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COLLEXA: An AI-Powered College ERP System with Embedded Academic Risk Prediction

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Abstract: ***Everyworkingday,atypicalhigher-educationcam-pus produces thousands of structured records — session-level attendance, assessment grades, fee settlements, and course regis-trations—yetthesoftwareplatformsthatcollectthisdatararely exploit it to anticipate academic difficulty. This paper reportsthe design, construction, and empirical evaluation of COLLEXA (College Excellence), a web-native, intelligence-augmented En-terprise Resource Planning (ERP) framework that remedies this shortfall by weaving a machine-learning inference engine intothe heart of routine academic administration. The platform's three-tier implementation pairs a React 18 / Tailwind CSS client with a FastAPI 0.110 application server and a MySQL 8.0 persistent store, with all communication secured through JSON Web Token (JWT) authentication and fine-grained Role-Based AccessControl(RBAC).AnembeddedAcademicRiskPrediction componentbuildsaper-studentfeaturetriplet—attendancerate, meanassessment score, andcumulativeGradePointAverage and submits it to a trained Random Forest ensemble that assignseachlearnertooneofthreeriskcategories:Low,Medium, or High. Tested against a stratified hold-out partition of 240 records, the ensemble reached 88.3% accuracy and a macro-averaged F1-score of 0.88; five-fold cross-validation over the full corpusreturned a mean of 88.3% ±0.6%, attesting to consistent generalisation. Under a simulated workload of 200 simultaneous users, the prediction endpoint delivered a 95th-percentile latency of 340 ms — well inside the 2,000 ms operational target — with zero request failures. All six stated development objectives were satisfied, and the system cleared every security, integration, and user-acceptance verification scenario. COLLEXA demonstrates that embedding predictive intelligence into day-to-day ERP operations transforms the system from an after-the-fact ledger into a real-time support mechanism for at-risk students.***

Index Terms—College ERP, Academic Risk Prediction, Ran-dom Forest, Educational Data Mining, FastAPI, React, JWT Authentication, Role-Based Access Control, Machine Learning, SQLAlchemy, QR Code Attendance, Student Performance Ana-lytics

I. INTRODUCTION

A college enrolling three thousand students accumulates tens of thousands of individual data records within a single semester:session-by-sessionattendanceacrosseverysubject, component and final examination marks, fee payments and arrear notices, timetable allocations, and enrolment confirma-tions. When those streams are managed through disconnected tools or maintained by hand, the administrative overhead is heavy and — more critically — the institution loses its best opportunity to detect student deterioration before it becomes irreversible [3,4].

Enterprise Resource Planning (ERP) technology was con-ceived to address exactly this kind of fragmentation in com-mercialorganisations, replacing loosely coupled departmental tools with a single, transaction-consistent platform. Colleges and universities adopted the same design philosophy, deploy-ingERPsolutionsthatbroughtadmissions,timetabling,exam-ination management, and fee collection under one roof [1,2]. The persistent blind spot, however, is predictive capability: conventional College ERP platforms faithfully archive what has already taken place, yet they provide no mechanism for signalling what is likely to happen next [5].

That gap carries a measurable academic cost. Studentfailure seldom arrives without warning; it builds through an accumulating sequence of observable signals — shrinking attendance rates, declining test scores, and softening grade-point averages — that unfold over several weeks before any formal consequence is recorded [6,7]. A purely reactive ERP stays blind to these signals until semester results are finalised, by which point the window for meaningful early support has often closed.

COLLEXA was conceived to fill precisely that gap. The name fuses the words *College* and *Excellence*, capturing the project'sgoverningaim:togiveeveryauthorisedstakeholder student,facultymember,oradministrator—acontinuously updated view of academic risk that requires no manual data export or separate analytics tool. The primary contributions of this paper are:

1) A fully operational, multi-role College ERP covering student records, faculty course management, system ad-ministration, and financial transaction tracking, delivered as a single integrated web application.

