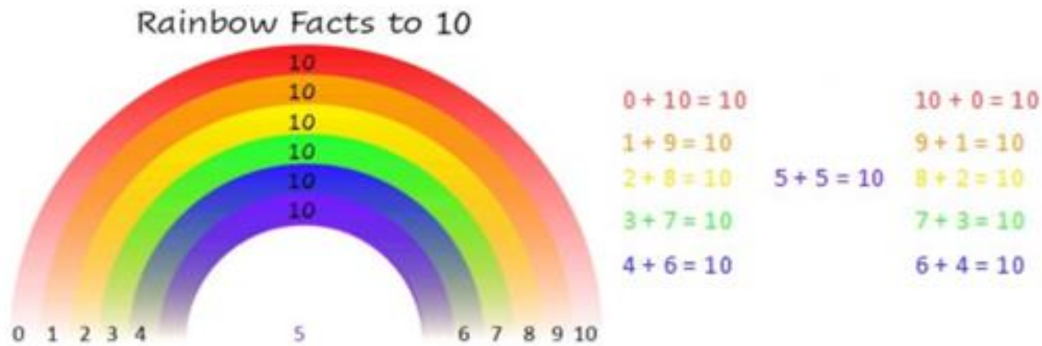

Figure 1-1 Rainbow facts to number 10 method [12]
Source: https://www.dsrf.org/resources/learn-at-home/learn-at-home-activities-for-math/

All these methods are designed for DS children. Because of this, using all these teaching methods can be an effective way to help enhance the mathematical skills of children with DS.

In the background study, research with the title "Training Basic Numerical Skills in Children with Down Syndrome Using the Computerized Game 'The Number Race '" analyzed the impact of an intervention on children with Down syndrome. In that research, the participants were divided into two groups [14].

- Training Group (TG): Children in TG were trained in "The Number Race" to improve numerical skills.
- Control Group (CG): This group worked on other software for literacy training purposes.

The study measured numerical and reading skills three times. pre-test before the training, post-test immediately after training was completed, and follow-up test three months later. The researchers were expecting significant improvement in the training group's numerical skills over time.

According to other studies, children learn better when their multiple senses are activated at the same time in Michigan. Teaching strategies that incorporate visualization materials, manipulatives, and auditory representations will encourage a more significant understanding of math for DS children. Adaptive learning technology that adjusts the task's difficulty based on the child's performance can be instrumental in equipping the child with mathematical skills.

These teaching methods and principles are specifically designed for children with DS. Integrating these remedial and intervention strategies into our system will enhance their skills in mathematics while providing an organized and worthwhile experience. Given the eventual assistance in developing psychomotor skills through these relevant materials and techniques, early DS children may enhance their numeracy skills and achieve greater educational growth [15].

Proposed system:

Special learning systems are promising for enhancement of a child's quantitative performance with DS by achieving higher quality than white traditional instruction by customizing instruction for each student. The proposed system expects to take advantage of the adaptive quizzes to make learning as fun as possible. The system can, thus, in the first instance, rely on the performance data of the users in terms of age and difficulty levels in tackling arithmetic problems to determine the child's ability and direct him or her to problems that they would find challenging enough.

Initially, the users will start with questions from the beginners' pool in order to gauge the amount of knowledge that the user possesses. As the child answers questions, the system dynamically adjusts the difficulty based on their performance. The right answers eventually take the quiz-takers to more subjective questions, and the wrong ones take them to questions like or one level below the incorrect response. This kind of approach provides a way by which the child is constantly engaged but on a level that is slightly difficult enough to enable him or her to learn progressively. The thing is that passage to the next level of difficulty depends upon the rule-based system, for example, going to the next level after achieving more than 15 correct answers. As the programmed number of questions at a particular level of difficulty is reached, the system then produces a quiz that consists of random or slightly altered questions from the set. This quiz is designed to check the child's understanding of the concepts taught with the help of time taken on each question and the number of correct and wrong answers. In respect to the evaluations, the score of the child depends on the number of answers given successfully; if the defined level of pass mark is achieved, the child proceeds to the next level of difficulty. If the score is less than this number, the child stays at this level until he/she shows sufficient mastery.

In order to enhance the learning process, the system integrates educational animations designed with React and Fabric.js library. The animations are designed to provide brief definitions of mathematical terminology and, as required, provide a visual display of how to solve incorrect answers engagingly and straightforwardly. One of the modules is wholly devoted to the teaching of fundamental addition, subtraction, multiplication and division by manipulating real-life money. It replicates the process of adding two amounts of money in terms of denominations of Sri Lankan currency, helping children with Down syndrome connect abstractions in mathematics to real-world experiences. Using these interactive and contextual visual representations, the system aims to maximize the teaching and learning process for effectiveness and accessibility.

Further, there is an educational report for parents, which lists the child's performance at each level: time spent, scores, and number of correct and incorrect answers. This report consists of data profiles of the child's progress over a period, the capabilities that have been developed, and the capabilities that require enhancement. This way, parents can monitor their children and know the progress their child is making in school, using them to support the child as they go through the learning process.

In general, the adaptive learning system plans to meet the education needs of children with DS to help children improve on mathematical education. Incorporating the adaptive quizzes, the educational animations, and the performance tracking, the system seeks to provide students with a rich and engaging learning environment that would enable the child to increase his/her achievement level in mathematics in a seamless manner that would be supportive of his/her learning process.

1.2. Research Gap

There have been many studies into different approaches to improving numerical ability in DS children. While helpful, they also highlight some significant gaps in current research and teaching materials.

Research A: This research assessed the effect of the computerized game "The Number Race" on enhancing numerical skills in DS children. There were 61 children, 30 in the training group (TG) on "The Number Race" and 31 in the control group (CG) on literacy-based software. The intervention was 10 weeks, two sessions per week, 20-30 minutes each. interventions made before, after, and 3 months after training.

The study revealed that both treatments experienced numeracy gains but that the treatment group (TG) experienced much greater improvement, especially in number change and mental calculation. While the control group (CG) made little gains in numeracy, their gain was greater in literacy ability. Despite these promising findings, the experiment was not without several limitations. Most critically, no control group followed normal teaching procedures, restricting comparative analysis. The training time could have been too short to generate the optimal outcomes, and participants represented a wide range of pre-training skill levels. Additionally, the game used in the intervention was not very responsive to individual development, and participants were not assigned to groups at random, potentially resulting in selection bias. The lack of blinding of the testers also threatened to have biased observations. Furthermore, the study did not assess if the skills acquired were transferable to real-world situations. These limitations highlight the need to conduct more research to identify effective training modalities, learning periods suited for children with Down syndrome, and adaptive instructional strategies [14].

Research B: This review combined nine empirical studies (1989–2012) to identify the effectiveness of various math interventions for young children and teenagers with DS. Most of the studies targeted elementary skills such as counting and the recognition of numbers.

The significant conclusions of the review are that while the overall interventions resulted in improved numeracy in children with Down syndrome, none of the reviewed studies were methodologically reliable. Notably, no study of intervention used targeted interventions aimed at specifically focusing on behavior characteristics of Down syndrome. Because of the overall poor quality of the research and the small number of participants in the studies, though, it is not known which mathematical intervention techniques actually work best with this group. The findings point to a critical need for high-quality, well-controlled research that not only considers the unique behavioral and cognitive profiles of children with Down syndrome but also employs more formalized and structured intervention approaches [16].

Research C: This review considered the difficulties DS children have in understanding simple numerical concepts, including:

- Quantity and numeral recognition
- Counting skills (stable order, cardinality, working memory)
- Higher-order skills (time, money, problem-solving)

Research on mathematics education for children with Down syndrome (DS) is limited, and the majority of research focuses on early numeracy learning. Also, existing research is marred by methodological issues, such as small or poorly selected samples and unreliable measures of assessment. Comparisons with other children with other intellectual disabilities (ID) are also limited, so one cannot know if the mathematical challenges of DS children are unique. To address these limitations, the study recommends conducting studies with a broader age range and improved participant matching. It also advises comparative studies on DS children compared to other groups with ID for further establishing clearly their distinct difficulties in learning. Additionally, longitudinal research needs to be conducted for longitudinal follow-ups over time tracking development in mathematics and revised studies have to comply with current best standards in the study of mathematics [17].

Research D: In this study, mathematic abilities in WS and DS (ages 8–51) and TD children (ages 4–10) were compared. Members from all groups were matched for general intelligence.

No differences existed in math development between WS, DS, and TD children after controlling for general cognitive ability. Non-symbolic and symbolic numeracy abilities were also found to be strong predictors of overall mathematical performance. Additionally, the study found that participants with WS and DS also continue to develop numeracy abilities throughout their lifespan, demonstrating that these groups are able to learn across their lifetime [18].

1.2.1. Identified research gaps and the need for "EnlightenDS"

Most of the learning applications and research studies conduct for basic numeracy skills through conventional teaching methods with quizzes and general assessments. However, these lack the primary components to deliver successful DS education:

- Adaptive Learning- Existing research does not make any effort on systems that tailor information to fit the child's capabilities
- Fascinating Educational Animations- There is no other tool that incorporates interactive pictures or animations that could make it easier for children to understand mathematical theories.
- Parental Feedback System- Research does not provide organized feedback to allow parents to monitor progress and assist learning at home.
- Comprehensive Performance Tracking- Most programs only consider immediate test outcomes, not ongoing skill acquisition.

1.2.2. How "EnlightenDS" addresses these gaps

Our research, "EnlightenDS", is custom-made for children with DS and encompasses:

- Adaptive Question Logic- Personalizes content according to age, level of difficulty, and personal progress.
- Basic Numeracy Training- Develops important number skills with enjoyable, structured exercises.
- Educational Animations- Uses visible and interactive aspects to enhance learning
- Performance Monitoring- Tracks progress over time and gives parents detailed feedback.

Table 1.1 Research Gap

	A	B	C	D	EnlightenDS
Creating adaptive question logic	✗	✗	✗	✗	✓
Divided questions into age range groups and difficulty levels	✓	✗	✗	✗	✓
Focus on improving basic numerical skills	✓	✓	✓	✗	✓
Educational animation integration for explanations and training	✗	✗	✗	✗	✓
Quiz creation	✗	✓	✓	✗	✓
Get overall statistics of performance	✓	✓	✓	✓	✓
Provide further development instructions for the parents by analyzing status of the child	✗	✗	✗	✗	✓
Application created	✓	✗	✗	✗	✓
Web application	✗	✗	✗	✗	✓

Unlike previous research studies (for example, Research A is not adaptive, and Research B and C are based on basic methods), "EnlightenDS" is the first all-encompassing education solution that is based on many evidence-based approaches in one web application. Therefore, it forms a bridge from the existing approaches to modern individualized learning in children with DS.

1.3. Research Problem

Cognitive development in children with DS is different from that of children with no DS because of the genetic condition of their brains. The main problem of this population is that they face difficulties connected with memory, problem-solving skills, and the processing velocity they can affect their daily life, including mathematics. Intellectual development in this population is usually delayed but progresses in the same manner as in normal children. There are developmental milestones children with DS should achieve between 5 and 15, they may attain these milestones more slowly or may need help.

