Predictive Modeling of Academic Success in Financial Mathematics Using Machine Learning Techniques

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ABSTRACT

This study develops and evaluates predictive models for student performance in Financial Mathematics (ASC303) using Machine Learning techniques. Building on prior research that established key relationships between prerequisite courses and ASC303 performance, the research analyses academic records of 226 Diploma in Actuarial Science students. The research applies Association Rule Mining (ARM) to identify critical course dependencies by evaluating both pre-university (SPM) qualifications and prerequisite courses. The ARM results reveal 3,385 significant patterns with strong predictive accuracy, showing that SPM Additional Mathematics and Mathematics grades significantly influence ASC303 performance. High-performing SPM students demonstrate 3.2 times greater likelihood of excelling in Financial Mathematics. The findings also highlight the critical role of early mathematical proficiency, particularly in Calculus and Probability during semesters preceding ASC303 in determining successful performance. The results further highlight the lasting impact of pre-university STEM preparation, indicating the need for targeted interventions to address knowledge gaps. The predictive models also enable early identification of at-risk students, providing a 2-3 semester gap for targeted support. Methodologically, the study establishes a novel framework that combines ARM's interpretability with machine learning's predictive power, addressing a significant gap in STEM education analytics. Future studies should expand datasets to improve generalization and investigate additional predictive factors.

Keywords: Financial Mathematics, Machine Learning, Predictive Modelling, STEM, Association Rule Mining

INTRODUCTION

The academic success of students in higher education has long been a subject of interest for educators and researchers alike, particularly in specialized and challenging disciplines such as Financial Mathematics. This field, integral to actuarial science, requires students to develop strong mathematical and analytical skills, making it a critical yet demanding component of their academic journey. The effective identification of factors influencing student performance in such courses can greatly enhance educational strategies and outcomes.

Despite the importance of Financial Mathematics, students often face significant challenges in mastering its concepts, resulting in a wide performance gap. Prior studies have highlighted the influence of foundational coursework, such as Calculus and Probability, on success in Financial Mathematics (Hanafi et al., 2019). However, these relationships are complex, and educators lack predictive tools to accurately identify at-risk students early in their academic progression. This gap underscores the need for advanced analytical approaches to model and predict student performance based on their academic history.

Many academic fields have made extensive use of machine learning to predict results including grades, course completion rates, and student retention (Esmael, 2024). The effectiveness of these methods in domains including computer science, engineering, and medicine has been shown in earlier research (Yağcı, 2022; Wang et al., 2024). Nonetheless, there is still a lack of research on the use of machine learning to forecast academic achievement, particularly in Financial Mathematics. Our disparity emphasises the significance of our study, which seeks to offer insightful information to the academic community and educational policymakers alike.

Hence, the purpose of this study is to address this issue by implementing machine learning techniques to predict academic success in Financial Mathematics. Building upon association rule mining methods that previously identified course dependencies, this research explores the efficacy of classification algorithms such as decision trees, support vector machines, and neural networks. By analysing students' performance in foundational and related courses, the study aims to develop a predictive model that identifies students at risk of underperformance early. The insights gained will inform targeted interventions and curriculum enhancements, ultimately improving academic outcomes and fostering student success in Financial Mathematics and related fields.

LITERATURE REVIEW

This section discusses topics related to this study, including the study plan of the Actuarial Science program, which serves as the foundational framework for students pursuing careers in fields like actuarial science and financial.

Study Plan

Diploma in Actuarial Science (CDCS112) is one of the undergraduate programs offered at the College of Computing, Informatics and Mathematics (KPPIM), UiTM Seremban Campus. The main objective of this program is to produce graduates who can fulfil the demands of the financial services industries, especially in the insurance industry. The graduates must be equipped with analytical and scientific method skills in the field of actuarial science.

The public and the private sectors, such as insurance companies, banks, and other financial institutions, such as investment firms, hire most of the diploma holders in this program. Their tasks include handling statistical investigations related to premium pricing, risk management, and retirement planning. The students will be granted a diploma certificate after they have completed five semesters of studies. Table 1 below shows the study plan for actuarial students up to the third semester before taking the Financial Mathematics course.