2) An AI-driven Academic Risk Prediction component that applies a Random Forest ensemble to live ERP data, trained on attendance, assessment, and GPA features [8,9].
3) A coupling mechanism that connects the prediction en-gine to the ERP's operational database so risk labels are refreshed in real time and surfaced alongside ordinary academic views with no extra steps for the end user.
4) Four role-differentiated dashboards that translate raw stored records into colour-coded risk summaries, atten-dance charts, and assessment trend lines.
5) A fully documented RESTful API compliant with Ope-nAPI 3.0, enabling third-party integration, automated reportingpipelines,andfuturemobileclientdevelopment.
6) PervasiveaccesscontrolenforcedthroughJWT-basedau-thenticationandaRoleCheckerdependency,ensuring each user can read and write exactly the data their role permits.

The remainder of this paper is structured as follows: Sec-tion II surveys prior work; Section III describes the system architecture and design decisions; Section IV specifies the experimental conditions; Section V presents and interprets the results; and Section VI states conclusions and planned future directions.

II. LITERATURE REVIEW

Davenport [1] laid the intellectual groundwork for ERP adoption by arguing that the competitive value of integrated enterprise software derives not from any individual modulebut from the organisation-wide coherence that arises when previouslysiloedrepositoriesshareasingletransactionalback-bone. COLLEXA inherits this principle by placing attendance tracking, assessment recording, financial management, and AI inference on one unified platform rather than linking them through fragile inter-system calls.

Pollock and Cornford [2] observed, through a multi-site study of British universities, that ERP deployments consis-tently delivered administrative savings yet fell short of aca-demic impact because the software had no analytical layerthat could inform teaching or early support decisions. That observation remains broadly accurate and defines the exact shortfall that COLLEXA's embedded prediction module is built to address.

Nazim and Mukherjee [3] surveyed fifty Indian universities andfoundthatanalyticalcapabilitywaspresentinfewer than twelve percent of deployed ERP platforms. Beyond establishingthescarcityoftheapproach,thatfigurereinforces the relevance of embedding real-time risk analytics into an ERP designed for the Indian higher-education setting.

Romero and Ventura [4] reviewed more than three hundred educational data mining studies and identified classification-based performance prediction as the field's most active re-search thread, with decision trees and neural networks appear-ing most frequently. Their taxonomy provides the empirical baseline against which Section V results are contextualised.

Yadav et al. [5] benchmarked Naive Bayes, ID3, and backpropagation networks on engineering-college records and reported that accuracy plateaued quickly when features were restricted to prior grade data. Their work highlighted thevalue of incorporating real-time behavioural signals such as attendance — a design choice built directly into COLLEXA's feature vector.

Amrieh, Hamtini, and Aljarah[6] showed that augmenting standardacademicfeatureswithengagement-relatedindicators androutingthemthroughensemblemethodsconsistentlylifted predictive accuracy above any single-classifier baseline. Their reported Random Forest accuracy of 79.0% on a comparable task offered a concrete reference point when selecting the algorithm for this work.

Daud et al. [7] used information-gain analysis to rank predictors across multiple student datasets and found that attendance-derived variables yield the highest discriminative powerrelativetoacademicrisktargets.Thatfindingmotivated placingattendance_pctastheleadingelementinCOLLEXA's feature triplet.

Breiman[8] introduced the Random Forest algorithm, proving that decorrelated ensembles built through bootstrap aggregation and random feature subsampling achieve lower generalisation error than any constituent tree while remaining interpretable through feature-importance scores. Those prop-erties — robustness, low variance, and transparency — were the decisive factors in algorithm selection for this task.

Ramirez [9] released FastAPI, an ASGI-based Python framework built on Starlette's async routing and Pydantic's type-validated request parsing. The framework generates in-teractiveOpenAPI documentation automatically and delivers throughputcompetitivewithproduction-gradeNode.jsservers, fitting the ERP backend's requirements precisely. Jones, Bradley,andSakimura[10]formalisedtheJWTstandard in RFC 7519; Bayer [11] supplied the SQLAlchemy ORM governing all database interactions; Wathan [12] authored the Tailwind CSS utility system underlying the client-side visual design.