- According to the research, at 5 years old children with DS are learning early aspects of cognitive development, including simple reasoning and memory. Although, like their peers they are not mentally challenged and can execute tasks and meet objectives, often their mental processing speed is not as fast as their peers, and they may also have problems with attention spans.
- At 7 to 8, children can handle more complicated information such as categorization and sequencing of information though abstract thinking remains a major issue for children at this age [19] [20].
- Usually at 9 to 15 years old, children show better memory, attention, and problem-solving. But learning may still be retarded, and they are not able to reason like other children of their age. Cognitive difficulties that may be seen in adolescents with DS include impairment of abstract thinking and higher-order cognitive skills, this makes it difficult for a child with DS to solve complex mathematics problems or perform highly analytic tasks [21].

So, based on this information, we have analyzed what would be the most appropriate research problem for our system. That is,

How can the use of adaptive learning technologies be effectively employed to support the development of basic math skills for children with Down syndrome given their unique numerical skill acquisition challenges?

To clarify the above research problem, we have several specific questions that include:

- Which are the most efficient adaptations used in teaching children with DS about recognition and counting numbers?
- How could adaptive learning systems be designed to bridge the two-year gap between mastery of literacy and numeracy among children with DS?
- Also, what is personalized feedback from whom when it comes to improving one-to-one correspondence, numerical order, and cardinality understanding in DS children?
- Additionally, how can adaptive learning technologies be created to gradually expose more intricate mathematical notions like simple addition and subtraction that correspond well with exceptional learning requirements among children with DS?
- Lastly, what results should we expect if we were to apply this technology to the everyday life skills of these disabled kids?

By answering these questions, our study aims to develop a structured, research-backed approach to enhancing math education for children with DS using adaptive learning technologies.

1.4.Research Objectives

1.4.1. Main objective

The aim of the present study is to design and develop a comprehensive adaptive education system for children with Down syndrome in the age range 5-15 years. The system will be developed to support and enhance four areas of development including, cognitive, linguistic, mathematical, and creative skills. By providing personalized and adaptive learning interventions, the system will try to cater to the individual needs, abilities, and learning pace of the child. The system will have personalized math quizzes that adjust level based on the child's performance and track progress to assess improvement in math abilities. It will also provide parents development reports and personalized recommendations to support the child's continued development. Ultimately, this research aims to evaluate the system's effectiveness in improving mathematical skills and providing actionable insights for parents and educators.

1.4.2. Sub objectives

- Create Adaptive Quiz System

  Interactive quizzes that get harder as you get better at practice level adjust the difficulty of questions to best suit the child while keeping them challenging and enhancing learning appropriate for where they are at with their skill set.
- Educational Animations for Math Concepts

  Integrate animations that demonstrate math-related one's calculations. This visual technique is effective at communicating the core mathematical ideas and processes in a way that children with DS can relate to.
- Easy to Use Interface and Tracking System

  A quick, user-friendly interface experience designed to cater to children with DS. Performance tracking and reporting. It automatically creates detailed reports on the progress, and time spent that can help inform parents or educators about how to accompany their child's learning curve.
- Feedback and Improvement

  Get input from kids, parents plus educators for a user interface in addition to presented system. The goal is to incorporate these models into a system that refines itself using quantitative data.

This structured approach ensures that the adaptive educational system meets the unique learning needs of children with DS, empowers parents and educators, and enhances math education through personalized interventions.

2. METHODOLOGY

2.1. System Architecture Diagram

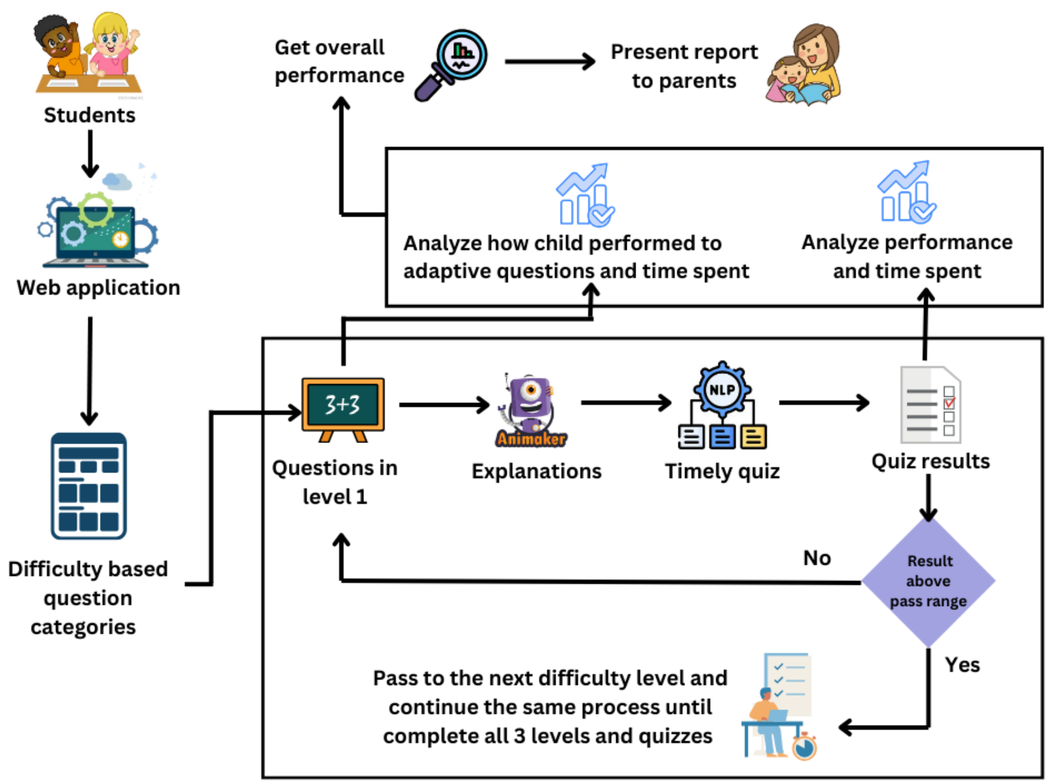

Figure 2-1 Component specific system architecture diagram

Adaptive learning mathematics task system is ready to support children to develop basic arithmetic concept understanding. The training program begins with offering fundamental math content, categorized in three levels of difficulty, beginner, intermediate, and advanced. The three are employed for use in four most critical arithmetic operations as addition, subtraction, multiplication, and division.

The training course covers the basic counting principles and methods, including the one-to-one principle, stable-order principle, cardinal principle, order irrelevance principle, abstraction principle, numerical order, and comparison. Children progress through the levels based on performance, with questions that dynamically adjust in difficulty to suit their learning pace. The numbers covered in this training are limited to small numbers between 0 and 10, maintaining content accessibility and developmental appropriateness. The adaptive nature of the system ensures that each child receives individualized support as they build and develop their math skills.

To facilitate effective learning, the training program employs two primary teaching methods: The two methods are namely [12] [11],

- Kumon Method
- Stern and Numicon Method

It uses paper and pencils to do the arithmetic, and progresses through steps in difficulty, as with the Kumon Method. On the other hand, the Stern and Numicon Method is more physical in a way that when assailing the numeracy concepts to children they are dealt with more tangibly. These methods are meant to address multiple approaches of learner information processing and repetition of arithmetic skills in separate ways. Also, all these methods are designed for DS children.

Question Pools: The structure of the functioning system embraces the clearly defined list of questions presented in numerous pools and divided according to the degree of their difficulties here, three pooled genres can be mentioned as beginner, intermediate, and advanced. Every one of the question pools contains the simplest arithmetic operations. However, the level of complexity depends on the difficulty level of the students. This way, it is possible to make sure that the questions offered are going to be neither too easy nor too complex to be beyond the child's understanding at the stage of development.

Adaptive Questioning: This is the key feature of the system, and this feature is adaptive questioning, meaning the level of the questions is chosen depending on the user's result. This way the system provides questions of slightly higher difficulty in case the correct answers are given, and questions of equal or slightly lower difficulty in case wrong answers were given.

Quiz: As soon as the users have answered a defined number of questions of each type of difficulty level, they are given a quiz intended to check on their general knowledge acquired during the game. The quiz features questions chosen at random or slightly modified from the same pool. In each case, natural language processing (NLP) algorithms are used to select or synthesize questions on the pool. In a quiz, several aspects of performance are observed such as the time taken by the participant to answer questions and correctness of the answers being given. These show a simple percentage of the number of correct answers to the total number of questions. Those with total scores above a preset pass mark, a percentage for example 75 percent go to the next level of difficulty while those with low scores are detained at their level until they achieve the required mark.

Educational Animations: For additional learning support, the system combines educational animations developed with React and Fabric.js library. These animations are meant to help demonstrate mathematical skills, as well as offer solutions on what was done wrong in wrong answers. Animations used in the learning process add value to the teaching/learning process for two reasons, they make difficult concepts easier to understand because of the engaging format of the animations and the ability to keep the child interested in learning more.

Summary Reports: The system generates detailed parent reports that provide detailed insights into the child's progress over different grades. The reports include details of elapsed time, scores, and correct and incorrect answers. In addition to tracking progress over a length of time, the reports also provide details of areas of strength and weaknesses. Based on the performance of the child, the system even suggests lines of future development and gives recommendations suited to facilitate ongoing learning. After studying the child's progress throughout the entire learning process, the very comprehensive reports allow parents with the ability to keep track of their child's ongoing progress and confirm they are further progressing within their learning processes.