Table 1. Study Plan for Diploma in Actuarial Science

Semester	Course Code	Course Name
1	ACC166	Financial and Cost Accounting
	CTU101	Fundamentals of Islam
	DSC119	Data Visualization and Information Reporting
	ECO162	Microeconomics
	HBU111	National Kesatria I
	LCC111	English for Communicative Competence I
	MAT183	Calculus I
	UED102	Study Skills
2	ASC173	Principles of Risk Management, Insurance and Takaful
	CSC128	Fundamentals of Computer Problem Solving
	CTU152	Values and Civilization

	HBU121	National Kesatria II
	LCC112	English for Communicative Competence II
	MAT233	Calculus II
	STA233	Introduction to Time Series Forecasting
3	ASC303	Financial Mathematics
	CTU242	Fundamental of Takaful
	FIN358	Investment Management
	ECO162	Microeconomics
	HBU131	National Kesatria III
	LCC113	English for Communicative Competence III
	STA206	Probability And Mathematical Statistics I
4	ASC302	Introduction to Actuarial Science
	ASC305	Introduction to Actuarial Mathematics
	ASC360	Personal Financial Planning
	MAT263	Linear Algebra I
	STA256	Probability And Mathematical Statistics II
5	ASC380	Fundamentals of Social Security
	ASC399	Insurance Data Analytics
	ENT300	Fundamentals of Entrepreneurship
	QMT341	Introduction to Operations Research
	STA250	Fundamentals of Regression Analysis

Financial Mathematics

Financial Mathematics is one of the core courses included in actuarial science studies. This course covers the financial market, emphasizing mathematical techniques for solving financial problems. It prepares the students for further analysing financial instruments. To become a certified professional actuary, the students need to pass a series of professional examinations. Society of Actuaries (SOA) and Institute and Faculty of Actuaries (IFoA) are among the well-known professional bodies offering professional exams encompassing different fields.

In Malaysia, UiTM receives an exemption from IFoA for its professional papers. One of the courses included in the exemption is Financial Mathematics (ASC303). Despite that, not all students would be granted exemption automatically. The exemption depends on the grades they obtained (Hanafi et al., 2019). Furthermore, machine learning techniques are increasingly being used in financial modelling. Students studying Financial Mathematics are frequently exposed to data science methods that improve financial decision-making and prediction models (Gao et al., 2024). Students can stay on the cutting edge of financial technology because of this combination of machine learning and programming.

Machine Learning

Machine learning has become a powerful tool in education, particularly for predicting student performance and achievement. These models use large datasets that include factors such as demographic information, past academic performance, and interactions within learning management systems to uncover patterns and correlations that may not be immediately apparent using traditional assessment methods. This capacity to predict future results is a potential opportunity for both pre-emptive treatments and individualised instructional strategies (Alsariera et al., 2022; Alhazmi and Sheneamer, 2023). In addition to predictive capabilities, machine learning models enable students to personalise their learning experiences. Identifying individual strengths and weaknesses allows instructors to give tailored help to kids who may be lagging behind. For example, predictive models might identify students who are expected to struggle in a specific subject, allowing instructors to provide additional resources, such as tutoring or concentrated study sessions, before the student reaches a key moment in their academic path. This personalised strategy has the potential to increase retention, lower dropout rates, and improve overall academic achievement (Alsariera et al., 2022; Moubayed et al., 2024).

Additionally, at the institutional level, machine learning models may be quite helpful in improving teaching methods. Universities and colleges can learn more about the macro-level elements that influence academic success or failure by examining patterns among a sizable student population. Course scheduling, curriculum development, and even the distribution of funds for student support services might all benefit from these findings. Institutions can create specialised assistance programs to address the difficulties experienced by students in particular demographic groups, for instance, if a predictive model indicates that these students are more likely to do poorly (Caicedo-Castro, 2023; Li et al, 2024).

Accurate prediction from the model can be helpful to guide instructors and students on how to improve their learning outcomes (Alsariera et al., 2022; Li et al., 2024; Zhaoet al., 2024). Numerous research has demonstrated these machine learning applications' beneficial effects. Esmael (2024), for instance, showed how machine learning algorithms like neural networks, decision trees, and random forests could accurately forecast students' academic performance in a variety of domains, including business, engineering, and the arts. Numerous input factors, such as students past academic records, interest levels, and even social interaction patterns, might be included by these models. Machine learning may contribute to the development of a more encouraging and productive learning environment by utilising predictive models to identify students who are at risk, customise instruction, and enhance institutional procedures. But in order to reach its full potential, ethical issues, data quality, and the incorporation of these technologies into more comprehensive teaching methodologies need to be carefully considered. Machine learning may offer a potent foundation for improving student results and promoting institutional advancements when applied carefully.