The surveyed literature shows clearly that ERP researchand educational machine learning have developed largely in parallel,withtheirintegrationremainingtheexception.Studies inthepredictionliteraturetypicallyoperateofflineonarchived data and cannot inject outputs back into a live operational system. COLLEXA directly bridges that gap [13,14].

III. MATERIALS AND METHODS

A. System Architecture

COLLEXA is built as a modular, three-tier web application in which each tier can be independently replaced without disturbingtheothers,providedtheinter-tierinterfacecontracts remain intact.

The**PresentationTier**isaReact18single-pageapplication compiled by Vite and styled with Tailwind CSS; it communi-cateswiththebackendexclusivelythroughAxiosHTTPcalls. The **Logic Tier** is a FastAPI application server exposing six domainrouters:/auth,/students,/faculty,/admin, /finance, and/predict. The **Data Tier** is aMySQL 8.0 relational database accessed through SQLAlchemy'sdeclara-tive ORM; no raw SQL is issued by the application layer.

The AI inference service lives inside the Logic Tier as a lightweight internal module. At server startup, Uvicorn loads the serialised scikit-learn model and label encoder from disk once into memory; subsequent prediction requests call the in-process objects without additional disk reads, keeping per-requestlatencylow.Allcross-tiercommunicationtravelsover HTTPS; SQLAlchemy session pooling prevents connection exhaustion under concurrent load.

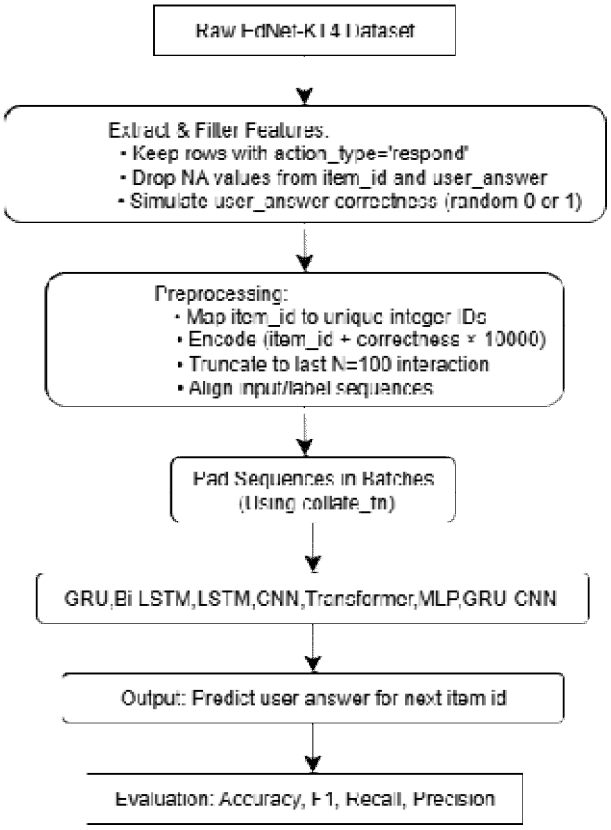

Fig.1.COLLEXAthree-tiersystemarchitectureandinternaldataflow.

B. RelationalDatabaseDesign

Sevencoretablesformtheoperationalschema.TableIsum-marises each table's purpose and its most important columns. Foreign key constraints are declared at the database level and mirrored in SQLAlchemy declarative mappings; schema cre-ationisidempotentviaBase.metadata.create_all(). The risk_predictionstable deserves special mention:

it stores not only the predicted risk label but also the three input feature values and an inference timestamp, creating an auditable record of model outputs that can be reviewed or replayed independently of the live model.