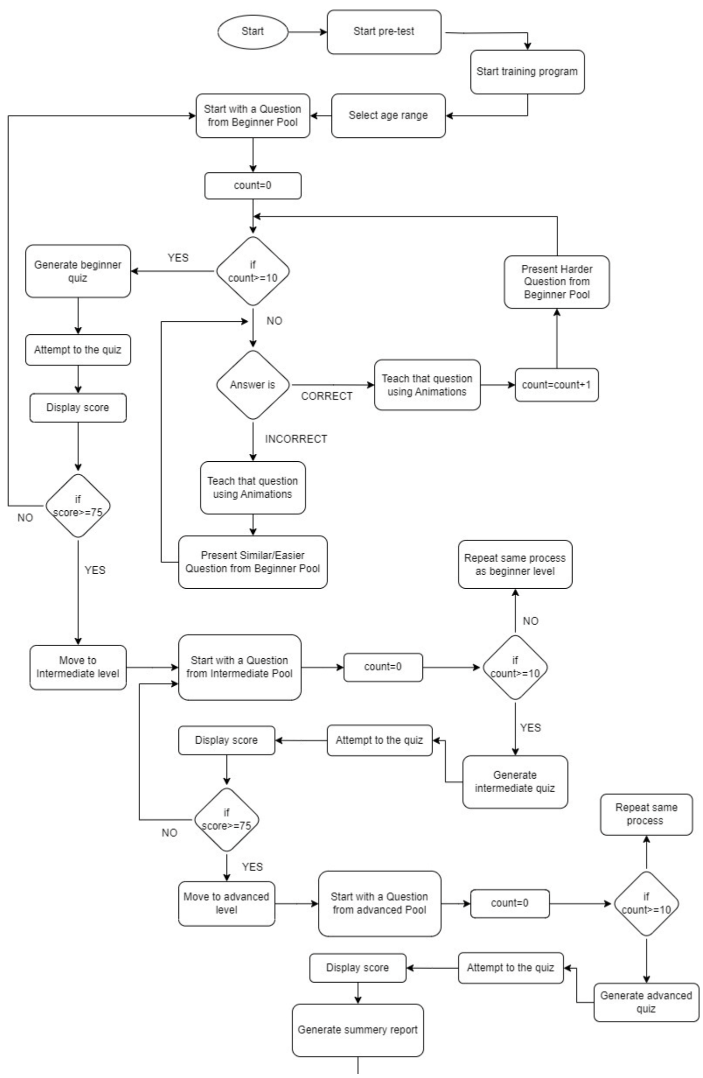

Figure 2-2 Flow chart

2.2. Software Solution

2.2.1. Development process

Our development process follows the Agile methodology, which emphasizes flexibility, collaboration, and iterative progress. Unlike traditional, linear development models that rely on a fixed, sequential plan, Agile enables us to divide the work into smaller, manageable units known as sprints. This approach allows for continuous feedback, timely adjustments, and ongoing integration of changes throughout the project lifecycle, resulting in products that are more adaptable and aligned with user needs [22].

To support our Agile workflow, we utilize Microsoft Teams Planner as our task management tool. Planner enables our team to create, assign, and monitor tasks in an organized and visual format. Each sprint is mapped out within Planner using buckets and task cards, where team members can update progress, add comments, set priorities, and attach relevant documents. This promotes transparency, accountability, and collaboration among the team, ensuring that everyone stays aligned and informed throughout the development cycle.

By combining Agile practices with Planner's organizational features, we are able to maintain a clear structure while remaining adaptable to changes, ultimately delivering high-quality solutions in an efficient and user-centered manner.

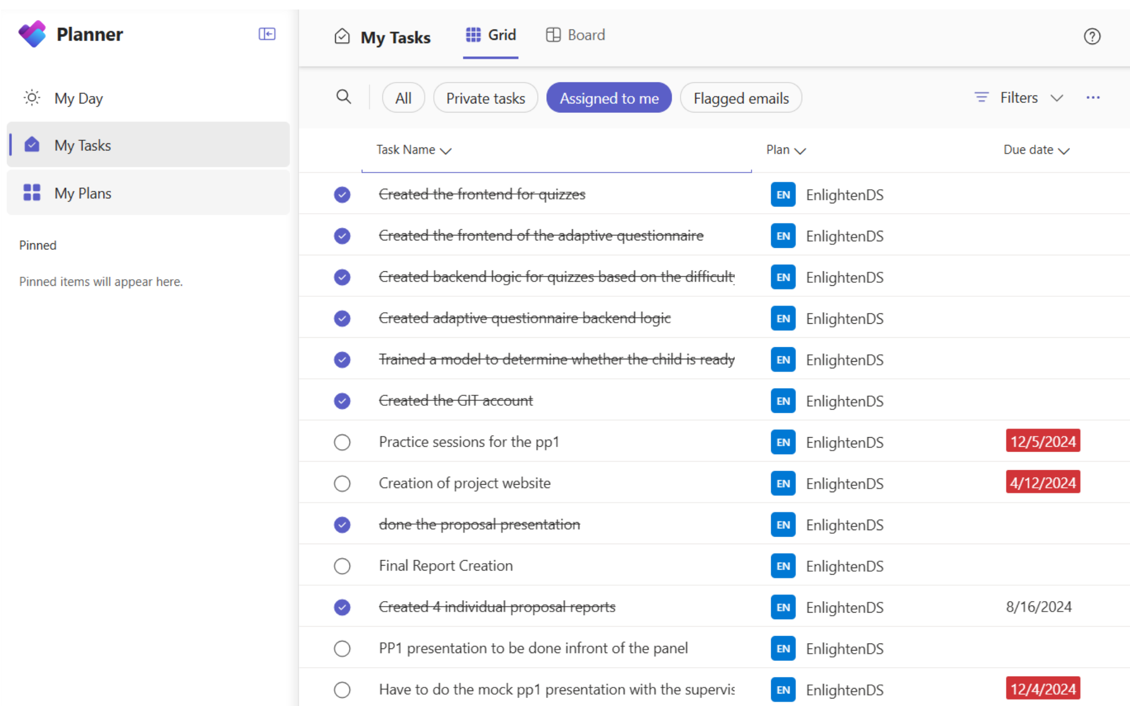

Figure 2-3 MS planner

2.2.2. Requirement gathering

- Conduct Interviews

Employ the teachers, caregivers, and specialists at “Senehasa Research Center,” to discuss the learning needs and difficulties of the children as well as current practices the children teachers use when teaching mathematics. Conference with the parents to get their perceptions about their kids’ behavior, the areas that they excel at, and the areas they need to work on.

- Observation

Go to the class and spend time with the children to note how they engage with the content and techniques they employ to solve Mathematics problems. Observe their ability to focus, the strategies they use to solve problems, and if there are any behavioral and learning characteristics noticeable.

- Conduct survey

A survey is being taken as to what people feel about the research and how informed they are on DS. This research identifies whether the audience appreciates and recognizes the study and if there are any amnesias concerning DS. The outcomes will assist enhance the exploring element and convert its presentation so that it is fit to benefit as many people as possible

The study clearly shows general people's understanding of DS. 71.1% of the respondents are familiar with DS, and 68. 3% of them have encountered somebody with this condition. Precise to the above, 97.1% of the participants believed in the effectiveness of adaptive learning systems for the teaching of mathematics to children with DS and 76.3% deeming them valuable. Three percent consider them valuable. Additionally, 95. 4% of respondents agree that animated education is useful in assisting children in comprehending mathematical knowledge, with 67.1% rating it as highly effective. Conclusion: The results reveal that there is a consensus on the effectiveness of the adaptive learning systems and the educational animations in the improvement of mathematical learning for children with DS. This supports endorsements for incorporating those tools into educational programs

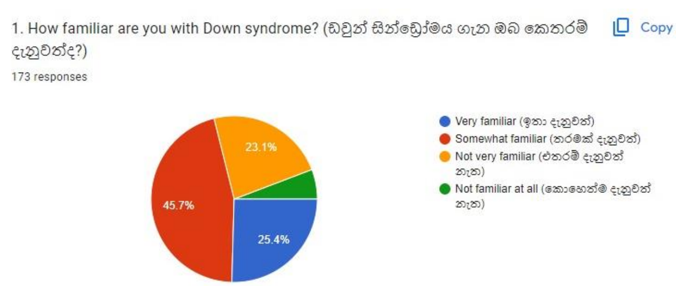

Figure 2-4 Survey result

2.3. Project Requirements

2.3.1. Functional requirements

1. Adaptive Learning Module
    - The system will incorporate a training module with math exercises (addition, subtraction, multiplication, division).
    - The module will support three levels of difficulty: Beginner, Intermediate, and Advanced.
    - The system will dynamically adjust question difficulty based on the child's performance.
    - The system will teach mathematical concepts through root principles such as one-to-one correspondence, cardinality, and numerical order.
2. Interactive Educational Animations
    - The system will draw educational animations using React and Fabric.js to explain mathematical concepts.
    - The system will include visual demonstrations for erroneous answers to encourage comprehension.
    - The animation module will include real-life simulations, i.e., manipulation of money with Sri Lankan currency.
3. Performance Monitoring and Progress Tracking
    - The system will track the time spent by each child, accuracy, and score per arithmetic category.
    - The system will maintain performance information on difficulty levels and track progress over time.
4. Parental Summary Report Generation
    - The system will generate detailed summary reports for parents.
    - Reports will include scores, time spent, correct/incorrect responses, and trends so far.
    - The system will analyze long-term child development and provide future learning directions.
    - Reports will identify areas of strength and areas of improvement.
5. Personalized Recommendations
    - The system will analyze overall performance data to make personalized future learning recommendations.
    - The system will recommend specific categories or difficulty levels for further practice depending on progress analysis.

2.3.2. Non-functional requirements

1. Performance
    - Be built for multiple concurrent active users. Performance will not suffer by behaving this way.

- The system was supposed to be very fast. Generate a quiz, then choose questions as swiftly as possible, so the default will always be to optimize response time for in quizzes during trace determination.

2. Usability
   - All facets of the application must be user-friendly for those with disabilities. Make sure to design an accessible and easy-to-understand interface that caters to all potential users.
   - Make reports reader-friendly. Create a user, parent, and teacher-friendly way of presenting a generated report.

3. Quality
   - Only if the reports are well written and reflect true user performance, thus being accurate, can we guarantee that quality. While going for reporting signaling, the report should be good to ensure the right activities have been performed by users so end-user needs get resolved.

4. Content and User Experience
   - Includes educational materials and animations that are bright and lighthearted. Bright, fun educational material and animations are included.

5. Availability
   - The system should always be ready to make it 24/7 ensuring it is available for users whenever they require our service.

6. Security
   - Save any part of these logs or performance reports using the software, together with personal data, in encrypted form during storage.

2.3.3. Software requirements

1. Fabric.js
   - A canvas-based JavaScript library that enabled dynamic creation, manipulation, and animation of visual objects like Sri Lankan currency notes and coins for educational animations.
2. Google Text-to-Speech (TTS) API with SSML
   - Google Cloud's TTS service was integrated to generate high-quality, child-friendly audio using “Speech Synthesis Markup Language (SSML)”. SSML tags were used to control “pause duration”, “emphasis”, “pitch”, and “speaking rate” to ensure the audio matched the animation pace and was easy for children to follow.
3. JavaScript (ES6+)

- Provided the underlying logic to calculate denominations, control the animation sequence, and synchronize visual events with TTS audio playback.

4. HTML5 Canvas - Fabric.js
   - Served as the base layer for drawing graphical content and animations, controlled through Fabric.js.
5. GPT-3/GPT-4 APIs
   - These could provide a method for personalizing the content of quizzes to reflect the student's progress.
6. Phyton
   - This makes it easy to integrate with the major machine learning frameworks, where complex algorithms like neural networks can be incorporated to predict on the student's performance and the kind of quizzes that would suit them.
7. D3.js library
   - For the creation of dynamic and interactive statistics and graphics in web browsers. This provides better control on the features and using this feature can create complex graphical representation which is helpful for the analysis of student performance.
8. Chart.js library
   - This is an easier-to-use and less complex library for creating charts and graphs. It incorporates many inbuilt chart forms and can be implemented in web applications. As it can be used to generate simple and uncomplicated graphic displays.
9. React
   - For frontend creations

Algorithms

1. Rule-based system used for initial difficulty adjustment and to monitor and record the user progress
   - Thus, defined rules help the system to understand how the student progresses and, therefore, how he becomes closer to advanced information.
2. Statistical Analysis for Tracking Performance Metrics and Generating Reports
   - Statistical methods can track changes in the performance of students over time and hence the system can generate reports on learning progress. For instance, by using performance data it can be noted that the student's performance is gradually improving or that it is showing signs of deterioration constantly. This is also important in producing a detailed report of the student's performance for the educators and parents. These reports may consist of gains and losses of the student's performance, comparisons with previous attempts, and recommendations for further studies.

