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Predictive Analytics and Insights for Personalizing Special Education of Students with Dyscalculia

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Abstract - *Learning disability encompasses the unique challenges faced by a student to acquire process and demonstrate any knowledge or skill. Identification of learning disability students helps the educators to create an inclusive environment enabling the students to reach their full potential. The paper delves deep into the machine learning based personalized learning pathways, prediction of student performances, intervention with assistive technologies, math related educational tools and games along with behavior analysis using machine learning. Classification algorithms of machine learning analyses and learns patterns from the dataset. This study analyses the statistics of all the features of the dataset and creates models with different classification algorithms like Logistic Regression, Decision Tree, Random Forest, K-nearest neighbor, Support Vector Machine and XG Boost for predicting quarterly goal for these students. Finally the results are compared by creating the confusion matrix and computing the accuracy, precision, recall and F1 score to predict the optimum models for the purpose.*

Key Words: **Dyscalculia, Learning Disability, Logistic Regression, Decision Tree, Random Forest, K-nearest neighbour, Support Vector Machine, XG Boost, Accuracy, Precision, Recall, F1 Score.**

1. INTRODUCTION

Learning disability, a neurological disorder can range from specific academic areas to broader cognitive functions. Specific learning disability affecting a student's ability related to understanding, learning and performing math related task is called dyscalculia. Dyscalculia affects academic performance as students struggle with number sense, basic arithmetic, and mathematical reasoning. Students with dyscalculia experience difficulties with number identification, patterns, geometrical shapes and basic mathematical operations. Machine Learning has proved to be a powerful tool used for the detection and diagnosis of Dyscalculia. Classification algorithm in machine learning plays a vital role in categorizing data into a number of predefined labels and thus helps in automatic decision making by analysing large datasets and improving accuracy. This paper discusses the comparison of a few classification algorithms for predicting quarterly goals for students suffering from dyscalculia by analysing the different features related to dyscalculia.

2. LITERATURE REVIEW

2.1 Early Detection and Diagnosis

Several studies have been proposed to study data from various cognitive tests by machine learning and identifying the students with dyscalculia with great accuracy. [1] A study suggests that adaptive tests can be implemented to adjust the difficulty based on the individual's response and machine learning algorithms can be used to identify patterns in large datasets for identifying dyscalculia. [2] Another research highlights the need of machine learning to enhance the learning experience by applying adaptive algorithms to detect dyscalculia. It also summarizes the various AI advancements especially in the field of screening and intervention tools to provide tailored interventions. [3] Application of Convolutional Neural Networks (CNNs) to model the factors associated with dyscalculia y simulating impaired neural connections through dropout is suggested in another research. [4] Various algorithms like Support Vector Machines (SVM), Simple Logistic Regression, Naive Bayes, and Random Forest are explored to identify dyscalculia so that the challenges in its diagnosis can be addressed. [5] Further research has been done in exploring the abilities of complex algorithms for the detection of dyscalculia by analyzing medical data. [6] Substantial work has been done for the development of a system to enhance the detection of Dyscalculia through machine learning and hence reducing the efforts required behind the traditional detection process. [7] Another study shows proposes a knowledge-based analytical tool utilizing a machine learning decision tree algorithm to identify mathematical difficulties associated with dyscalculia in students. [8] Machine learning can also be applied to create adaptive assessment tools for promotion of inclusive educational environment. [9]

2.2 Personalized Learning

Research shows machine learning-based personalized learning path decision-making method that can be adapted for children with Dyscalculia. By analysing learners' behavioural data and mastery of knowledge points, the

method predicts the difficulty of mathematical concepts tailored to individual needs. This approach allows for dynamic adjustments in learning path recommendations, providing refined support that enhances learning experiences and outcomes for children with Dyscalculia, ultimately addressing their unique challenges in mastering mathematical skills. [10] Another model the Dynamic Feedback-Driven Learning Optimization Framework (DFDLOF) suggests personalizing educational pathways by analysing student's data using machine learning. Real-time feedback for analysing learning pathways is a special feature of this framework. [11] "Ganitha Piyasa", an innovative machine learning application uses a Random Forest Classifier to predict a child's improvement leading to the creation of personalized learning pathways. [12] Similar studies suggest supervised machine learning techniques helps in analysing a learner's performance and preferences and customizing resources and learning paths. This methodology not only addresses specific challenges faced by students with Dyscalculia but also emphasizes the significance of data security, algorithmic fairness, and transparency for formulating personalized learning solutions. [13]