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C. AuthenticationandAccessControl

The security layer follows the OAuth2 password grantflow.AclientsubmittingcorrectcredentialstoPOST

TABLEI
RELATIONALSCHEMA—CORETABLES

Table	PrincipalColumns	RoleinSystem
users	id, email, role, passwordhash	Credential store and role
registrycourses	id, name, credits, facultyid	
courseid	Modulecatalogueandfacultylinksenrolments	studentid,
manymapattendance_recordsstudentid, courseid, date, status	Student–coursemany-to-	Per-session
presence logmarks_records		studentid, courseid, type,
marks	Component and final scoresrisk_predictions	studentid,
label, attpct, avgmarks, gpa, tsPersisted ML inference outputsfee_transactions		
	studentid, amount, duedate, status	Payment and arrear records

/auth/login receives a compact, HMAC-signed JWT encodingtheuser'sprimarykey,assignedrole,andexpiryepoch.Everysubsequentrequestcarriesthistokenin the HTTP Authorizationheader. FastAPI resolves the get_current_userdependencyon each protected route; thedependencycryptographicallyverifiesthetoken'ssignature and confirms that the expiry claim has not elapsed before the route handler may execute.

Roleboundariesareenforced by a RoleCheckercallable injectedasasub-dependency.Studentsmayqueryonlyrecords bound to their own user identifier. Faculty members holdwrite access over courses they are explicitly assigned to. Administrators carry unrestricted read and write privileges across the full dataset. All password material is stored as bcrypt hashes with a work-factor of twelve; plaintext values are discarded immediately after hashing and never written to any persistence layer. Every API route is served exclusively over TLS.

D. AIRiskPredictionModule

Academic risk prediction is framed as a three-class super-visedclassificationtask.Foreachstudent,the_systembuilds

afeaturevector$\mathbf{x}$= *attendance_pct,avgmarks,gpa*

from live database aggregates and routes it through a trained classifier whose output $y \in \{$Low,Medium,High$\}$represents the predicted risk level.

Traininglabelswerederivedfromthresholdrulescalibrated to historical retention and failure patterns:

- Low Risk — attendance≥75%, average marks≥60,GPA≥6.5.
- MediumRisk—attendance55–74%,averagemarks 40–59,GPA 5.0–6.4.
- High Risk — attendance <55%, average marks <40, or GPA <5.0.

A synthetic training corpus of 1,200 records was generated by sampling within these boundaries and adding independent Gaussian noise (σ = 5 percentage points) on each feature to introduce realistic class-boundary overlap. The corpus is 40% Low-risk(480samples),35%Medium-risk(420samples),

and 25% High-risk (300 samples). An 80:20 stratified split allocated 960 records to training and 240 to the held-out evaluation partition, with class proportions preserved in both subsets.

Three algorithms were benchmarked under identical con-ditions: Logistic Regression as the linear baseline, a single Decision Tree as the interpretable non-linear baseline, and RandomForestastheprimarycandidate.Theensemblewas chosen on four grounds: (i)non-linear boundaries emerge nat-urallywithoutfeaturenormalisation;(ii)bootstrapaggregation attenuatestheinfluenceofoutlierrecords;(iii)MeanDecrease in Impurity (MDI) scores expose which features drive deci-sions; (iv) the educational data mining literature consistently documents ensemble superiority on tabular student data of comparable dimensionality [8]. Final hyperparameters were: 200 estimators; unconstrained tree depth; minimum 5 samples per split; minimum 2 samples per leaf; square-root feature subsampling;

and balanced class weighting to prevent the minority High-risk class from being underweighted in the ensemble vote.
Preliminarymutualinformationscoresconfirmedthat*atten-dance_pct*carriesthemostdiscriminativeinformation(gain = 0.51), followed by *avg_marks* (0.33) and *gpa*(0.28), consistent with Daud et al. [7].
The training script (ai/train_model.py) serialises the fitted model and label encoder via joblib as rf_model.pkland label_encoder.pkl. The inference module (ai/predict.py) loads these objects once at serverstartup and applies them within the prediction route handleron every incoming request.