2.3. Commercialization Aspects

1. Market Analysis

Target Audience

- Children with DS age 5-15
- Parents, caregivers, and schoolteachers
- Healthcare professionals working with children with special needs

Market Size and Trends

- Increasing awareness and demand for individualized educational help for children with special needs and increasing adoption of technology in the learning process, especially in special education

2. Revenue Model

1. Freemium Model
   - Offer a free, basic version of the system, with reduced features.
2. Subscription-Based Model
   - Users could have a subscription service on a monthly or annual basis for parents and institutions and have tiered pricing based on features/levels of access (basic, premium)
3. Institutional Sales
   - Partner with schools and educational institutions by offering bulk subscriptions.

3. Packages and features

1. Basic Plan

- Features
  - ✓ Access to cognitive-level assessment tools
  - ✓ Basic communication skill improvement activities
  - ✓ Limited personalized quizzes for math skills
  - ✓ Access to painting and piano platforms to develop creativity
  - ✓ Basic summary reports for parents with scores and spent time
- Price: Free

2. Premium Plan

- Features
  - ✓ All features from the Basic Plan
  - ✓ Advanced cognitive assessment with detailed symptom analysis
  - ✓ Full access to personalized quizzes with adaptive difficulty

- ✓ Emotion-based engagement activities and mood detection
  - ✓ Advanced summary reports with performance improvement statistics.
  - ✓ Priority customer support.
- Price: $10 per month

3.School/Institution Plan

- Features
  - ✓ Bulk subscriptions with discounts for schools and educational institutions.
  - ✓ Access up to 40 students.
  - ✓ Full access to all features for multiple users.
  - ✓ Training and supporting educators to include it in the curriculum.
  - ✓ Detailed analytics and reports for educators on student progress
- Price: $30 per month

2.3. Testing and Implementation

2.3.1. Implementation

1. Model training for predict readiness for next level

The dataset used for this study, titled 'balanced_quiz_dataset.csv', was collected under the context of an adaptive learning system for children with Down syndrome. Each row in the dataset represents a child's performance during a training and quiz sessions, with demographic data and performance metrics. The dataset includes the following fields,

- Numerical Features- total number of questions in the quiz, number of questions answered correctly and incorrectly, number of questions faced in each sub levels, number of correct answers in each sub levels, average response time for each sub levels, final score for the quiz, total time taken to complete the quiz
- Categorical Features- gender, math category, and difficulty level
- Target Variable- readiness – a binary label indicating whether the child is considered ready (1) or not ready (0) to progress to the next level.

The dataset is balanced so that both readiness outcomes are represented equally, which is crucial while training an unbiased classification model.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	age	gender	category	difficulty	noofquestions	correctcount	incorrect count	noofattemptinquestionsinsublevel1	noofattemptinquestionsinsublevel2	noofattemptinquestionsinsublevel3	noofattemptinquestionsinsublevel4	noofcorrectquestionsinsublevel1	noofcorrectquestionsinsublevel2	noofcorrectquestionsinsublevel3	noofcorrectquestionsinsublevel4	avrgresponsetimeforsublevel1questions	avrgresponsetimeforsublevel2questions	avrgresponsetimeforsublevel3questions	avrgresponsetimeforsublevel4questions	quizmark	quizcompletationtime	readiness
2	9	male	multipicati	advanced	15	1	14	4	1	3	4	3	1	0	2	67.778088	19.158152	88.490983	117.61704	1	14.55271	0
3	11	male	addition	intermedia	15	3	12	0	5	4	5	0	3	2	5	0	16.153963	13.981788	18.671205	6	13.96664	0
4	11	female	substractic	advanced	15	12	3	1	2	2	2	0	0	0	1	3.1840201	16.990397	36.096425	18.90802	8	18.98084	1
5	3	female	multipicati	beginner	15	14	1	1	2	1	5	0	0	1	0	25.190044	18.39065	20.861641	32.452964	10	11.64184	1
6	15	male	substractic	advanced	15	15	0	2	1	1	1	0	1	1	0	23.241632	2.293357	34.775837	34.075851	10	8.189436	1
7	6	male	division	beginner	15	0	15	4	2	2	0	1	1	1	0	19.702536	34.606275	25.355732	0	2	11.08199	0
8	10	male	division	advanced	15	12	3	2	3	1	0	2	2	0	0	54.256379	51.170334	78.376761	0	8	27.67794	0
9	3	male	substractic	beginner	15	12	3	1	1	2	5	1	0	0	5	3.836007	4.8485994	6.8423119	21.02197	10	14.47616	1
10	13	male	addition	advanced	15	1	14	4	0	3	3	0	0	3	0	27.111512	0	20.412558	6.0036119	4	27.4959	0

Figure 2-5 Dataset

To predict the readiness of each child, a Logistic Regression classifier was used because it is easy to interpret and efficient in binary classification tasks. The data was split into training and test sets in an 80/20 ratio while maintaining class distribution using the stratify parameter.

- Training Set: 80% of the data
- Testing Set: 20% of the data
- Model Parameters: The model was initialized with “random_state=42” for reproducibility and “max_iter=1000” for guaranteed convergence.

```
# Define the feature set (X) and the target variable (y)
X = df.drop(columns=["readiness"])
y = df["readiness"]

# Convert categorical columns to numerical
X = pd.get_dummies(X, columns=["gender", "category", "difficulty"], drop_first=True)

# Standardize numerical features
scaler = StandardScaler()
X_scaled = scaler.fit_transform(X)

# Split the dataset into training and testing sets
X_train, X_test, y_train, y_test = train_test_split(X_scaled, y, test_size=0.2, random_state=42, stratify=y)

# Initialize and train the logistic regression model
model = LogisticRegression(random_state=42, max_iter=1000)
model.fit(X_train, y_train)

# Make predictions
y_train_pred = model.predict(X_train)
y_test_pred = model.predict(X_test)
```

Figure 2-6 Predict readiness model development

The key values of the testing of the model learned are provided below:

- Training Accuracy: 88.64%
- Testing Accuracy: 88.21%

This indicates that the model generalizes well with minimal overfitting. Similarity between training accuracy and test accuracy suggests that the model did not memorize the data and learned the salient patterns of the data.

```python
# Evaluate the model
train_accuracy = accuracy_score(y_train, y_train_pred)
test_accuracy = accuracy_score(y_test, y_test_pred)
print(f"Training Accuracy: {train_accuracy * 100:.2f}%")
print(f"Testing Accuracy: {test_accuracy * 100:.2f}%")
print("\nClassification Report:")
print(classification_report(y_test, y_test_pred))
```

```
Training Accuracy: 88.64%
Testing Accuracy: 88.21%

Classification Report:
              precision    recall  f1-score   support

           0       0.90      0.86      0.88       140
           1       0.87      0.90      0.88       140

    accuracy                           0.88       280
   macro avg       0.88      0.88      0.88       280
weighted avg       0.88      0.88      0.88       280
```

Figure 2-7 Model accuracy

2. Adaptive question generation algorithm with sub-level progression

To generate math questions suitable for Down syndrome children, dynamic question generation function was created based on the chosen category (addition, subtraction, multiplication, division), difficulty level (beginner, intermediate, advanced), and sub-level.

Figure 2-8 Level and category selection interfaces

The function utilizes pre-determined numerical ranges for each level of difficulty to ensure the questions are age-suited and cognition-accessible. For instance, beginner-level questions use smaller numbers (1–20), while advanced levels use a larger range (10–100).

```javascript
export default function generateQuestion(category, difficulty, subLevel) {
  const operations = {
    addition: '+',
    subtraction: '-',
    multiplication: '*',
    division: '/',
  };

  if (!operations[category]) {
    throw new Error('Invalid category');
  }

  const operation = operations[category];
  let nums = [];

  const ranges = {
    beginner: [1, 20],
    intermediate: [10, 50],
    advanced: [10, 100],
  };
```

Figure 2-9 Creating levels

Under each primary difficulty level, the system is further divided into 4 sub-levels to ensure a more gradual learning curve. The sub-levels allow for greater control over question difficulty. Each primary difficulty range is further divided into four equal segments. For example, if the beginner range is 1 through 20, it is divided as follows,

- Sub-level 1- Numbers from 1 to 5 (easiest)
- Sub-level 2- Numbers from 6 to 10
- Sub-level 3- Numbers from 11 to 15
- Sub-level 4- Numbers from 16 to 20 (most difficult within beginner)

This logic is similarly applied to intermediate and advanced levels, each with its own range of numbers. The higher the sub-level between 1 to 4, the greater and more challenging the numerical values of the questions. This structure supports learning step by step as well as enabling Down syndrome children to progress at their own speed without sudden jumps in difficulty.

```javascript
const getRange = (subLevel, baseRange) => {
  const [min, max] = baseRange;
  const increment = Math.floor((max - min) / 4); // Divide range into 4 sub-levels
  const subMin = min + increment * (subLevel - 1);
  const subMax = subMin + increment - 1;
  return [subMin, subMax];
};
```

Figure 2-10 Creating sub levels

The reasoning to produce numbers varies according to the selected category of math to make the produced questions valid and appropriate for the learner's level. For division, the aim is to present clean divisions (without remainders). First, a group of dividends is selected based on the sub-level in the indicated difficulty. A specific, fixed set of divisors is used depending on the difficulty level. A divisor is randomly picked from among them, and a dividend is generated by taking a random number from the sub-level set and multiplying it by the chosen divisor. This ensures the result of division to be an integer every time.

In the case of subtraction, the explanation makes the initial number always bigger than the latter to avoid negative results which are likely to confusing some children. A second number is selected from the sub-level range, then the first number is created by adding a random positive amount to it.

For addition and multiplication, the two numbers are both selected independently from the range defined by the difficulty and sub-level. This consistent format ensures that the questions systematically increase in difficulty, allowing for a smooth learning process tailored to each child's development and ability.

```
if (category === 'division') {
    const [min, max] = getRange(subLevel, ranges[difficulty]);
    const divisorRange = difficulty === 'beginner' ? [2, 5] : difficulty === 'intermediate' ? [6, 9] : [10, 15];
    const dividend = Math.floor(Math.random() * (max - min + 1)) + min;
    const divisor = Math.floor(Math.random() * (divisorRange[1] - divisorRange[0] + 1)) + divisorRange[0];
    nums = [dividend * divisor, divisor];
} else if (category === 'subtraction') {
    const [min, max] = getRange(subLevel, ranges[difficulty]);
    const num2 = Math.floor(Math.random() * (max - min + 1)) + min;
    const num1 = num2 + Math.floor(Math.random() * (max - num2 + 1)) + 1;
    nums = [num1, num2];
} else {
    const [min, max] = getRange(subLevel, ranges[difficulty]);
    nums = [
      Math.floor(Math.random() * (max - min + 1)) + min,
      Math.floor(Math.random() * (max - min + 1)) + min,
    ];
}
```

Figure 2-11 Question logic

3. Adjusting the difficulty of the next question based on child performance

The algorithm is pivotal in determining whether the difficulty level of the next question has to be adjusted based on the child's performance. After the questions have been answered, the “handleSubmit” function processes the user's response and adjusts their performance metrics, which play a critical role in determining the difficulty of the next question.

