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Visualizing Student Performance in Linear Algebra Course: A Power BI Dashboard Analysis

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ABSTRACT

BACKGROUND & CONTEXT

In technically challenging disciplines, such as engineering mathematics, data-driven techniques can offer students quick insights into their performance. Microsoft Power BI platforms have proven to be effective tools for visualizing academic data; however, their potential in item-level assessment analytics still needs to be fully explored.

PURPOSE OR GOAL

The primary objective of this study is to visualize student achievement across demographic groups (gender, ethnicity and English proficiency) and assess the quality of exam items by analysing metrics like item difficulty and discrimination indices. This is done with an explicit focus on how these metrics align with course-specific Learning Outcomes (LOs) related to conceptual understanding and complex problem-solving in linear algebra.

APPROACH OR METHODOLOGY

The research employs a six-phase design-based research methodology, which includes planning, analysis, data modelling, design, prototype development and initial validation. Data, incorporating demographic characteristics, mid-semester exam scores and MUET English proficiency bands, were collected from 171 civil engineering students across two academic cohorts (2023/2024 and 2024/2025).

OUTCOMES

The results indicated that the cohorts were gender-balanced, with a majority of Malay students with intermediate English proficiency. Most students obtained a grade of A or B+. Furthermore, item-level analysis revealed that Question 3 had the highest difficulty and discrimination, making it the most effective at differentiating student achievement.

CONCLUSIONS

The findings underscore Power BI's potential to support evidence-based teaching in engineering mathematics and offer a scalable model for diagnostic analytics across higher education institutions, thereby enhancing the formative feedback loop.

KEYWORDS

Power BI, Engineering Mathematics, Item Analysis, Assessment Analytics.

Introduction

Higher education has undergone a profound transformation since the COVID-19 pandemic, primarily due to the increasing reliance on digital technologies to support teaching and learning. This shift has brought data analytics to the forefront, especially in technically demanding disciplines such as engineering and mathematics, where timely and accurate insights can enhance both pedagogy and student outcomes. As class sizes expand and teaching approaches diversify, higher education institutions are increasingly recognising the importance of data-informed decision-making. In response, many have adopted business intelligence (BI) tools to better manage and understand their academic environments (Metre et al., 2023; Tirupati et al., 2023).

Microsoft Power BI, for example, is now widely used because of its ability to consolidate data from multiple sources, produce real-time interactive visualisations, and develop dashboards tailored to specific departmental or course needs. These features not only improve institutional monitoring but also equip educators with powerful tools to make informed decisions aligned with student needs and academic objectives.

In engineering mathematics, Power BI enables lecturers to evaluate student performance at a micro level, including performance by individual question, concept mastery, and cohort analysis across semesters. Its DAX (Data Analysis Expressions) functions support advanced statistical calculations such as mean, standard deviation, variance, linear regression, correlation indices and conditional probabilities (Saranya, 2024; Pape, 2016). This functionality allows Power BI dashboards to track student performance across questions, topics, or learning domains, facilitating more effective formative assessment.

The efficacy of learning analytics tools is intrinsically linked to theories of knowledge acquisition. Specifically, the interactive and visual nature of the Power BI dashboard aligns with constructivist principles, encouraging students' metacognitive reflection and self-regulated learning when they receive immediate feedback (Azevedo & Hadwin, 2005). For educators, the visual data facilitates evidence-based teaching cycles rooted in experiential learning (Kolb, 2015).

A key component of improving assessment quality is item analysis. Classical Test Theory (CTT) supports the evaluation of item difficulty, discrimination index, and test reliability (Ridwan et al., 2021), ensuring each test item fairly and accurately assesses student proficiency. Although Birch et al. (2014) demonstrated the potential for item modelling using engineering spreadsheets in conjunction with visualisation tools such as Power BI, such spreadsheet-based approaches lack the capacity for real-time integration of psychometric diagnostics or granular item-level comparisons across demographic groups, thereby limiting their applicability for proactive curriculum refinement.

In contrast, more recent studies emphasise the need for dynamic learning analytics dashboards that can provide fine-grained, real-time insights to educators (Ifenthaler, 2021; Siemens, 2022). These limitations underscore the novelty of the current study's Power BI framework, which integrates item-level psychometric indicators alongside demographic filters to enhance evidence-based teaching. Furthermore, Saranya (2024) demonstrated that Power BI can replace conventional statistical platforms by automatically computing and displaying discrimination indices and Cronbach's alpha values.

Some studies have incorporated Item Response Theory (IRT) to better understand latent ability and item reliability in a dynamic manner (Kadhem & Nikolouloupoulos, 2021). Models such as 2PL and 3PL IRT determine the likelihood of a correct response based on a student's ability level. Although Power BI is not natively designed for IRT, Cheng, S., & Liu, Q. (2019) showed that IRT modelling outputs can be integrated into Power BI dashboards to support learning diagnostics.