Declining Demands in the STEM Field

It has become a concern for educators and industry as the demand in Science, Technology, Engineering, and Mathematics (STEM) fields among Malaysian students have declined for the past few years. The requirement for a strong STEM labor force is critical as Malaysia is heading towards technology and innovation growth economics. Several studies have highlighted the declining percentage of students choosing STEM-related careers (Mahlan et al., 2024).

The nation's goal of achieving a 60:40 ratio of science/technical to art students in secondary schools, as outlined in the Malaysia Education Blueprint 2013-2025, has not been met (Idris et al., 2023). Another area of concern is the STEM achievement between schools in urban and rural areas. Rural students tend to perform less in STEM subjects than in urban schools (Nor et al., 2021).

Several factors may contribute to this declining demand, including curriculum rigidity, lack of funding, inadequate teacher training, and limited resources (Wen, 2023). The lack of interest in the STEM field can significantly impact students' academic performance in higher education. Therefore, once analysis is done by this study, intervention action should be taken to ensure universities are able to meet the industry’s demand for STEM graduates.

METHODOLOGY

This section discusses the research method carried out to achieve the objective of this study, which includes the datasets and sampling procedure, data preparation, association rules mining, visualization, hypotheses, as well as tools and environment. Figure 1 below shows the flowchart illustrating all the key steps in carrying out the research procedure.

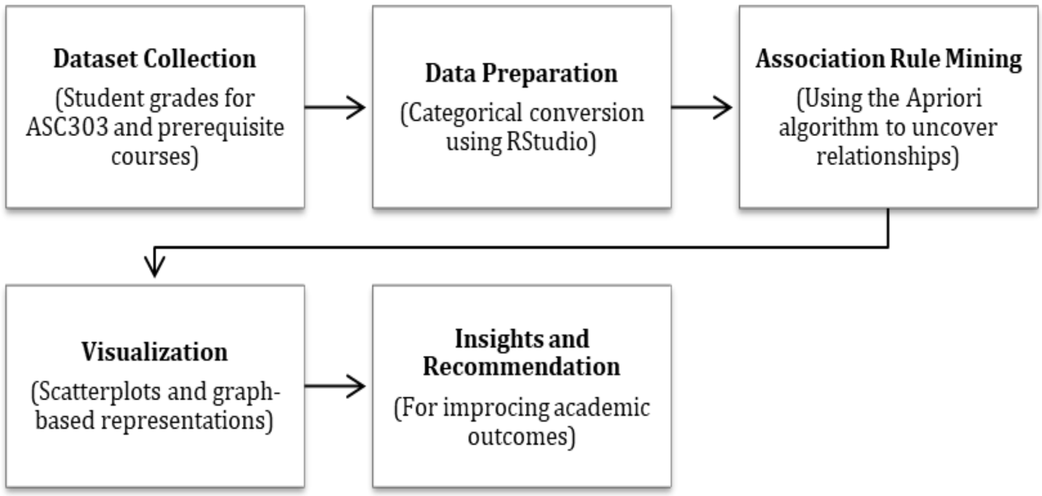

Figure 1. Methodological Flowchart Illustrating Key Steps in the Research Process

Dataset and Sampling Procedure

This study utilized the examination results of students enrolled in the Diploma in Actuarial Science (CDCS112) program at UiTM Seremban Campus. The dataset includes grades for 15 subjects taken during semesters 1 and 2, along with the results for Financial Mathematics (ASC303) in semester 3. ASC303 was chosen as the focus of this study due to its significance in actuarial science education and its known difficulty level among students.

The data consisted of categorical grades (e.g., A+, A, B+) and was analyzed without further discretization. The total dataset contained the academic records of 226 students. All students who did not take ASC303 during semester 3 were excluded from the analysis to ensure consistency.

While the current study analyzed data from 226 students at UiTM Seremban Campus, future work will expand the dataset to include records from three additional campuses (e.g., UiTM Shah Alam, Penang) and three related programs (e.g., Data Science, Quantitative Finance) to enhance model generalizability.

Data Preparation

The dataset was imported into RStudio using the ‘readxl’ package, and all columns were converted into factors to prepare for Association Rules Mining (ARM). The preparation process ensured that the dataset was in a transactional format suitable for the Apriori algorithm. No additional preprocessing, such as binning or scaling, was necessary due to the categorical nature of the grades. Future iterations will incorporate continuous grading scales (e.g., exam scores 0-100) and topic-level mastery metrics (e.g., calculus sub-skills) to refine predictive granularity

Association Rules Mining

ARM was conducted to identify patterns and relationships between the results of semester 1 and 2 subjects (independent variables) and ASC303 (dependent variable). The Apriori algorithm, implemented through the ‘arules’ package in RStudio, was used for rule mining.