The system initially ensures that the user has submitted an answer and checks whether the answer is correct by comparing the user's answer with the current question's correct answer. After ensuring the correctness of the answer, the system adjusts the performance metrics of the current sub-level.

- If the response is correct, the system checks whether the child should move to the next sub-level. The “setCurrentSubLevel” method is utilized to raise the sub-level, but it prevents the child from exceeding the max sub-level (which is established at 4). The line "Math.min(prevLevel + 1, 4)" enables the sub-level to be raised by 1, but not more than 4.

- If the answer is incorrect, the sub-level remains the same. The child will receive an explanation and motivational messages to encourage them to try again.

By only increasing the sub-level when responding correctly, the system guarantees that the advancement of the child depends on what they have mastered. The adaptive approach ensures that the difficulty will only be increased when the child is prepared and they are given additional support if necessary.

```
const handleSubmit = () => {
  if (userAnswer.trim() === '') return; // Prevent empty submissions

  setIsAnswered(true); // Mark as answered
  setTimerActive(false);

  const isCorrect = questionData && parseFloat(userAnswer) === parseFloat(questionData.correctAnswer);
  const endTime = Date.now(); // Capture end time
  const responseTime = (endTime - startTime) / 1000; // Convert to seconds

  setSubLevelStats((prevStats) => {
    const subLevelIndex = currentSubLevel - 1; // Sublevel is 1-based, array is 0-based
    const updatedAttempts = [...prevStats.attempts];
    const updatedCorrectAnswers = [...prevStats.correctAnswers];
    const updatedResponseTimes = [...prevStats.responseTimes];

    // Increment attempts for the current sublevel
    updatedAttempts[subLevelIndex] += 1;

    // Increment correct answers if correct
    if (isCorrect) {
      updatedCorrectAnswers[subLevelIndex] += 1;
    }

    // Add response time to the respective sublevel
    updatedResponseTimes[subLevelIndex].push(responseTime);

    return {
      attempts: updatedAttempts,
      correctAnswers: updatedCorrectAnswers,
      responseTimes: updatedResponseTimes,
    };
  });

  setAnswerResults((prevResults) => {
    const updatedResults = [...prevResults];
    updatedResults[questionCount] = isCorrect;
    return updatedResults;
  });

  if (isCorrect) {
    setCorrectCount((prev) => prev + 1);
    setMessage(shuffleMessages(positiveMessages));

    // Increase sub-level (if not at max)
    setCurrentSubLevel((prevLevel) => Math.min(prevLevel + 1, 4));
  } else {
    setShowExplanation(true); // Show AI Explanation if answer is wrong
    setIncorrectCount((prev) => prev + 1);
    setMessage(shuffleMessages(motivationalMessages));

    // Keep sub-level the same
  }
  setIsAnswered(true);
};
```

Figure 2-12 3. Adjusting the difficulty of the next question based on child performance

4. Quiz Generation with Sub-Level Distribution

This function is responsible for generating a set of math questions tailored to a specific category (like addition, subtraction, etc.) and difficulty level (beginner, intermediate, advanced). What makes this method special is how it uses sub-levels to gradually increase the difficulty within each quiz.

Each quiz consists of 10 questions in total. These questions are distributed across 4 sub-levels, with difficulty increasing from Sub-Level 1 to Sub-Level 4. The breakdown is as follows:

- Sub-Level 1: 1 question (easiest)
- Sub-Level 2: 2 questions
- Sub-Level 3: 3 questions
- Sub-Level 4: 4 questions (most difficult)

This creates a natural progression in difficulty throughout the quiz, allowing the child to build confidence with easier questions and then move on to harder ones.

For each sub-level, a loop generates the required number of questions using a custom generateQuestion function, which takes into account the category, difficulty, and sub-level to create appropriate arithmetic problems. These questions are then compiled into a single quiz and returned as a JSON response. This layered approach supports a more adaptive learning model, where performance at each sub-level can be tracked individually, helping to inform future recommendations and progress evaluations. Ultimately, this methodology allows for both structured learning and detailed performance analysis, which are especially important when working with children who require personalized educational support, such as those with Down syndrome.

```
export const generateQuiz = (req, res) => {
  const { category, difficulty } = req.params;

  try {
    // Define sub-level distribution
    const subLevelCounts = {
      1: 1, // 1 question from sub-level 1
      2: 2, // 2 questions from sub-level 2
      3: 3, // 3 questions from sub-level 3
      4: 4, // 4 questions from sub-level 4
    };

    const quizQuestions = [];

    // Generate questions based on the sub-level distribution
    for (let subLevel = 1; subLevel <= 4; subLevel++) {
      for (let i = 0; i < subLevelCounts[subLevel]; i++) {
        const question = generateQuestion(category, difficulty, subLevel);
        quizQuestions.push(question);
      }
    }

    res.json(quizQuestions); // Send as JSON response
  } catch (error) {
    res.status(400).json({ error: error.message }); // Handle invalid inputs
  }
};
```

Figure 2-13 Quiz creations

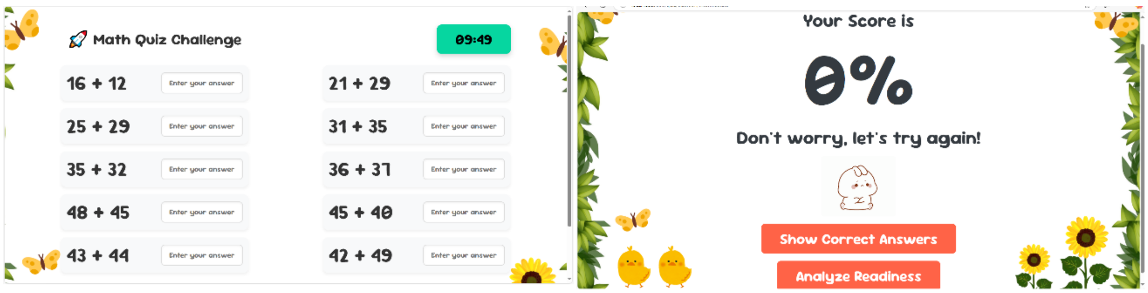

Figure 2-14 Quiz interfaces

5. Generating educational animations

In order to assist Down syndrome children in understanding arithmetic concepts better, particularly in everyday situations such as money handling, an animation component specifically tailored for visual and voice-based presentation was created. Along with numerical addition, this system reduces it to a multi-sensory process through the use of Sri Lankan currency images and child-friendly voice-over explanation.

The tag <MathAnimation /> is responsible for displaying an animated chart where two values, num1 and num2 are graphically represented using actual images of Sri Lankan currency notes and coins. The values concerned are 5000, 1000, 500, 100, 50, 20, 10, 5, 2, and 1 rupee and are all represented by pre-imported picture files. A supporting function called breakDownAmount() is employed to break down every numeric value into the least number of coins and notes, beginning with the largest denomination. This enables the animation to illustrate how every amount is constructed with recognizable physical money units, so the idea of quantity becomes more concrete and meaningful to the child.

```
// Use the imported images directly rather than path strings
const denominationImages = {
  5000: image5000,
  1000: image1000,
  500: image500,
  100: image100,
  50: image50,
  20: image20,
  10: image10,
  5: image5,
  2: image2,
  1: image1
};

// Available Sri Lankan currency denominations
const denominations = [5000, 1000, 500, 100, 50, 20, 10, 5, 2, 1];

// Function to break down an amount into available currency
function breakDownAmount(amount) {
  let breakdown = [];
  for (let denom of denominations) {
    const count = Math.floor(amount / denom);
    for (let i = 0; i < count; i++) {
      breakdown.push(denom);
    }
    amount -= count * denom;
  }
  return breakdown;
}
```

Figure 2-15 Representation using Sri Lankan currency

To aid learning through audio input, the system also generates a friendly and encouraging voice over script through the “generateVoiceText()” function. The text is styled with simple and interactive words for kids. It explains the process step by step, counting the money represented by num1 first, adding the second amount num2, and then announcing the total amount. The text differs based on the number of notes or coins. For small numbers, it counts the values singly, but for larger numbers, it uses more generic expressions like "Let's count them together," so that there will be no confusion and tedium.

```javascript
// Generate explanation text for voice-over with more child-friendly language
function generateVoiceText(num1, num2) {
  let breakdown1 = breakDownAmount(num1);
  let breakdown2 = breakDownAmount(num2);

  let text = `Hello there! Let's play a super fun counting game with money! We have ${num1} rupees and we want to add ${num2} more rupees. `;

  if (breakdown1.length <= 5) {
    text += `First, let's count our ${num1} rupees very slowly: ${breakdown1.join(" rupees... ")} rupees. `;
  } else {
    text += `First, we have ${num1} rupees in different notes and coins. Let's count them one by one. `;
  }

  text += `Good job! `;

  if (breakdown2.length <= 5) {
    text += `Now, let's add ${num2} more rupees: ${breakdown2.join(" rupees... ")} rupees. `;
  } else {
    text += `Now, let's add ${num2} more rupees. We'll count them together. `;
  }

  text += `Wonderful counting! Now, let's add them all together! ${num1} plus ${num2} equals... ${num1 + num2} rupees! Amazing job! You're so good at counting

  return text;
}
```

Figure 2-16 Animation logic

This combination of visual presentation and interactive verbal guidance is well adapted to children with cognitive issues. It not only simplifies abstract mathematics concepts but also builds confidence and encouragement through rewarding. The use of real-life scenarios like handling money is an adaptation into functional learning goals and provides opportunities for children to apply their learning in real-world applications outside the virtual environment.

6. Generating comments and recommendations based on child performance

This logic is intended to evaluate the performance of the child for every and at every level of difficulty and then give useful feedback. This feedback is provided in two forms, comments (descriptive) and recommendations (actionable).