Several empirical studies have explored the application of Power BI in technical education as well as in developing undergraduate engineering mathematics students' conceptual and

procedural knowledge of complex numbers using GeoGebra. Seloane et al (2025), for instance, demonstrated that visual tools such as GeoGebra can enhance students' understanding in mathematics courses. Similarly, a study by SEFI (2013) emphasised the role of computer algebra systems like Mathematica in making abstract concepts more accessible. All these tools align with Power BI's core philosophy: promoting interactive and visual learning in STEM education. Beyond education, Power BI has also been shown to enhance project tracking and process automation, further demonstrating its versatility as a data-driven platform (Attar et al., 2025).

However, a research gap remains concerning the direct use of Power BI for item-level analysis within engineering mathematics (Tirupati et al., 2023). Most studies emphasise general applications of Power BI in education without focusing on its potential to refine teaching and feedback at the question level. Thus, further research is needed to integrate item analysis (both CTT and IRT) with Power BI visualisation, particularly in mathematically intensive courses such as Linear Algebra, Vector Calculus, and Engineering Mathematics.

Hence, this study aims to design and develop an interactive Power BI dashboard to visualise item-level student performance using authentic mid-semester examination data. The dashboard integrates demographic variables, such as gender, ethnicity, English language proficiency, and academic session in order to support fine-grained and comparative analyses. Ultimately, the study contributes a scalable model for evidence-based teaching in higher education, advancing diagnostic analytics and curriculum refinement in quantitative disciplines. While existing research primarily explores Learning Management System (LMS) analytics or large-scale summative reporting (Siemens, 2022), the unique contribution of this work lies in the real-time, granular integration of psychometric diagnostics within a customisable Power BI framework specifically tailored for evidence-based formative intervention in undergraduate engineering mathematics.

To provide a rigorous framework for this study, the following research questions (RQ) are addressed:

RQ1: To what extent does the Power BI dashboard facilitate the identification of statistically discriminatory and difficult test items?

RQ2: How does the dashboard support lecturers in refining assessment design and aligning exam items with intended Learning Outcomes?

RQ3: What is the perceived utility of the dashboard among lecturers and students for informing teaching decisions and self-regulated learning?

Methodology

This study adopts a design-based research (DBR) methodology to construct and evaluate an interactive Power BI dashboard for item-level assessment analytics in engineering mathematics. The process comprises six structured phases: namely, Planning, Analysis, Data Modelling, Design, Prototype Development, and Initial Validation.

Planning Phase

This initial phase involved identifying the pedagogical objectives and technical requirements for the dashboard. The study focused on the Linear Algebra course delivered to first-year students in Semester II at the Department of Civil Engineering (JKA). The aim was to develop a visual reporting tool capable of facilitating item-level performance analysis and linking academic outcomes to demographic variables. Preliminary planning included centralising and restructuring existing data, such as student demographics, examination scores and English proficiency levels. This is to enable multidimensional reporting within Power BI. Key performance indicators (KPIs) were also established, including:

- (a) Student composition by gender, ethnicity and English proficiency,

- (b) Mid-semester examination statistics (mean, standard deviation, highest and lowest scores),
- (c) Item-level (Q1–Q3) performance comparisons by demographic group.

Analysis Phase

In this phase, lecturer reflections and historical assessment practices were analysed to identify specific challenges. These included the difficulty of manually diagnosing student strengths and weaknesses at the item level, and the lack of tools to correlate academic performance with cohort or demographic profiles. The dataset comprised mid-semester examination results for two academic cohorts (2023/2024 and 2024/2025), including item-level scores and demographic variables (gender, ethnicity and English proficiency) as shown in Figure 1.

Student Details:

No.Pend	Nama	Tarikh Lahir	Jantina	Bangsa	Agama	Negeri Lahir	Year Intake	Thp Kelayakan BI	MUET
A208583	MOHAMAD AFIQ IZZUDDIN BIN MOHD SULAIMAN	Thursday, 24 May, 2001	Lelaki	Melayu	Islam	Johor	2024/2025	MUET: 4.0	4
A208657	MUHAMMAD AZRI BIN RAMLEE	Sunday, 10 February, 2002	Lelaki	Melayu	Islam	WP Kuala Lumpur	2024/2025	MUET: 4.0	4
A209390	AININ SOFYA BINTI JASMAN	Sunday, 1 February, 2004	Perempuan	Melayu	Islam	Melaka	2024/2025	MUET: 4.0	4
A210043	MUHAMMAD ADHWA' IZZ BIN MUHAMMAD IKHWAN	Thursday, 19 August, 2004	Lelaki	Melayu	Islam	WP Kuala Lumpur	2024/2025	MUET: 4.0	4
A210517	NURIN ALYA NATASYA BINTI MOHD AMIRUDIN	Wednesday, 5 January, 2005	Perempuan	Melayu	Islam	Perlis	2024/2025	MUET: 4.0	4
A210613	ANIYA DHANIYAH BINTI ZAINUDDIN	Friday, 21 January, 2005	Perempuan	Melayu	Islam	Kelantan	2024/2025	MUET: 4.0	4
A210833	ELI SYAZWANI BINTI AZIMAN	Wednesday, 23 February, 2005	Perempuan	Melayu	Islam	Melaka	2024/2025	MUET: 4.0	4
A210905	MUHAMMAD FAKHRURRAZI BIN NOOR SHAM	Saturday, 5 March, 2005	Lelaki	Melayu	Islam	Melaka	2024/2025	MUET: 4.0	4
A211283	MUHAMMAD AFIQ DAENISH BIN WAN ZAINUDIN	Sunday, 1 May, 2005	Lelaki	Melayu	Islam	WP Kuala Lumpur	2024/2025	MUET: 4.0	4
A211425	NUR ATHILAH AMIRAH BINTI MOHD NOOR	Monday, 23 May, 2005	Perempuan	Melayu	Islam	Kedah	2024/2025	MUET: 4.0	4
A211802	NUR HURIN NABIHAH BINTI HAZLAN	Wednesday, 27 July, 2005	Perempuan	Melayu	Islam	Pahang	2024/2025	MUET: 4	4
A211820	NUR IRDINA ILMUNA BINTI MOHAMAD SALZELI	Friday, 29 July, 2005	Perempuan	Melayu	Islam	WP Kuala Lumpur	2024/2025	MUET: 4.0	4

Student Midterm Results:

No. Pend	Nama	Total	Grand_Total	GredMidsem	GredOrder	Soalan	Markah
A212580	ASHRAF HAKEEM BIN MOHD ARIF	27.00	54.00	C	7	Q3	5.00
A212579	MUHAMMAD IQBAL BIN ROSMAN	36.00	72.00	B+	3	Q3	3.00
A212525	HAMDAN HAMIDEEN BIN MD AMIR	31.50	63.00	B-	5	Q3	8.00
A212503	NAJWAN BIN NASARUDDIN	45.00	90.00	A	1	Q3	12.00
A212442	MUHAMMAD KHAIRIL BIN MAKHTAR	25.50	51.00	C	7	Q3	6.00
A212192	NURUL AISYAH AQILAH BINTI MOHAMAD RIZAL	37.00	74.00	B+	3	Q3	9.00
A212174	AMIRAH MAISARAH BINTI MOHD RAMADHANI AMIN	36.00	72.00	B+	3	Q3	13.00
A212170	ZUHRAH MUSFIRAH BINTI JAMALUDIN	21.00	42.00	D+	9	Q3	2.00
A211982	MUHAMMAD AZHAR BIN AMIN	37.00	74.00	B+	3	Q3	11.00
A211804	SIVANESAN A/L PUSHPANATHAN	MUHAMMAD AZHAR BIN AMIN		E	11	Q3	0.00
A211548	MOHAMAD AMIRUL ADLI BIN AZMI	31.00	62.00	B-	5	Q3	3.00
A211493	NUR RASYIAH BINTI IRWAN	42.00	84.00	A	1	Q3	8.00
A211353	NUR AFRINA BATRISVIA BINTI HAIRI	26.50	53.00	C	7	Q3	6.00
A211188	IRDINA IMAN BINTI MOHD KHAIRUL SABRI	29.00	58.00	C+	6	Q3	7.00
A211157	MUHAMMAD AFINAN BIN MOHAMAD KHAIRUDDIN	32.00	64.00	B-	5	Q3	3.00
A210964	AIRIN FATINIE BINTI AMITABKHAN	40.00	80.00	A	1	Q3	7.00

Figure 1: Student demographic and midterm performance data in Excel

International students from China were also part of the sample, allowing for cross-cultural comparison. Each student was uniquely identified using an education ID (*No. Pend.*), and each item response was annotated with attributes such as question number, full mark, and topic (see Figure 1). This hierarchical data structure facilitated multilevel analysis at the individual student, item and cohort levels.

Data Modelling

The data modelling phase employed the Kimball methodology, enabling the structuring of a star schema model within Power BI. This included a central fact table and four-dimension tables:

- (a) Time (When): Year of enrolment (e.g., 2023/2024 and 2024/2025)
- (b) Subject (What): Exam question codes (Q1, Q2 and Q3)
- (c) Student (Who): Gender, ethnicity and English proficiency
- (d) Assessment (How): Raw scores and grades

These dimension tables were designed to support slicing and filtering across multiple reporting axes within the dashboard.