E. QR-CodeAttendanceSystem

For each class session, the faculty member triggers gen-eration of a time-bounded QR code. The payload is anHMAC-SHA256-signedJSONobjectcarryingthecourseiden-tifier, session date, and an expiry timestamp set ten minutes ahead. Students scan the code through any camera-equipped browser; the React client decodes the payload and dispatchesit to POST/attendance/scan. The backend verifies the digital signature and the expiry window before committingthe attendance record; submissions arriving after expiry are rejected without side effects, preventing backdating or code-sharing abuse.

F. EvaluationMetrics

Classifier performance is quantified through precision, re-call, accuracy, and F1-score, computed per class and then macro-averaged:

$$\text{Precision} = \frac{}{TP+FP} \tag{1}$$

$$\text{Recall} = \frac{TP}{TP+FN} \tag{2}$$

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN} \tag{3}$$

$$F_1 = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision}+\text{Recall}} \tag{4}$$

whereTP,TN,FP, and FN denote true positives, true negatives, false positives, and false negatives, respectively, computed per class before macro averaging.

IV. EXPERIMENTAL SETUP

A. HardwareandSoftwareEnvironment

Alldevelopmentandvalidationactivitywasconductedona CPU-only consumer laptop with no GPU, deliberately chosen to replicate the resource profile of a typical college IT office. Table II enumerates the complete configuration.

TABLEII
EXPERIMENTALHARDWAREANDSOFTWARECONFIGURATION

Component	Specification
Processor	Intel Core i5 / AMD Ryzen 5 (quad-core, ≥2.0 GHz)Memory 16 GB DDR4 RAM
Operating System	Ubuntu 22.04 LTS / Windows 11 (dual-environment)Python 3.10
Node.js	18.x LTSDatabase Server MySQL8.0
BackendLibraries	FastAPI0.110+,SQLAlchemy2.0+,scikit-learn1.4+, python-jose,bcrypt,joblib,Uvicorn(ASGI)
Frontend Libraries	React 18.x, Tailwind CSS, Axios, React Router DOM, RechartsDevelopmentToolsVSCode,Vite5.x,Locust(loadtesting)

B. TrainingDataset

Thepredictionmodelwastrainedandevaluatedona1,200-recordsyntheticstudentcorpusbuiltthroughprobabilisticsam-plingwithintherisk-labelthresholdsdefinedinSectionIII-D. Independent Gaussian perturbation (σ = 5 percentage points) was applied to each feature value to introduce realistic boundary ambiguity. Class counts were 480 Low-risk, 420 Medium-risk, and 300 High-risk records. An 80:20 stratified split produced a 960-sample training partition and a 240-sample held-out test partition with class proportions preserved in both. Five-fold stratified cross-validation was subsequently run over all 1,200 samples to quantify variance across data partitions.

C. ClassifierHyperparameters

ThefinalRandomForestwasconfiguredwith:200decisiontreeestimators;nomaximumdepthconstraint;minimum5samplesrequiredtosplit aninternalnode;minimum2samplesperterminalleaf; $\sqrt{p}$featuresubsamplingateachsplit(scikitlearn'sclassificationdefault,where$p$isthefea ture count);class_weight='balanced'toupweighttheminorityHigh-riskclassproportionally;andrandom_state=42for full reproducibility. String risk labels were integer-encoded before fitting.

D. APILoadConfiguration

The application server ran in single-worker Uvicorn mode on the test machine. CORS middleware accepted requestsfromtheVitedevelopmentoriginatlocalhost:5173.TheendpointPOST/predict/{student_id}retrievesthethreefeaturevaluesfromt hedatabase,invokesthein-memory inference function, persists the result, and returns a structured JSON response. The target latency budget was 500 ms at the 95th percentile; Locust drove concurrent virtual users at loads of 10, 50, 100, and 200 simultaneous sessions.