Parameter Settings

The following parameter settings were employed to ensure meaningful and interpretable rules:

1. Support threshold (supp): Set to 0.01–0.02 to identify patterns occurring in at least 1–2% of the dataset.
2. Confidence threshold (conf): Set to 0.8 to extract rules with a high likelihood of association.
3. Lift: Used as a sorting criterion to prioritize rules with stronger relationships compared to random chance.

Rule Generaton

Rules were generated in two stages:

1. General Rules: All subjects were considered for both the antecedents (lhs) and consequents (rhs) to explore broad relationships.
2. Targeted Rules: ASC303 grades were explicitly set as the consequent, enabling a focused analysis of its dependencies.

Focused Subsets

Two specific subsets of rules were extracted for further investigation:

1. SPM Subjects: Rules where English, Additional Mathematics, and Mathematics appeared as antecedents hypothesized to strongly influence ASC303 results.
2. Core Diploma Subjects: Rules involving MAT183, MAT233, CSC128, and STA233 subjects, hypothesized to have a significant impact on ASC303 performance.

Removal of Redundancy

ARM algorithms usually produce many redundant rules even though high value of thresholds is used. Redundant rules are considered as a hindrance to efficiently discovering meaningful and significant rules and should be removed. To remove these redundant rules, is.redundant() function in R was used to retain only unique and meaningful patterns.

Visualization

Scatterplots and graph-based visualizations were employed to analyze the relationships between subjects and ASC303. Scatterplots depicted the interaction between support, confidence, and lift, while graph visualizations illustrated the network of associations. These visualizations were created using the ‘arulesViz’ package and saved as static images for reporting.

Hypotheses

The study was guided by the following hypotheses:

1. SPM subjects, especially Additional Mathematics, significantly influence the results of ASC303.
2. Key diploma subjects, such as MAT183, MAT233, CSC128, and STA233 courses, have a substantial impact on ASC303 outcomes.

Tools and Environment

The analysis was conducted in RStudio, utilizing the following packages:

1. 'readxl' for data import.
2. 'arules' for association rules mining.
3. 'arulesViz' for visualization.

Computational efficiency was demonstrated, with the generation of up to 6,515 rules completed in approximately 1.5 seconds per run. All visualizations were exported as PNG files for documentation and further analysis.

RESULTS AND DISCUSSION

This section discusses the analysis of the datasets in predicting the students' success in Financial Mathematics by applying the association rule mining in analyzing course dependencies by implementing machine learning classification algorithms.

Overview of Association Rule Mining Results

The Association Rules Mining (ARM) approach applied in this study, through the Apriori algorithm, yielded a wealth of insights into the academic dependencies between prior coursework and ASC303 (Financial Mathematics) performance. The study generated 6,515 rules in total, which were filtered to retain 3,385 unique, non-redundant rules. These rules serve as a robust dataset for understanding how specific academic achievements influence subsequent success in a challenging core subject. This multi-layered analysis explored:

1. General patterns across all courses.
2. Subsets focusing on foundational SPM subjects.
3. Targeted relationships between diploma-level courses and ASC303.

By systematically exploring these layers, the analysis ensures comprehensive coverage of potential predictors of academic success.

General Patterns in the Dataset

The scatterplot of all rules in Figure 2 reveals distinct clusters of associations, with a significant proportion exhibiting both high confidence (greater than 0.8) and substantial lift values (greater than 1). This pattern underscores the strong predictive relationships inherent in the dataset. Furthermore, the graph visualization of the top 100 rules in Figure 3 illustrates a dense network of interconnected courses, with ASC303 grades prominently featured as consequents.