2.3 Predicting Student Performance

Machine learning can help in predicting student performance by understanding the patterns of their historical data. Applying the same procedure on children affected with dyscalculia would help to address their challenges and needs. This may lead to improve their academic outcomes. [14] Random Forest and K-Nearest Neighbour models can predict grades with high accuracy based on past academic achievements and core subject scores. Same model can be deployed for learners with dyscalculia in near future. [15]

2.4 Assistive Technologies

The paper does not specifically address machine learning applications in assistive technologies for children with dyscalculia. It focuses on PosiCalculia, an adaptive virtual environment that personalizes learning experiences through assessment tools and adaptive serious games to improve mathematical skills. [16] The paper does not specifically address the use of machine learning in assistive technologies for children with dyscalculia. It focuses on the effectiveness of the Mathlete tool in improving early numeracy skills through traditional and adaptive learning methods. [17]

2.5 Educational Tools and Games

Research proves that gamified learning materials formulated to teach basic numeracy skills to 4-6-year-old children with dyscalculia through visualization helps in improving their grades considerably.[18] Machine learning can also validate neural shifts by analysing neurocognitive signatures as evident in another study. [19] Educational tools like Exer games for children deploys machine learning to create personalized learning paths. [20]

2.6 Behavior Analysis

Both detection and intervention strategies for behaviour analysis of children with dyscalculia can be done using Machine learning. Identification of patterns in learning behaviours and cognitive responses can help in designing tailored educational resources for these students. Decision tree algorithm has proved to be successful in early diagnosis and intervention of dyscalculia. [21] Another study explores an Intelligent System utilizing data from the dis MAT app to identify children affected with dyscalculia. Logic Programming and Case-Based problem solving techniques help in enabling effective behaviour analysis in this scenario. [22]

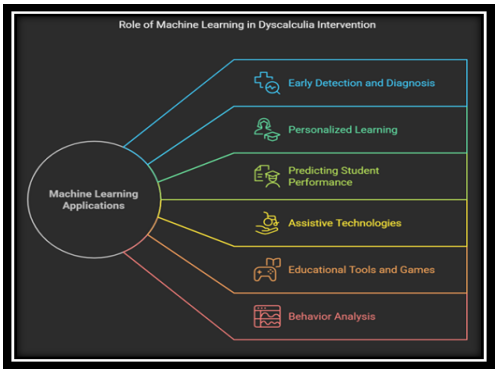

Fig -1: Role of Machine Learning in Dyscalculia Intervention

3. GAP ANALYSIS

Substantial work has been done in the field of dyscalculia with machine learning mostly for early diagnosis and screening of dyscalculia, creating personalized games, assistive technologies and apps for children with dyscalculia, behavior analysis and prediction of student performance. There is a gap in research related to creation of classification model for goal prediction of students with dyscalculia. Further studies can prove to be beneficial in this direction.

4. RESEARCH OBJECTIVES

a) To create a classification model that predicts quarterly learning goals for students with dyscalculia based on their current mathematical abilities.
b) To identify key features influencing goal achievement in dyscalculic students, such as number identification, arithmetic reasoning, and spatial understanding.
c) To compare the effectiveness of different classification algorithms in accurately predicting student goals.

d) To evaluate the proposed model using standard classification metrics (e.g., accuracy, F1-score, precision, recall) and suggest an optimal model for the same.

5. EXPERIMENTAL WORK

5.1 Dataset

This study uses self-generated dataset acquired from school containing 100 samples of students suffering from dyscalculia of the age group 5 to 7 years with eight features as shown in Table 1. The dataset containing 100 records has no missing values. The dataset consist of 7 features and 4 categories of labeled goals.