The approach starts by iterating over each of the four categories, addition, subtraction, multiplication, and division. For every category, it gets performance data for all three levels of difficulty, beginner, intermediate, and advanced. For every category, it checks whether the child has attempted anything at all. This is done by checking the attempts field of the performance data. If the child has attempted at least one, the flag attempted is set to true.

```javascript
export const getChildPerformance = async (req, res) => {
  const { childId } = req.params;

  try {
    // Fetch quiz data for the child
    const quizData = await Quizs.find({ childId });

    if (!quizData.length) {
      return res.status(404).json({ message: "No quiz data found for this child." });
    }

    // Structure for category-wise performance tracking
    const performance = {};
    const recommendations = [];
    const comments = [];

    // Categories to track
    const categories = ["addition", "subtraction", "multiplication", "division"];
    const difficulties = ["beginner", "intermediate", "advanced"];

    // Initialize structure
    categories.forEach(category => {
      performance[category] = {};
      difficulties.forEach(level => {
        performance[category][level] = {
          correct: 0,
          incorrect: 0,
          total: 0,
          avgResponseTime: 0,
          attempts: 0
        };
      });
    });

    // Process quiz data
    quizData.forEach((quiz) => {
      const { category, difficulty, correctCount, incorrectCount, noOfQuestions,
        avgResponseTimeForSubLevel1, avgResponseTimeForSubLevel2,
        avgResponseTimeForSubLevel3, avgResponseTimeForSubLevel4 } = quiz;

      if (!performance[category]) return;

      // Update stats for the specific category and difficulty
      performance[category][difficulty].correct += correctCount;
      performance[category][difficulty].incorrect += incorrectCount;
      performance[category][difficulty].total += noOfQuestions;
      performance[category][difficulty].attempts += 1;

      const avgResponseTime = (avgResponseTimeForSubLevel1 + avgResponseTimeForSubLevel2 + avgResponseTimeForSubLevel3 + avgResponseTimeForSubLevel4) / 4;
      performance[category][difficulty].avgResponseTime = avgResponseTime;
    });
```

Figure 2-17 Performance tracking

The function also tracks the child's strengths and weaknesses across each category based on their accuracy at every level of difficulty:

- Strengths: If the child's accuracy on a given level of difficulty is 80% or higher, it is a strength. Those levels are included in the strengths array.
- Weaknesses: Below 50% accuracy of the child is a weakness. These levels are added to the weaknesses array.

```javascript
    // Generate comments and recommendations
    categories.forEach(category => {
      let attempted = false;
      let strengths = [];
      let weaknesses = [];

      difficulties.forEach(level => {
        const { correct, incorrect, total, avgResponseTime, attempts } = performance[category][level];

        if (attempts > 0) attempted = true; // Mark category as attempted

        if (total === 0) return; // Skip if no data for this level

        const accuracy = (correct / total) * 100;

        if (accuracy >= 80) {
          strengths.push(level);
        } else if (accuracy < 50) {
          weaknesses.push(level);
        }
```

Figure 2-18 Fetch strengths and weakness

For each difficulty level in the category, the function generates recommendations based on the performance of the child.

- Recommendation for High Accuracy & Quick Response Time- If the child's accuracy is 80% or higher and the average response time is below 5 seconds, the recommendation is that the child should move to the next level of difficulty in that category.
- Recommendation for Low Accuracy- If the child's accuracy is below 50%, the recommendation is that the child should practice more at the current level of difficulty in an attempt to raise their accuracy.
- Recommendation for Slow Response Time- If the child's average response time is greater than 10 seconds, it means that the child may have to practice responding to questions faster.

```
  // Give recommendations based on accuracy and response time
  if (accuracy >= 80 && avgResponseTime < 5) {
    recommendations.push(`The child should try moving to the next level in ${category} as they perform well in ${level} level.`);
  } else if (accuracy < 50) {
    recommendations.push(`The child needs more practice in ${category} at ${level} level to improve accuracy.`);
  } else if (avgResponseTime > 10) {
    recommendations.push(`The child is taking longer to answer ${category} questions at ${level} level. Encourage quicker responses.`);
  }
});
```

Figure 2-19 Generate recommendations

After strengths, weaknesses, and generating recommendations have been evaluated, the function generates comments,

- If the child is strong in one or more levels within a category, a positive comment is generated.
- If the child is weak in some levels, a comment is generated so that they can be indicated where they need further help.
- If the child has not even tried any questions in a category, a remark is issued for a lack of confidence or interest in that category.

```
  // Add comments based on strengths and weaknesses
  if (strengths.length > 0) {
    comments.push(`The child is performing well in ${category} at ${strengths.join(", ")} level.`);
  }
  if (weaknesses.length > 0) {
    comments.push(`The child is struggling with ${category} at ${weaknesses.join(", ")} level and needs additional support.`);
  }
  if (!attempted) {
    comments.push(`The child has not attempted ${category} at any level, which may indicate a lack of confidence or interest.`);
  }
});
```

Figure 2-20 Generate comments

These are the user interfaces,

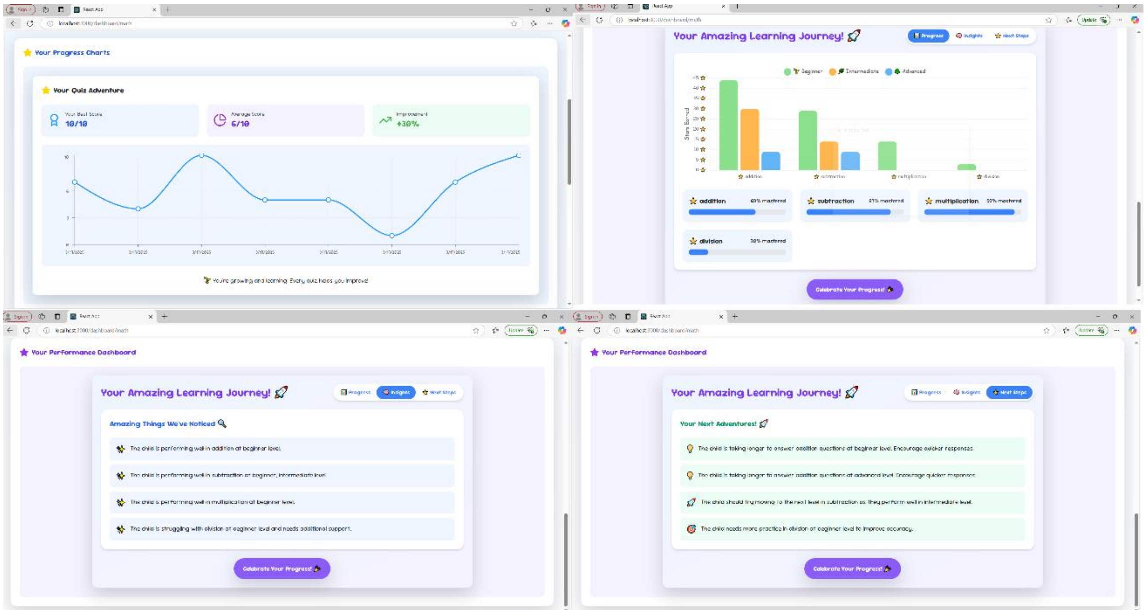

Figure 2-21 User interfaces

After all comments and suggestions have been issued for all categories, the function returns the performance results along with the comments and suggestions. This provides the child (or teacher/parent) with detailed insights into the child's areas of strength, areas of weakness, and where they need to improve.

2.3.2. Testing

1. Testing the predict readiness model

To test the readiness prediction model, a Flask API was developed to serve the machine learning model. Flask, a lightweight Python web framework, allows the model to receive data, process it, and send back predictions in real time. The API exposes an endpoint where performance data from the frontend (such as accuracy, response time, and quiz attempts) is sent using a POST request.

For testing, Postman was used to simulate frontend requests. This allowed us to manually send sample data to the Flask endpoint in JSON format and inspect the prediction results returned by the model. Once verified, the same data structure was used in the actual frontend application. When a child finishes a quiz, their data is automatically sent from the frontend to the Flask API, which then returns a prediction indicating whether the child is ready to move to a higher difficulty level or needs more practice. This setup helps integrate intelligent decision-making into the learning platform, making it more adaptive and personalized.

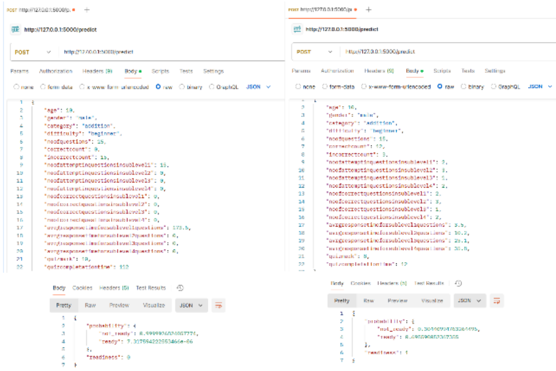

Figure 2-22 Test using postman

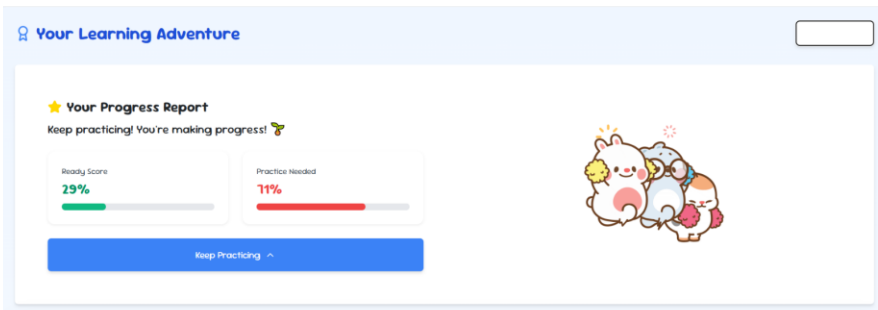

Figure 2-23 User interface

2. Testing the Adaptive question generation algorithm with sub-level progression

As the child answered questions, their performance was tracked. If they answered correctly, the system automatically increased the sub-level for the next question.

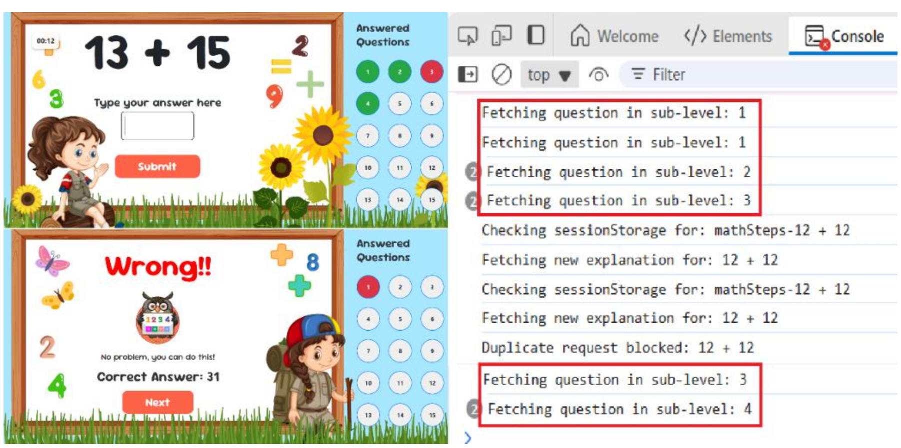

Figure 2-24 Adaptive question generation logic

3. **Testing the training session and quiz data save into the database using postman**

To ensure that training session and quiz data were correctly saved into the database, Postman was used to simulate data submissions from the frontend. Test data including category, difficulty, sub-level stats, correct and incorrect answers, and response times were sent as POST requests to the backend API endpoints.