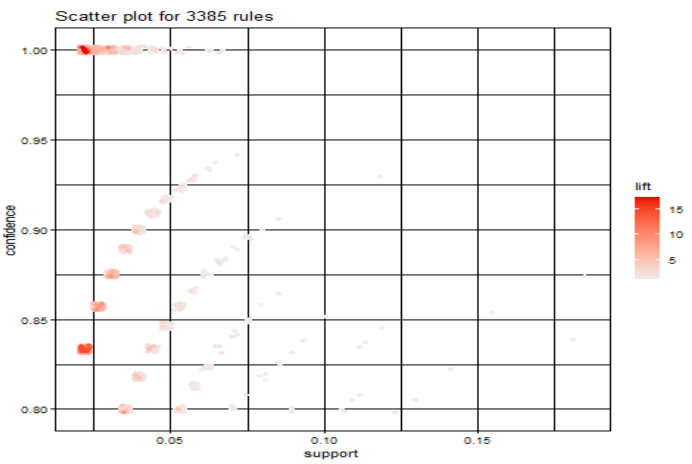

Figure 2. Scatterplot of all rules

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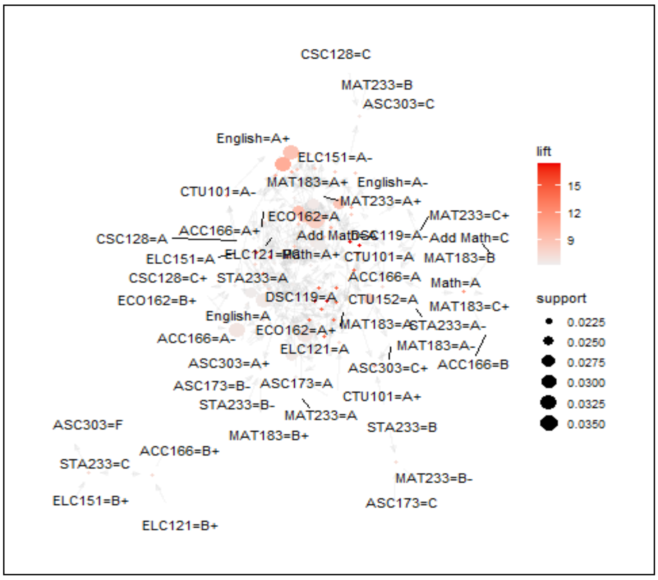

Figure 3. Graph visualization of the top 100 rules

Key Findings:

1. MAT183 (Calculus I) and MAT233 (Calculus II) emerged as the most influential antecedents, indicating that mathematical proficiency acquired early in the diploma program significantly affects ASC303 performance.

2. STA233 exhibited moderate to high associations with ASC303, suggesting that statistical reasoning complements mathematical problem-solving in Financial Mathematics.

These results confirm that success in foundational courses creates a cascading effect, positively influencing outcomes in advanced subjects. Additionally, the high lift values observed suggest that these relationships are not merely coincidental but are driven by intrinsic academic dependencies.

Influence of SPM Subjects

An in-depth analysis of rules with SPM subjects (Additional Mathematics, Mathematics, and English) in the antecedent identified 536 unique rules. These rules demonstrate the enduring impact of high school performance on tertiary education outcomes. The scatterplot in Figure 4 highlights clusters of rules with high support and confidence values, while the graph visualization in Figure 5 depicts the networked relationships linking SPM subjects to diploma coursework and, subsequently, to ASC303.