Table -1: Features used and their description

Name of the Feature	Description
noid	Number Identification (0=no, 1=yes)
Rtlt	Right Left Organisation (0=no, 1=yes)
symid	Symbol Identification (0=no, 1=yes)
plcv	Place Value Identification (0=no, 1=yes)
Co	Carry Over in Addition (0=no, 1=yes)
Br	Borrow in Subtraction (0=no, 1=yes)
Rea	Arithmetic Reasoning (0=no, 1=yes)

5.2 Methodology

All the key features related to goal prediction are collected from the students and their goals are assigned with the help of special educators. The four goals A,B,C and D are number recognition and count, identifying shapes, patterns and basic mathematical operations respectively. Statistical analysis and visualization of data with charts and graphs resulted in uncovering the dependencies of goal prediction on different features. Finally classification models are trained with the data using various algorithms like Logistic Regression, Random Forest, SVM, KNN, Decision Tree, XG Boost and their confusion matrix is drawn to compare the results using different classification metrics.

	noid	rtlt	symid	plcv	co	br	rea
count	100.000000	100.000000	100.000000	100.000000	100.000000	100.00000	100.000000
mean	0.820000	0.540000	0.640000	0.540000	0.240000	0.08000	0.460000
std	0.386123	0.500908	0.482418	0.500908	0.429235	0.27266	0.500908

Fig-2: Count, Mean and standard deviation of all the features.

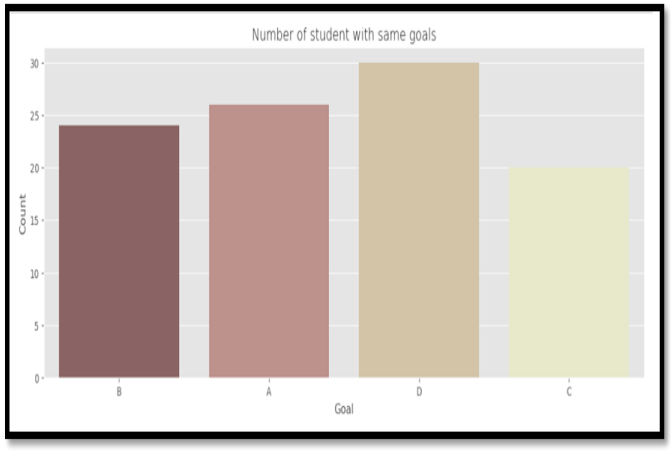

Fig-3: Number of students with same goal.