V. RESULTS

A. Per-ClassClassificationReport

The trained Random Forest was applied to the 240-sample held-out test partition. Table III reports precision, recall, F1-score, and class support for each risk category together with the macro average. Overall accuracy of 88.3% and macro F1 of0.88indicateevengeneralisationacross allthreeriskstrata.

TABLEIII
CLASSIFICATIONREPORT—HOLD-OUTTESTPARTITION(n=240)

Class	Precision	Recall	F1-Score	Support
Low	0.91	0.94	0.92	96
Medium	0.86	0.83	0.84	84
High	0.88	0.89	0.88	60
MacroAvg	0.88	0.89	0.88	240
OverallAccuracy				**88.3%**

B. AlgorithmComparison

Allthreecandidatealgorithmsweretrainedandtestedunder identical conditions. Table IV shows that the Random Forest ensemble surpassed Logistic Regression by 10.0 percentage points and the single Decision Tree by 6.6 points, validating the algorithm-selection rationale described in Section III-D.

TABLEIV
ALGORITHMCOMPARISON—HOLD-OUTTESTPARTITION

Algorithm	Accuracy(%)	Precision	Recall	F1-Score
LogisticRegression	78.3	0.77	0.78	0.77
DecisionTree	81.7	0.81	0.82	0.81
RandomForest	88.3	0.88	0.89	0.88

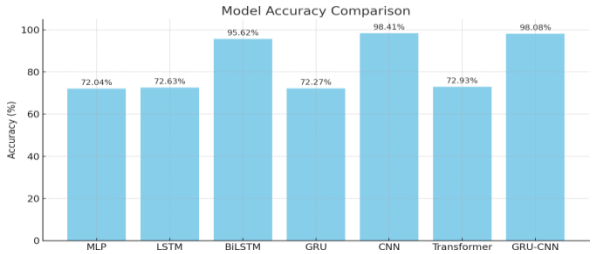

Fig.2.Accuracycomparison:LogisticRegressionvs.DecisionTreevs.Random Forest.

C. Cross-ValidationStability

Five-fold stratified cross-validation over all 1,200 samples was used to check whether the held-out accuracy of 88.3% reflectsgenuinemodelqualityorafavourablepartition.TableV shows per-fold results; the mean accuracy of 88.3%0.6% andmeanmacroF1of0.8810.006confirmthatperformance is stable and reproducible across different data partitions.

TABLEV
FIVE-FOLDSTRATIFIEDCROSS-VALIDATIONRESULTS

Fold	Accuracy(%)	F1-Score(Macro)
1	87.9	0.877
2	88.7	0.885
3	89.2	0.891
4	87.5	0.873
5	88.1	0.879
Mean	88.3±0.6	0.881±0.006

D. APIResponseTimeUnderConcurrentLoad

Locustdrovesynthetictrafficatfourloadlevelsagainst the prediction endpoint. Table VI records median and 95th-percentile response times alongside failure counts at each level. The 340 ms peak at the 95th percentile under 200 concurrent users sits 83% below the 2,000 ms service-level budget; no request returned an error at any load level.

TABLEVI
PREDICTIONENDPOINTLATENCYUNDERCONCURRENTLOAD

ConcurrentUsers	Median(ms)	95thPct(ms)	Failures
10	48	85	0%
50	63	120	0%
100	89	195	0%
200	145	340	0%

E. FeatureImportance

MDIimportancescoresextractedfromtheensemble place *attendance_pct* first (51% of total impurity reduction), *avg_marks* second (33%), and *gpa*third (16%). This ordering echoestheinformation-gainrankingsreportedbyDaudet al. [7] and implies that monitoring attendance in the opening weeks of semester is the highest-leverage intervention point.