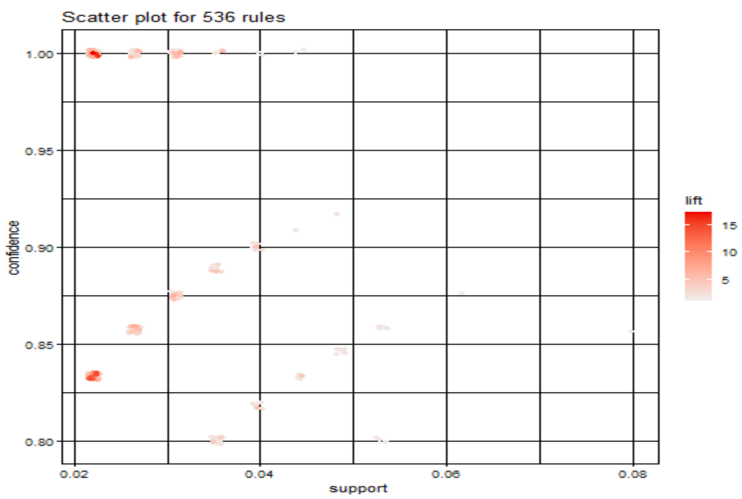

Figure 4. Scatterplot of rules with SPM subjects

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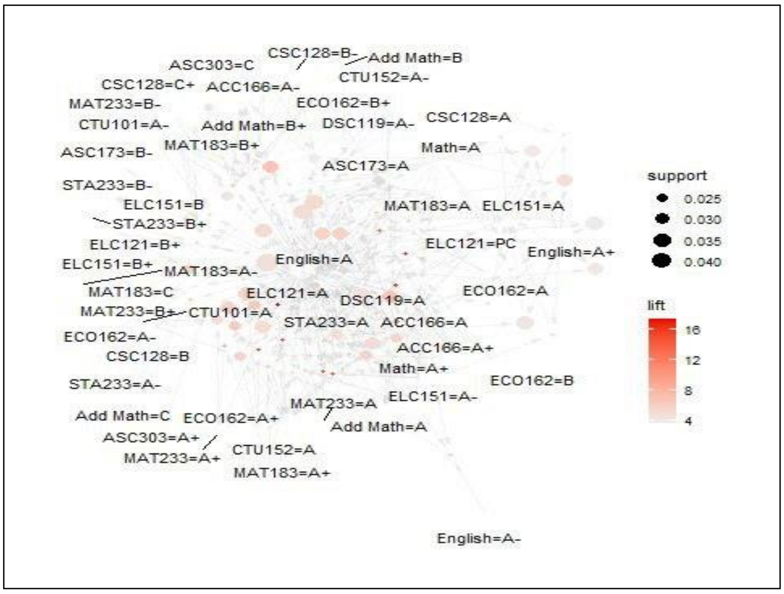

Figure 5. Graph visualization of top 100 rules for SPM subjects

Key findings:

1. Additional Mathematics and Mathematics emerged as dominant antecedents, with high-confidence rules linking excellent performance in these subjects to higher grades in MAT183, MAT233, and ASC303.

2. English, while less prominent, showed moderate associations, suggesting that language proficiency plays a supportive role, particularly in understanding complex problem statements.

The findings validate the hypothesis that foundational knowledge from SPM subjects serves as a cornerstone for advanced academic achievement. This highlights the importance of ensuring strong pre-university preparation in mathematical subjects, particularly for students aspiring to excel in technical disciplines.

Rules Specific to ASC303 (Financial Mathematics)

Rules explicitly targeting ASC303 as the consequent resulted in 332 unique, non-redundant rules. These rules provide granular insights into the factors most closely associated with success in this challenging subject. The scatterplot in Figure 6 reveals concentrated clusters of high-confidence, high-lift rules, while the network graph in Figure 7 illustrates the prominence of specific courses as antecedents.