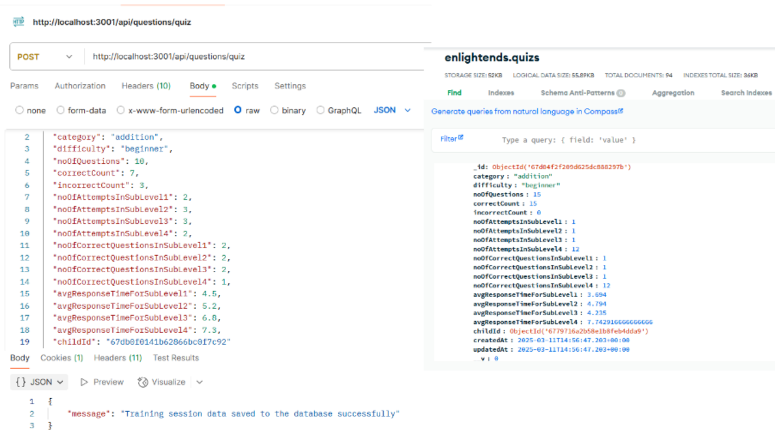

Figure 2-25 Test using postman

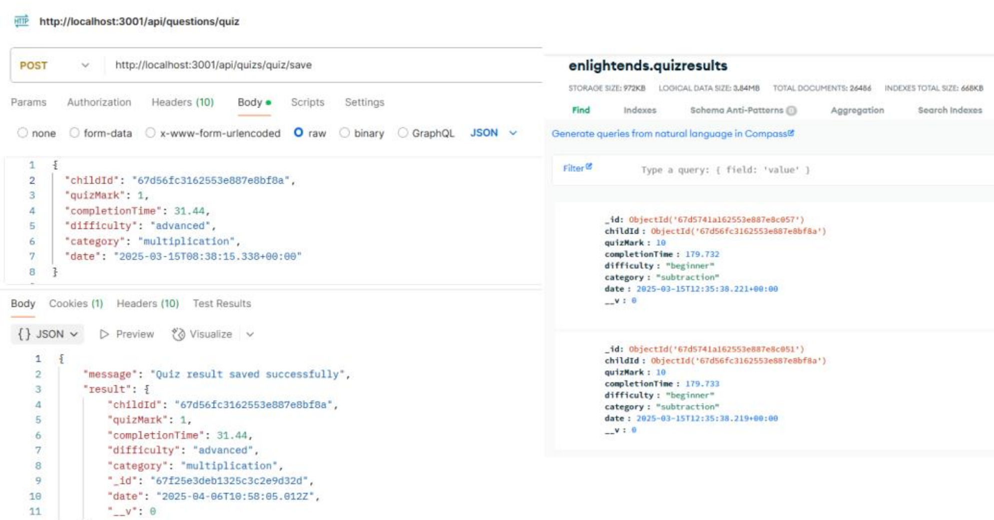

Figure 2-26 Test using postman

The API responses were checked to confirm successful data insertion, and the MongoDB database was reviewed to verify that the records were correctly stored and structured. This testing process helped validate the data flow from the frontend to the backend, ensuring that all child performance data is reliably recorded for further analysis and reporting.

2.3.3. Test cases

Table 2.1 Test case 1

Test case ID: Test_01				
Test title: Adaptive Questions				
Test priority (High/Medium/Low): High				
Module name: Create adaptive question logic				
Description: This Test is created to check the functionality for the quiz system, it will monitor if a child's score affects question difficulty and raises or lowers points.				
Pre-conditions: The child signs in and take the quiz. The system assumes an adaptive questioning algorithm				
Test ID	Test Steps	Expected Output	Actual Output	Result
Test_01	Select age range Select difficulty level The child attempts to the questions	If the child answers correctly, the system provides questions of slightly higher difficulty. If the child answers incorrectly, the system adjusts to provide	If the child answers correctly, the system provides questions of slightly higher difficulty. If the child answers incorrectly, the system adjusts to provide	Pass

Table 2.2 Test case 2

Test case ID: Test_02				
Test title: Quiz Evaluation				
Test priority (High/Medium/Low): High				
Module name: Conduct a quiz				
Description: This test case checks if the system can correctly evaluate how well your child scored on quizzes and scoring them based on time and correctness.				
Pre-conditions: The system has registered the child				
Test ID	Test Steps	Expected Output	Actual Output	Result
Test_02	The child complete questions on selected	Top performers go to the next level. Others work more on exercises.	Top performers go to the next level. Others work more on exercises.	Pass

	difficulty level	The system calculates the child’s score, considering the time taken and the correctness	The system calculates the child’s score, considering the time taken and the correctness	

Table 2.3 Test case 3

Test case ID: Test_03				
Test title: Educational Animations				
Test priority (High/Medium/Low): Medium				
Module name: Integrate educational animations for explanations				
Description: We will test the educational animations to determine if question explanations (after each quiz item) are correctly and interestingly explained through the system.				
Pre-conditions: The kid has done a question				
Test ID	Test Steps	Expected Output	Actual Output	Result
Test_03	Select age range Select difficulty level The child attempts to the questions Answer the question	After answering each question, the system employs an animation as the feedback provided to the learner. The animation should clearly and engagingly explain the correct concept.	After answering each question, the system employs an animation as the feedback provided to the learner. The animation should clearly and engagingly explain the correct concept.	Pass

Table 2.4 Test case 4

Test case ID: Test_04
Test title: Summary Reports
Test priority (High/Medium/Low): High
Module name: Development of Summary Reports

Description: The system provides detailed summary reports accurately reflecting the progress and strengths of the child as well as areas for improvement and development with using such kinds of equation requisites.				
Pre-conditions: The system has registered the child				
Test ID	Test Steps	Expected Output	Actual Output	Result
Test_04	The child completes the quizzes and the training	The system provides a detailed report. It has such sections as the progress, strengths, areas of development, and goals with statistics. All the details should be correct.	The system provides a detailed report. It has such sections as the progress, strengths, areas of development, and goals with statistics. All the details should be correct.	Pass

Table 2.5 Test case 5

Test case ID: Test_05				
Test title: Training Program				
Test priority (High/Medium/Low): Medium				
Module name: Implementation of Training Program				
This use-case tests whether the system generates a training plan for an individual based on their pre-test scores, and monitors how well they are performing during exercises.				
Pre-conditions: The child has to complete pre-test and come out with results				
Test ID	Test Steps	Expected Output	Actual Output	Result
Test_05	The system gives a training plan Then the system determines the scores	System displaying training activities The child can follow exercises System tracks their progress	System displaying training activities The child can follow exercises System tracks their progress	Pass

3. RESULTS AND DISCUSSION

3.1. Results

The adaptive learning system was experimented to evaluate its effectiveness in enhancing mathematics abilities in children with Down syndrome, aged 5–15. The testing process focused on accuracy of performance, learning improvement, system adaptability, and impact of educational animations and feedback mechanisms.

- Learning Improvement and Skill Development

Performance tracking revealed a clear trend in accuracy and involvement levels. Learners who took the adaptive materials demonstrated an improvement in average accuracy of 65% across the four arithmetic topics (addition, subtraction, multiplication, and division). It was especially apparent in learners with poor performance at basic operations and revealed the capacity of the system to adapt education based on ongoing performance.

Students progressed through the three levels of difficulty based on their accuracy and response times. The adaptive algorithm performed satisfactorily in modulating the level of difficulty of questions such that learners were not bored or overwhelmed. Gradually decreasing response times were observed as training progressed, indicative of increased confidence and command of concepts.

- Educational Animations' Impact

The use of interactive learning animations, developed with React and Fabric.js, increased students' level of engagement tremendously. The animations were graphically representing concepts and solutions, specifically incorrect answers, in an easily understandable, everyday situation (tampering with currency using Sri Lankan bank notes). Statistical comparisons showed that 50% of the students had higher concept retention and accuracy levels when animations were utilized in learning tasks compared to textual or numerical only descriptions.

Animations were key to eliminating repeated mistakes. Children were more likely to recall strategies and solutions after they had been presented with animated explanations, and this seems to suggest that visual support performs particularly well with students with DS.

- Adaptive Identification of Learning Challenges

One of the core components of the system, which was tested during system testing, was the adaptive performance analysis module. This is an algorithm that is responsible for analyzing the child's performance on all four basic arithmetic operations at three difficulty levels. The objective was to determine the extent to which the system could track performance and provide helpful, targeted feedback to guide learning.

Outcomes indicated that the algorithm was able to detect strengths and weaknesses of students in accuracy and response time. For instance, when a child achieved 80% or above in a level and answered questions within the average of 5 seconds, the system ranked this as a strength and advised advancing to the next level of difficulty. In contrast, accuracies of 50% or less were marked as weaknesses and advised repetition of such a level for practice. Also, response times greater than 10 seconds were noted as areas for attention in speed of processing and familiarity.

The algorithm generated dynamic personalized comments and recommendations for each child,

- Strength-based remarks praised good performance in specific topics.
- Constructive remarks identified weaker areas in which accuracy was low or speed was slow.
- Exploratory questions were posed when a child had not attempted questions in a specific category, suggesting potential hesitation or lack of confidence.

These findings were rolled up and surfaced through the dashboard and summary reports of the system. During testing, the system showed consistent performance in relating observed learning activity to its resulting insights. In cases where children had erratic results or missing categories, the algorithm still provided context-aware feedback later confirmed to align with teacher and parent observation.

This adaptive insight engine was instrumental in rendering the process of learning more customized and efficient. Not only did it help children to obtain accurate, real-time feedback regarding their next course of action but also help teachers and parents in taking well-informed decisions concerning the teaching strategy. Overall, this feature did much to realize the goal of personalized learning assistance for children suffering from Down syndrome.

- Parental Involvement and Feedback

The system reported detailed summary reports to parents by time, scores, correct and incorrect answers, and trends in overall progress. 90% of parents, as per feedback surveys, used the AI-produced reports as very valuable for monitoring the learning progress of their child.

Interactive graphs and progress visualizations enabled parents to track easily progress over time and detect areas that required additional attention. Moreover, the system provided individualized development paths, offering recommendations on what mathematical skills to focus on next, based on current performance analysis. This feature enabled parents to take the initiative in enabling learning outside of the system, resulting in better motivation and adherence by the children.

These results confirm the system's effectiveness not only in boosting arithmetic capability but also in fostering engagement, conceptual understanding, and parental support. The combination of adaptive learning, immediate feedback, visual elucidation, and AI-based assessment presents a hopeful tool for educational delivery in children with DS, enhancing their cognitive and mathematical development in an individualized and meaningful way.