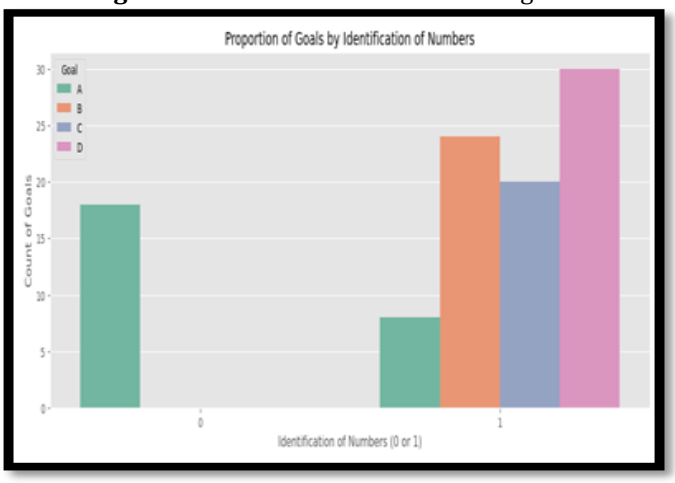

Fig-4: Proportion of Goals by Identification of numbers

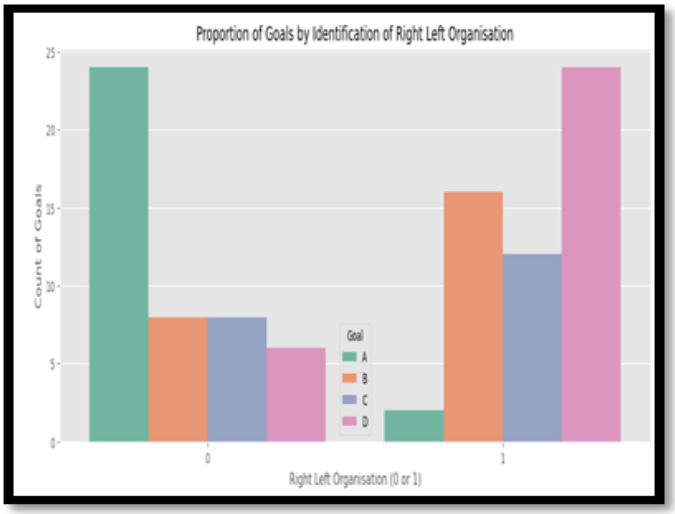

Fig-5: Proportion of Goals by Identification of Right Left Organization

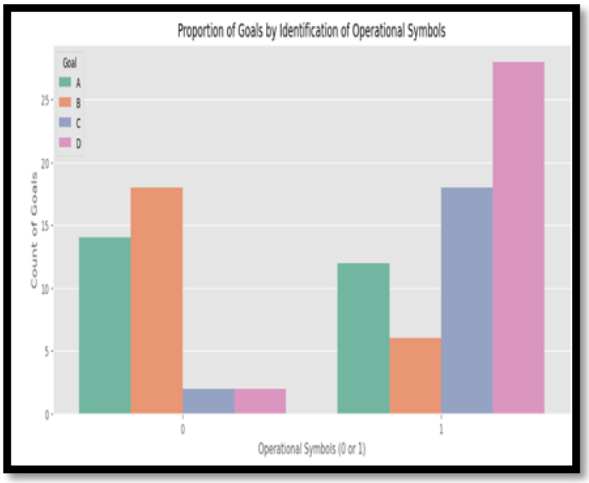

Fig-6: Proportion of Goals by Identification of Operational Symbols

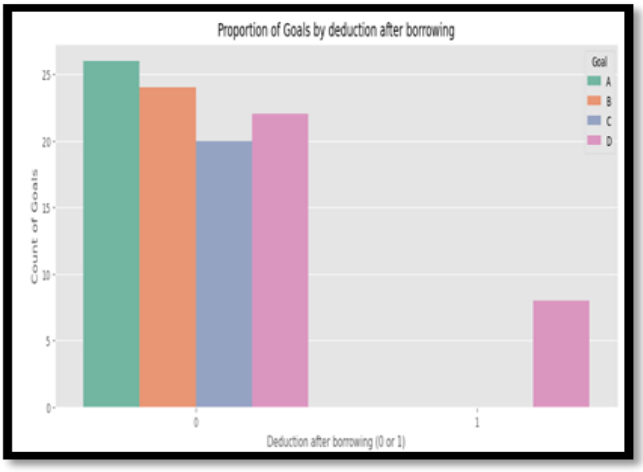

Fig-9: Proportion of Goals by Identification of Deduction after Borrowing

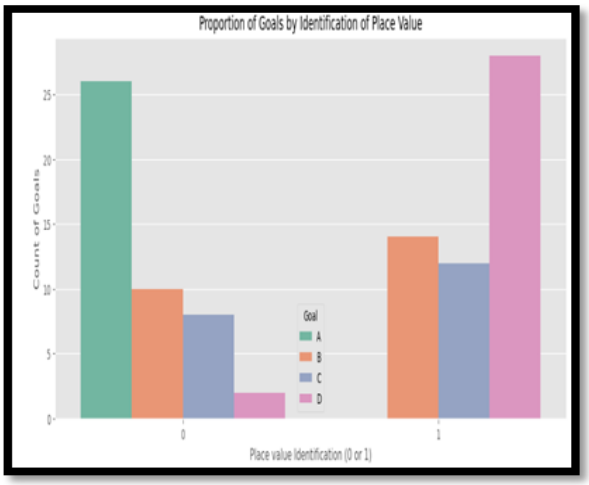

Fig-7: Proportion of Goals by Identification of Place Value

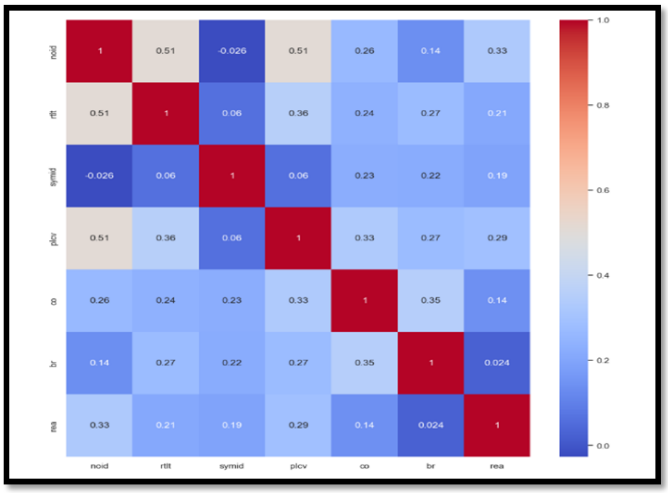

Fig-10: Heat Map

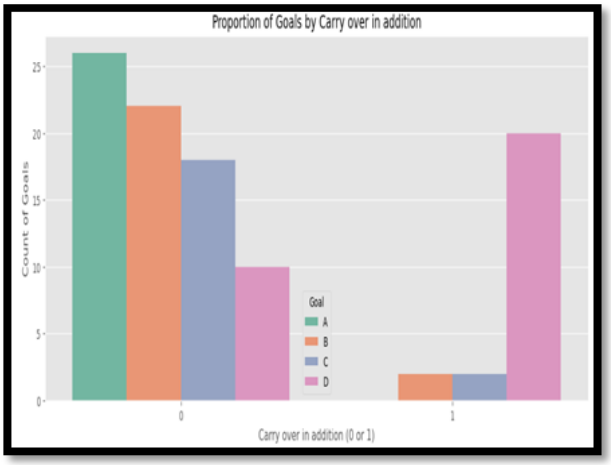

Fig-8: Proportion of Goals by Identification of Carry Over in Addition

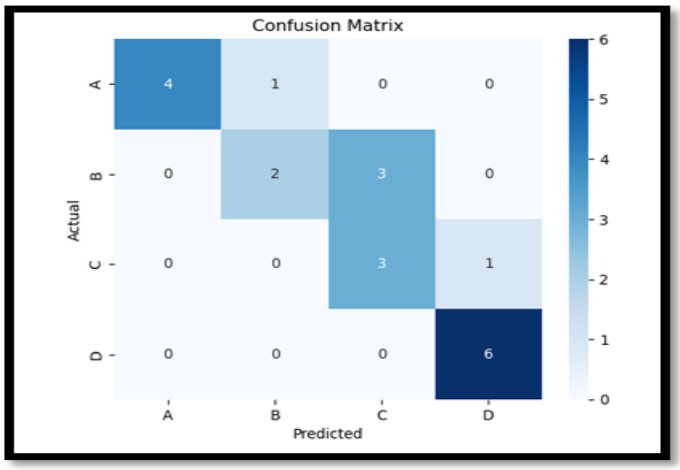

Fig-11: Confusion Matrix for Logistic Regression

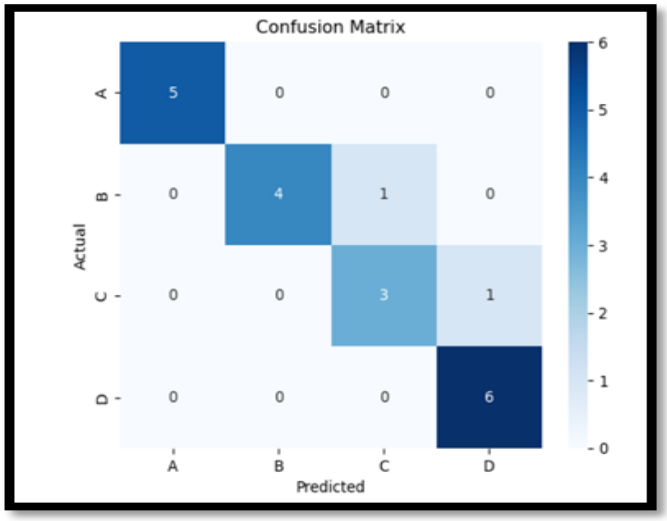

Fig-12: Confusion Matrix for Random Forest

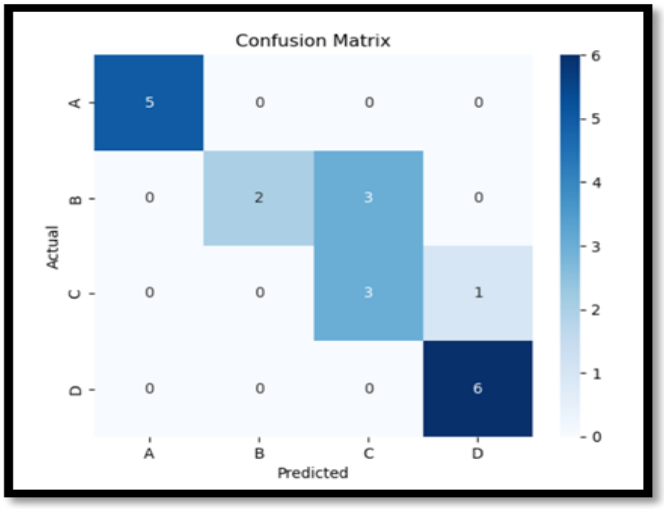

Fig-13: Confusion Matrix for SVM

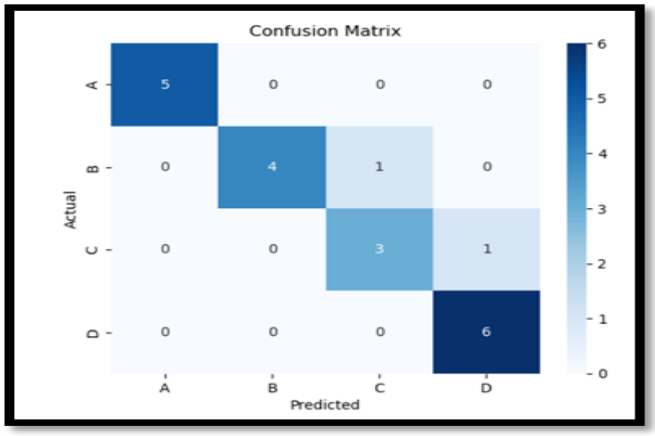

Fig-14: Confusion Matrix for KNN

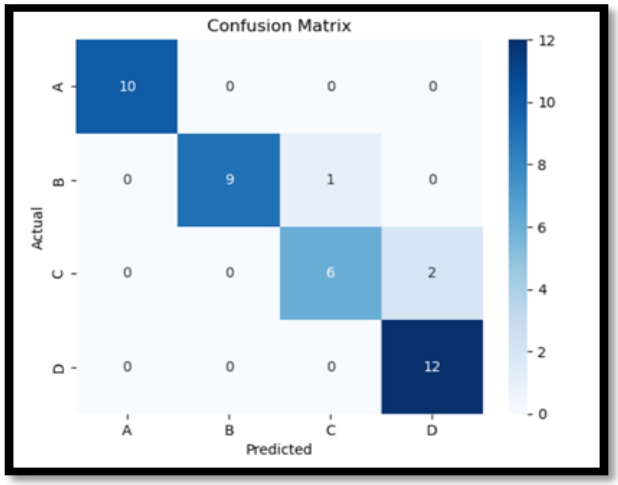

Fig-15: Confusion Matrix for Decision Tree

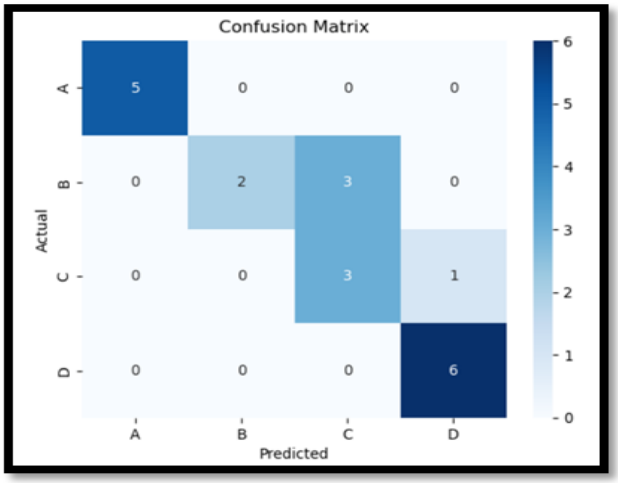

Fig-16: Confusion Matrix for XG Boost