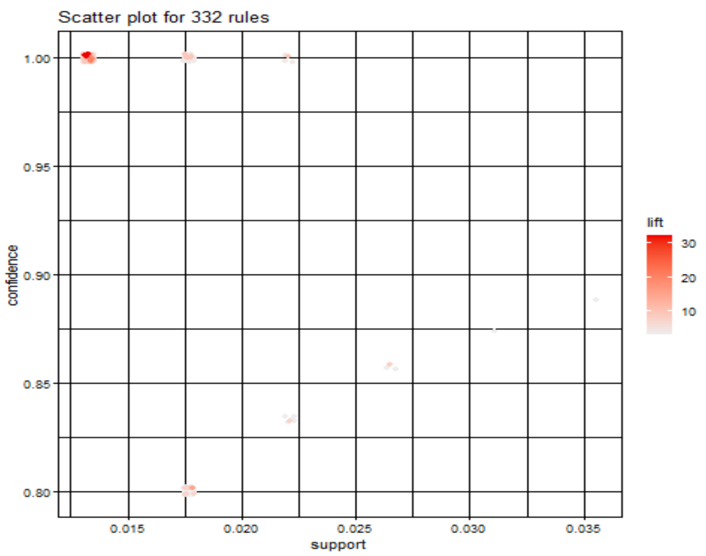

Figure 6. Scatterplot of ASC303-specific rules

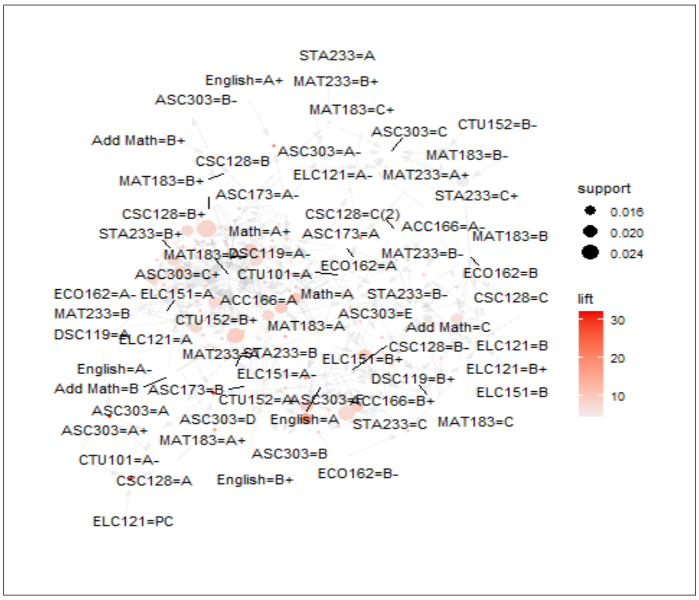

Figure 7. Graph visualization of the top 100 ASC303-specific rules

Key findings:

1. MAT183 and MAT233 consistently appear as top antecedents, with their high lift values underscoring their critical role in developing the mathematical maturity required for ASC303.

2. STA233 added value by building statistical reasoning, which is essential for understanding financial models and actuarial applications.

These findings underscore the cumulative impact of Mathematics and Statistics courses on students' ability to navigate ASC303. The results also suggest that academic support in these subjects should be prioritized to enhance performance in Financial Mathematics.

Combined Influence of SPM and Diploma Subjects on ASC303

The subset of rules combining SPM subjects as antecedents and ASC303 grades as consequents produced 86 unique rules, providing a deeper understanding of how pre-university and diploma-level coursework collectively shape outcomes in advanced subjects. The scatterplot in Figure 8 and graph visualization in Figure 9 highlight the compounded influence of these predictors.

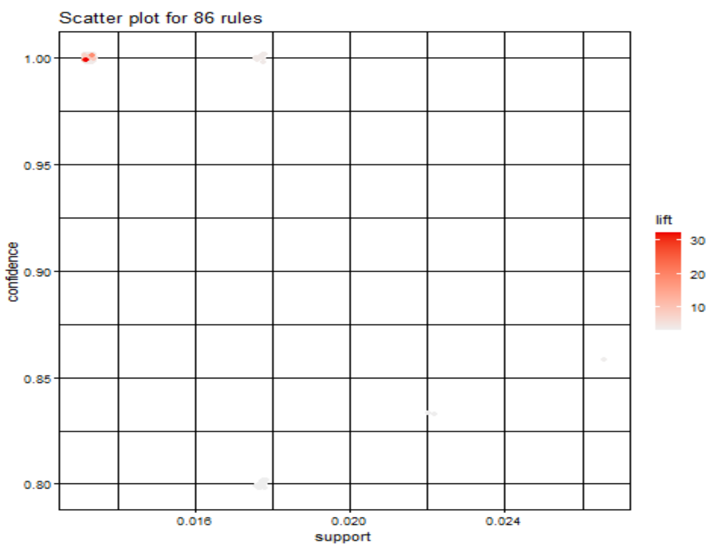

Figure 8. Scatterplot of combined SPM-diploma rules for ASC303

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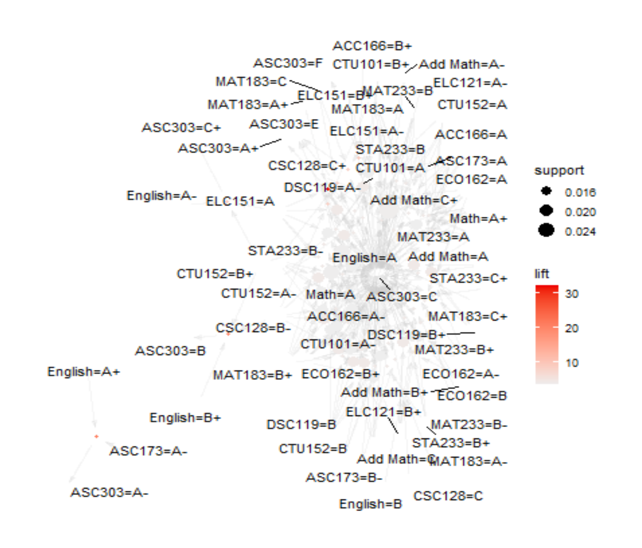

Figure 9. Graph visualization of the top 100 combined rules for ASC303

Key findings:

1. When combined with MAT183 or MAT233, additional Mathematics frequently appears in high-lift rules, emphasizing the synergistic relationship between foundational and advanced mathematics.

2. Rules with both SPM and STA233 courses as antecedents indicate a dual dependency on mathematical and statistical proficiencies for excelling in ASC303.