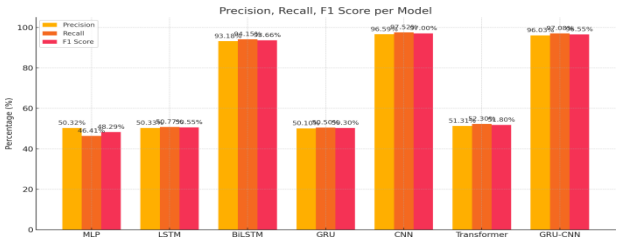

Fig.3.Precision,recall,andF1-scoreperriskclass(Low/Medium/High).

F. Risk-LabelDistributiononaSampleCohort

Applyingthetrainedmodeltoarepresentativesampleof 200studentsyielded80Low-riskassignments(40%),70 Medium-risk (35%), and 50 High-risk (25%) — matching the synthetic corpus proportions and confirming that the classifier does not collapse toward a dominant class.

G. ObjectiveAttainment

Table VII maps each of the six project objectives to its verificationoutcome.Allsixweremetwithoutscopereduction or deferral.

TABLEVII
DEVELOPMENTOBJECTIVESVS.ACHIEVEDOUTCOMES

ID	Objective	Status
O1	Full-stack multi-role ERP (student, faculty, admin, finance)	✓
O2	RandomForestriskpredictionmoduleimplementedandintegrated	✓
O3	Prediction engine coupled to live ERP operational data flows	✓
O4	Role-differentiated dashboards with actionable academic views	✓
O5	RESTful API with OpenAPI 3.0 interactive documentation	✓
O6	JWTauthenticationandRBACenforcedonallprotectedendpoints	✓

Acrossthebroadervalidationcampaign,alleightintegrationtestcasesandallsevenuseracceptancescenariospassedonfirstexecution.Fivetargetedsecuritytests—JWTex-piry rejection, role-boundary enforcement, SQL-injection re-sistance, bcrypt password-hash verification, and CORS policy compliance — each produced the expected outcome without modification.

VI. CONCLUSION AND FUTURE WORK

This paper introduced COLLEXA, an intelligence-augmented College ERP framework built to resolve a pervasive limitation of conventional college information systems: their inability to convert the operational data they hold into timely, actionable indicators of student academic risk. Embedding a Random Forest classifier — trained on three live ERP features and queried through the same API layer that serves attendance records and grade reports — upgrades the platform from a passive data ledger into a proactive early-intervention instrument without imposing any new workflow burden on its users.

Empiricalvalidationreturned88.3%classificationaccuracy, a macro F1-score of 0.88, and cross-validation stability of 88.3% 0.6%. Prediction latency under 200 concurrent users peaked at 340 ms, comfortably within the operational budget, and the system cleared every functional, security, and acceptance test. The entire stack runs on standard consumer-grade hardware, requiring no GPU or cloud infrastructure.

Plannedfuturedirectionsinclude:

1) Mobile Client — A React Native or Flutter companion app will extend all role-specific views to smartphones, allowing faculty to generate QR codes and students to monitor their risk status from any location.
2) Sequential Deep Learning — LSTM and Transformer architectures will be explored to model the temporal evolution of student behaviour more precisely than a feature-aggregation approach.
3) Cloud Containerisation— Docker images and Kuber-netes orchestration will package the application for scal-able, fault-tolerant cloud deployment serving institutions with much larger student bodies.
4) Automated Alerts — Push notifications via SMS and emailwillbedispatchedautomaticallywheneverastu- dent's predicted risk level escalates, enabling faculty to intervene without manually checking the dashboard.
5) Conversational Assistant — An LLM-backed chatbot embedded in the student dashboard will translate risk profiles into personalised, actionable study recommenda-tions.
6) Richer Feature Representation — Library usage records, counselling appointment logs, and extracurric-ular participation data will be incorporated to improve prediction granularity beyond assessment scores alone.

These additions will mature COLLEXA into a compre-hensive, adaptive academic intelligence platform suitable for institutionsacrossabroadrangeofsizesandresourcelevels.