Table -2: Value of Weighted Average of Classification Metrics for Machine Learning Algorithms

ALGORITHM	ACCURACY	PRECISION	RECALL	F1 SCORE
LOGISTIC REGRESSION	0.75	0.77	0.75	0.74
RANDOM FOREST	0.90	0.91	0.90	0.90
SVM	0.80	0.86	0.80	0.79
KNN	0.90	0.91	0.90	0.90
DECISION TREE	0.925	0.93	0.93	0.92
XGBOOST	0.80	0.86	0.80	0.79

5.3 Result

Count value is 100 for each sample indicates absence of missing value. According to the dataset on average, students correctly identify numbers 82% of the time whereas most of the students suffering from dyscalculia struggle with carryover in addition and borrowing in subtraction as evident in Fig 2. Fig 3 shows Goal D has the highest number of students, followed by Goal A, Goal B and finally Goal C signifying that the dataset is not perfectly balanced across goals and hence all classification metrics needs to be considered. Students who struggle with number identification are mostly assigned foundational Goal A and students who can identify numbers are more likely to be assigned advanced Goals B, C, and D as evident from Fig 4. For Fig 5 Goal A dominates among students who struggle with right-left organization, while Goals B, C, and D increase significantly for students who have mastered it. According to Fig 6 students who are unable to identify operational symbols are mostly assigned Goals A and B and students who can identify operational symbols are mostly assigned Goals C and D. Students who are able to identify place values are mostly assigned Goal D as evident in Fig 7. Fig 8 and Fig 9 suggests mastery of carry over and deduction after borrowing is highly associated with Goal D, indicating advanced mathematical skills and hence the students who can perform Carry Over in Addition or borrowing in subtraction are primarily assigned Goal D.

6. CONCLUSION

Data of weighted average of the classification metrics suggests that Decision Tree (0.925 accuracy, 0.93 precision, 0.93 recalls, 0.92 F1-score) performs the best on the dataset and is able to capture the pattern on our data very efficiently but might not give exact predictions for unseen data due to overfitting. Random Forest and KNN both perform very well (0.90 accuracy, 0.91 precision, 0.90 recall, 0.90 F1-score) and can be considered to a safer and robust option. Random Forest benefits from ensemble learning and thus reduces overfitting and improves generalization. KNN working well suggests that our dataset has clear class boundaries in feature space that is similar students tend to have similar quarterly goals. SVM and XG Boost both have 0.80 accuracy and similar precision, recall, and F1-score values and would also prove to be useful for classification purpose. Logistic Regression has the lowest accuracy (0.75) and F1-score (0.74) implying that the dataset is likely non-linearly separable, making simple linear models less effective in this case. XG Boost shows lower accuracy and might improve after hyper parameter tuning.

7. FUTURE SCOPE

Personalized teaching material, resources and learning pathways can be designed based on the predicted goals so that each student with dyscalculia can be upgraded to the next level. This model can also be generalized to different grade levels to identify dyscalculia patterns. Students with different goals can be provided with different game based learning modules for making the teaching learning materials more interactive and immersive. AI based tutors can also be implemented for adaptive learning pathways.

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BIOGRAPHIES

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