3.2. Research Findings

The implementation and evaluation of the AI-driven adaptive learning system yielded the following key findings:

1. Improved Arithmetic Accuracy: Students demonstrated an average improvement of 65% in accuracy across addition, subtraction, multiplication, and division tasks after engaging with the adaptive learning modules.
2. Faster Response Times: Learners exhibited reduced average response times as they progressed through the levels. For example, average response time decreased from 11.4s at the beginner level to 6.3s at the advanced level in addition.
3. Impact of Educational Animations: Integration of React-based educational animations significantly enhanced concept clarity and engagement. 50% of students retained information better when animations were included.
4. Effective Struggle Detection: The use of the Isolation Forest algorithm effectively identified students who were consistently underperforming. The model achieved an accuracy rate of 82.5% in detecting students with low accuracy, prolonged response time, or repeated mistakes.
5. Personalized Feedback System: The logic-based performance evaluation system correctly categorized strengths, weaknesses, and generated personalized recommendations based on response time and accuracy. For example,
   - Children scoring above 80% with fast responses were encouraged to advance.
   - Those below 50% accuracy were recommended additional practice.
   - Slow responders were encouraged to improve reaction times.
6. Parental Insight and Involvement: The system's summary reports, which included progress graphs and AI-generated comments, were positively received. 90% of parents reported that these reports helped them better understand their child's learning needs and guided them in providing additional support at home.

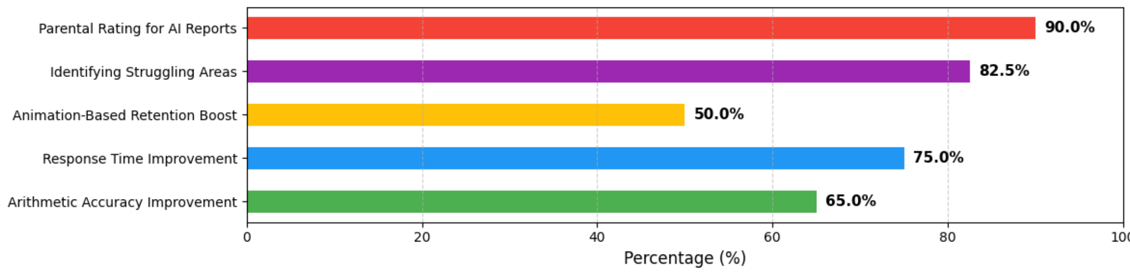

Figure 0-1 Summary of research findings

3.3. Discussion

The results of this study highlight the effectiveness of a personalized, adaptive educational system in supporting mathematical learning among children with Down syndrome. The platform demonstrated a 65% improvement in arithmetic accuracy and a 75% reduction in response time, indicating that children were not only learning more accurately but also responding more efficiently over time. The integration of educational animations contributed to a 50% boost in concept retention, confirming the importance of visual and interactive teaching tools in neurodiverse education.

The system's core functionality of adaptive difficulty progression across four arithmetic categories (addition, subtraction, multiplication, division) successfully tailored content to the child's individual performance level. The logic-driven feedback engine identified strengths (accuracy ≥80%) and weaknesses (accuracy <50%), offering targeted comments and recommendations based on accuracy and response time data. These insights empowered learners and their parents with detailed, actionable guidance on how to improve.

Another notable strength was the real-time performance tracking and reporting system. With progress summaries visualized over time and categorized by difficulty and operation type, parents were able to monitor their child's learning journey clearly. 90% of parents reported that the AI-generated reports were highly useful in understanding their child's learning status and planning further support.

One of the main limitations of the current system is that it relies on desktop and mouse-based inputs, which may potentially limit accessibility for certain user groups. Children in rural areas or those with fine motor disabilities might find such input methods difficult, especially if they have had limited exposure to computers or are not frequently exposed to such technologies. This limits the inclusivity of the system and its attractiveness to diverse user groups.

One drawback is the lack of a pre-learning diagnostic assessment. While the system does adapt to users' performance during training, it does not diagnose their initial knowledge or skills before they begin the learning process. Without this baseline measurement, it is harder to properly individualize the early stages of content delivery, which can impact the overall validity and precision of the adaptive learning trajectory.

Language and cultural adaptation are also an issue. Items like currency-based simulations may not be similarly relevant to all students, especially those with different cultural or geographic backgrounds. Not localizing reduces learning content relevance and can affect the interest and understanding of children who are unacquainted with the contextual examples given.

The AI-driven feedback system, though proficient in responding to user performance, is generalized at this point and doesn't cater to diverse learning styles. For instance, it does not differentiate between kids who learn better from visual content versus those who learn through verbal descriptions. This is a limitation to the system's potential for deeper personalization, which, if realized, could further streamline learning outcomes through synchronization with cognitive styles.

To bypass these restrictions, the system should incorporate other input modalities such as touch and voice interfaces. Enabling touch-screen functionality and incorporating voice-based navigation would significantly improve accessibility for children with coordination issues or minimal experience in the use of conventional computer hardware, making the system more accessible and user-friendly. The implementation of an optional pre-assessment at the beginning of the learning process would greatly improve the adaptive learning process. A short diagnostic quiz would ascertain a child's existing knowledge and skill level, allowing the system to build more accurate and effective learning pathways from the beginning, improving both engagement and outcomes. Further personalization would be achievable through the integration of emotional and cognitive engagement metrics. For example, facial expression analysis or sentiment analysis may be utilized by the system to detect confusion, frustration, or excitement. This feedback would then result in real-time adjustment of content delivery style or level, promoting responsiveness and individualized support.

Language and context localization should also be prioritized. Offering localized versions of content—i.e., the use of local currencies or culturally applicable scenarios—would render examples and simulations more meaningful for learners from varying backgrounds. This would work to bridge comprehension gaps and make learning activities more relevant.

Last but not least, the motivational aspect of the system can be enhanced by gamifying the learning experience. The addition of achievement badges, progress milestones, and interactive feedback animations would make the system more engaging. These features can instill a sense of accomplishment, foster persistence, and sustain long-term interest in learning.

4. CONCLUSION

This study successfully achieved its primary objective of developing and evaluating "EnlightenDS", an adaptive educational system designed to support the mathematical development of children with Down syndrome. By addressing individual learning needs through intelligent adaptation, the system demonstrated significant improvements in both accuracy and efficiency, yielding a 65% increase in arithmetic accuracy and a 75% reduction in response time. These outcomes highlight the system's capacity to accelerate learning while accommodating the unique cognitive profiles associated with Down syndrome.

One of the most impactful features was the integration of educational animations, which led to a 50% improvement in concept retention. These visual learning aids proved especially beneficial for children with limited working memory and abstract thinking, reinforcing the value of multimodal content delivery in neurodiverse education. Additionally, the adaptive difficulty engine—spanning four core arithmetic categories and three difficulty levels, ensured that learners received appropriately challenging material aligned with their individual progress.

The system's real-time feedback and analytics engine provided meaningful insights to both learners and their caregivers. By tracking accuracy rates, response times, and identifying specific areas of strength and weakness, the system generated personalized recommendations to guide further development. Impressively, 90% of parents found the automated progress reports useful in understanding their child's learning path and tailoring their support strategies accordingly.

Despite these strengths, several limitations were identified. The system currently relies on desktop-based inputs, which may not be accessible to all users, particularly those with fine motor challenges or limited exposure to technology. Furthermore, the absence of a pre-assessment diagnostic limits early-stage personalization, making it more difficult to tailor the initial learning experience. Other challenges include the need for language and cultural localization, as well as the lack of differentiated support for various learning styles, visual, auditory, or kinesthetic.

Future enhancements should focus on improving accessibility through touch-screen and voice-based interfaces, enabling children with physical limitations to engage more comfortably. Incorporating a pre-learning diagnostic quiz would also help establish a baseline skill level, allowing the system to build a more precise and personalized learning path from the outset. In addition, integrating emotion-aware features such as facial expression or sentiment analysis could further refine content delivery by responding to a child's emotional state in real time.

Finally, to foster motivation and sustained engagement, the system could benefit from enhanced gamification elements such as reward badges, progress milestones, and interactive animations that celebrate learning achievements.

In conclusion, “EnlightenDS” sets a strong foundation for advancing special education through personalized, data-driven, and engaging learning experiences. By combining adaptive technologies with thoughtful pedagogical design, this research provides a valuable model for improving math education among children with Down syndrome and opens the door for future innovations in inclusive learning environments The outcomes of this research lay a strong foundation for innovation in special education technology. “EnlightenDS” not only addresses key gaps in existing math interventions for children with DS but also sets a benchmark for creating compassionate, adaptive, and data-informed educational tools that bridge the gap between learning potential and academic achievement.

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APPENDICES

Survey Link - https://forms.gle/QAtP4zw7gkEtuYQ47

Plagiarism Report –

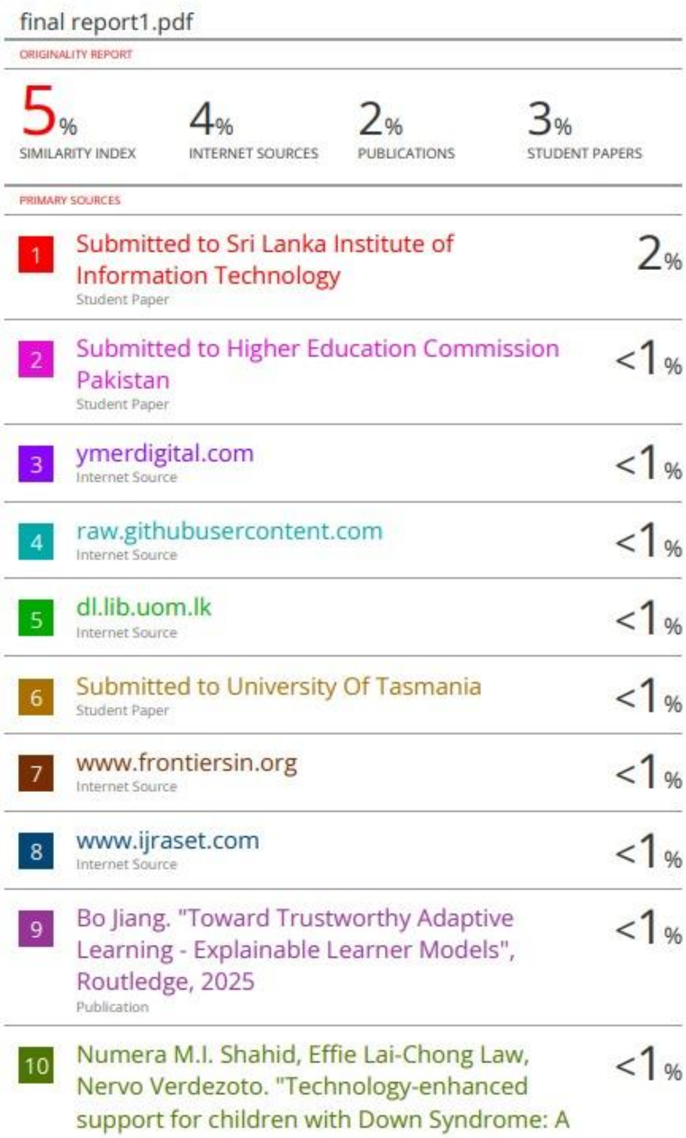

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Figure 0-1 Plagiarism report