These insights validate the layered nature of academic dependencies, where early preparation creates a foundation that is further refined and leveraged through diploma-level coursework. Such findings advocate integrated academic planning to optimize learning outcomes across educational stages.

Implications and Hypothesis Validation

The analysis conclusively supports the study’s hypotheses:

1. SPM Subjects’ Impact: Strong performance in Additional Mathematics and Mathematics is a consistent predictor of success in diploma-level courses and, ultimately, in ASC303. These findings underscore the need for robust mathematical preparation at the pre-university level.

2. Diploma Subjects’ Role: MAT183 and MAT233 emerge as pivotal courses, directly influencing ASC303 outcomes. STA233, while secondary, provided essential statistical competencies.

3. Integrated Dependencies: The combined influence of SPM and diploma coursework highlights the importance of a cohesive academic trajectory. Interventions aimed at strengthening foundational knowledge and providing ongoing support in critical courses can significantly enhance student performance.

Broader Implications:

1. The results advocate for targeted curriculum enhancements and teaching strategies to address gaps in foundational knowledge.

2. Institutions should consider implementing diagnostic assessments to identify at-risk students early and offer tailored support in Mathematics and Statistics.

3. Collaborative efforts between pre-university and diploma-level educators could further align curricula to ensure a seamless academic transition.

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Intervention Strategies

Based on the ARM rules, targeted interventions include:

1. Pre-Semester Bootcamps: Students scoring <B in SPM Math complete intensive calculus modules during Semester 1.
2. Dynamic Grouping: At-risk cohorts (e.g., MAT233 grade <B+) receive supplemental STA233 problem-solving workshops.
3. Just-in-Time Remediation: Real-time alerts trigger tutoring when midterm scores predict ASC303 failure (e.g., via neural network thresholds).

CONCLUSION AND RECOMMENDATIONS

This study explored the intricate relationships between students' prior academic performance and their outcomes in ASC303 (Financial Mathematics) using Association Rules Mining (ARM). The findings provide a comprehensive understanding of the dependencies between foundational knowledge and success in advanced coursework, offering actionable insights for educators and policymakers.

Key Findings

1. Influence of SPM Subjects: Strong performance in Additional Mathematics and Mathematics at the SPM level significantly influences outcomes in key diploma courses and ASC303. These findings underscore the enduring importance of robust mathematical preparation at the pre-university level.
2. Critical Diploma Courses: MAT183 (Calculus I) and MAT233 (Calculus II) were identified as pivotal antecedents to ASC303 success. STA233 courses further complement these by providing essential statistical reasoning skills, reinforcing the role of foundational coursework in shaping academic trajectories.
3. Integrated Academic Dependencies: The layered influence of SPM and diploma-level subjects highlights the importance of a cohesive and aligned academic curriculum. Students’ performance is shaped by an interplay of early preparation and consistent support in key subjects throughout their educational journey.

Implications for Practice

The study’s results advocate for targeted interventions at multiple levels:

1. Curriculum Design: Pre-university and diploma-level curricula should be designed with greater alignment to ensure foundational competencies are effectively built upon in advanced courses.
2. Early Diagnostics: Institutions should implement diagnostic assessments to identify gaps in students’ foundational knowledge and provide tailored support, particularly in Mathematics and Statistics.
3. Integrated Support: A structured system of academic interventions, spanning both pre-university and diploma levels, could enhance overall student outcomes in challenging disciplines like actuarial science.

Limitations and Future Research

While this study provides significant insights, there are limitations that future research could address:

1. Scope of Dataset: The analysis focused on a single program at one campus. Expanding the dataset to include multiple campuses could improve generalizability.

2. Granularity of Performance Metrics: Future studies could explore more granular performance metrics, such as continuous grades or specific topic-level mastery, to refine the analysis.

3. Single-Campus Focus: Generalizability could be strengthened by incorporating multi-campus data and cross-disciplinary cohorts in future replication studies

In conclusion, this study highlights the interconnected nature of academic success, demonstrating that a strategic focus on foundational subjects and critical coursework can significantly enhance outcomes in advanced subjects like ASC303. By leveraging these insights, institutions can foster a more supportive learning environment, empowering students to excel in rigorous academic disciplines. This work lays the foundation for further exploration into optimizing educational pathways for actuarial science and other STEM fields. Expanding beyond categorical grades to topic-level diagnostics (e.g., time-value-of-money proficiency) could uncover nuanced learning gaps.

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