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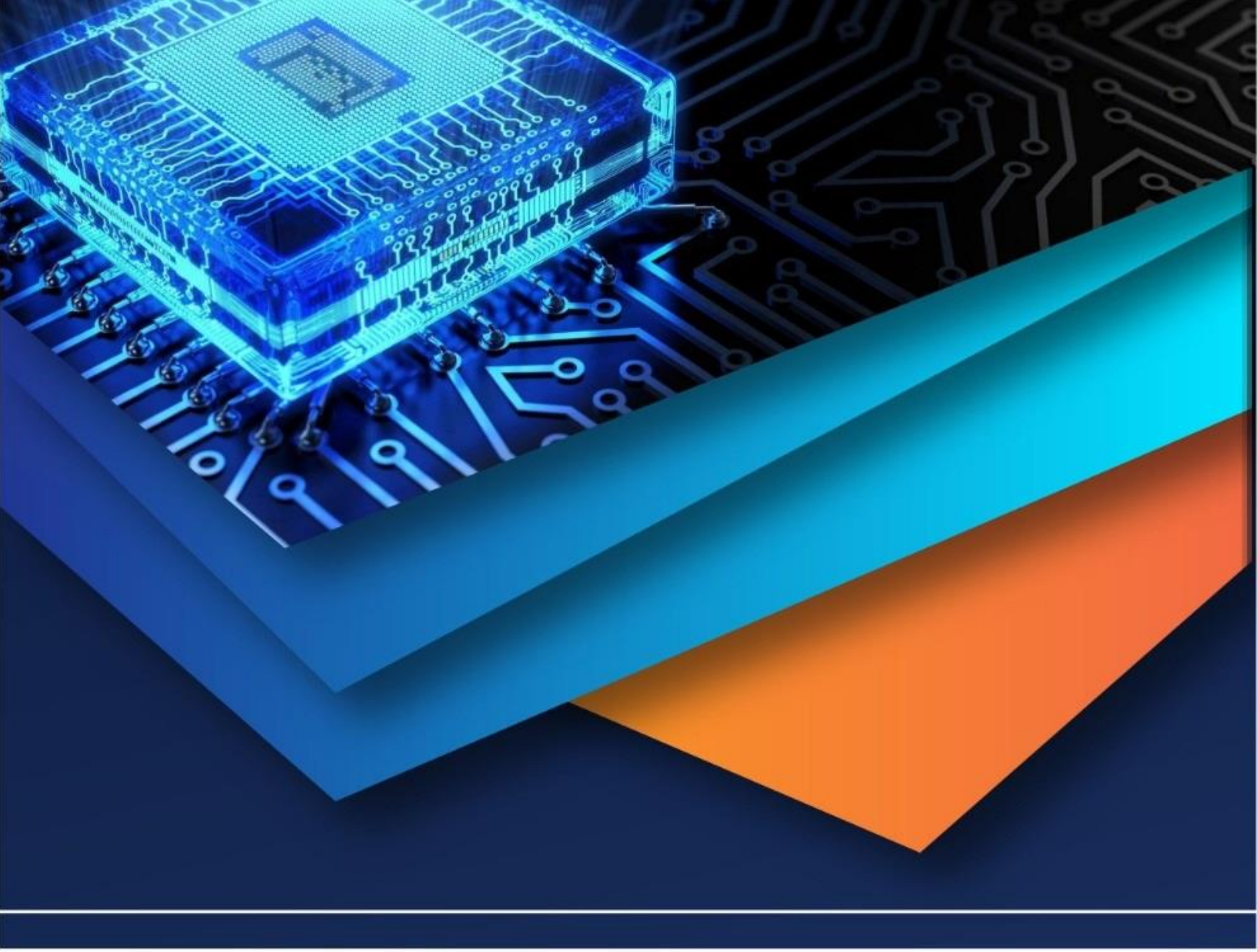

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