Design Phase

The design phase focused on aligning dashboard functionality with lecturer expectations and course learning outcomes. Microsoft Power BI was selected for its ability to integrate various data sources, apply statistical measures via DAX (Data Analysis Expressions) and support interactive visualisations.

Key design decisions included:

- (a) Use of slicers or filtering by cohort, topic and gender.
- (b) Selection of visuals: bar charts, matrices. Combo charts and tables
- (c) DAX metrics: mean, standard deviation, maximum and minimum scores.

Dashboard elements were developed iteratively based on educator feedback to ensure relevance and usability.

Prototype Development

The Power BI prototype was developed using Power BI Desktop and included the following visuals:

- (a) Bar and doughnut charts are used to display gender, ethnicity, religion, and English distributions score,
- (b) Matrix and column charts are used to show performance according to demographics and year of entry.
- (c) A combo chart and interactive slicer are used for comparing the average item scores based on demographic variables.

The layout was optimised for clarity, with particular attention paid to the interpretability of graphs for non-technical users.

Initial Validation

The initial prototype underwent pilot testing with two course coordinators. Feedback indicated, for example, that the initial filtering controls lacked clarity. This direct input led to a revision that included clearer tooltips and pre-set comparative views (e.g., 'High vs. Low English Proficiency') to streamline the diagnostic process, thus validating the prototype's usability. However, a comprehensive pedagogical efficacy study, which will involve formal, mixed-methods data collection (e.g., interviews, surveys) to capture lecturer reflections on how visual analytics specifically influence their teaching decisions and to assess student perceptions, remains the focus of future work.

Microsoft Power BI, ETL and Data Modelling

Microsoft Power BI is a cloud-based data analytics and visualization software widely used in the business and education sectors to analyse performance and deliver insights visually through interactive dashboards. In this study, Power BI is used as the main platform to build a student dashboard that integrates examination performance data, demographic profiles, and the English proficiency levels of engineering students.

Power BI offers a variety of analytical tools that enable data connection from various sources, the creation of reports, charts, graphs, and interactive dashboards. This capability enables non-technical users to understand and evaluate key performance indicators (KPIs) more effectively.

Power BI is widely recognised for its affordability, making it accessible to a broad range of users. It also offers regular updates and an intuitive, user-friendly interface, which enhances its appeal for both technical and non-technical users. Among its key features are a diverse range of visualisation tools, including bar charts, donut charts, card indicators, and interactive

slicers, all of which support dynamic data exploration. Furthermore, Power BI integrates seamlessly with various data sources such as Microsoft Excel and SQL Server. It also empowers users to develop advanced analytics using Data Analysis Expressions (DAX), facilitating the creation of custom formulas and in-depth reporting.

Extract-Transform-Load (ETL)

The ETL process consists of three primary stages: extraction, transformation, and loading data into the central data model. This study extracts data from Excel files that include student information (gender, ethnicity and year of enrolment), mid-semester exam results (marks and grades), and English proficiency scores. The data was then cleansed and organised prior to being uploaded to Power BI. The transformation process involves the following steps:

- (a) Removal of irrelevant columns,
- (b) Merging data from various files based on No. Pend.,
- (c) Changing column names to a consistent format (for example, "MidsemScore" and "GredMidsem"),
- (d) Reorganising the data structure to enable the construction of factual and dimensional table.

Through this process, several dimension tables have been identified and formed, among them are as listed below:

- (a) DimPelajar: contains No. Pend., gender, ethnicity and year of enrolment
- (b) DimSoalan: contains the code and question numbers of the exam (Q1, Q2, Q3)
- (c) DimMUET: contains MUET band scores (Band 3.0, 3.5, 4.0, 4.5)
- (d) DimTahun: academic years or semester of enrolment.

Meanwhile, the fact table (FactPrestasiMidsem) stores the actual scores and grades for each student for each question.

Results and Discussion

This section analyses the findings derived from three interactive Power BI dashboards designed to explore student demographics, mid-semester examination performance, and item-level analysis with demographic correlations. Descriptive statistics and visual analytics were employed to uncover performance patterns, identify potential gaps, and inform targeted improvements in teaching strategies.

Student Demographics and Profile Overview

The *Student Profile* dashboard (see Figure 2) visualises demographic data for Civil Engineering (JKA) students enrolled in an undergraduate engineering mathematics course at UKM across the 2023/2024 and 2024/2025 academic sessions. A total of 171 students participated in the study, with a relatively balanced gender distribution. The 2024/2025 cohort comprised 48 males and 42 females, while the 2023/2024 cohort included 35 males and 46 females. This gender balance strengthens the reliability of demographic comparisons in performance analysis.

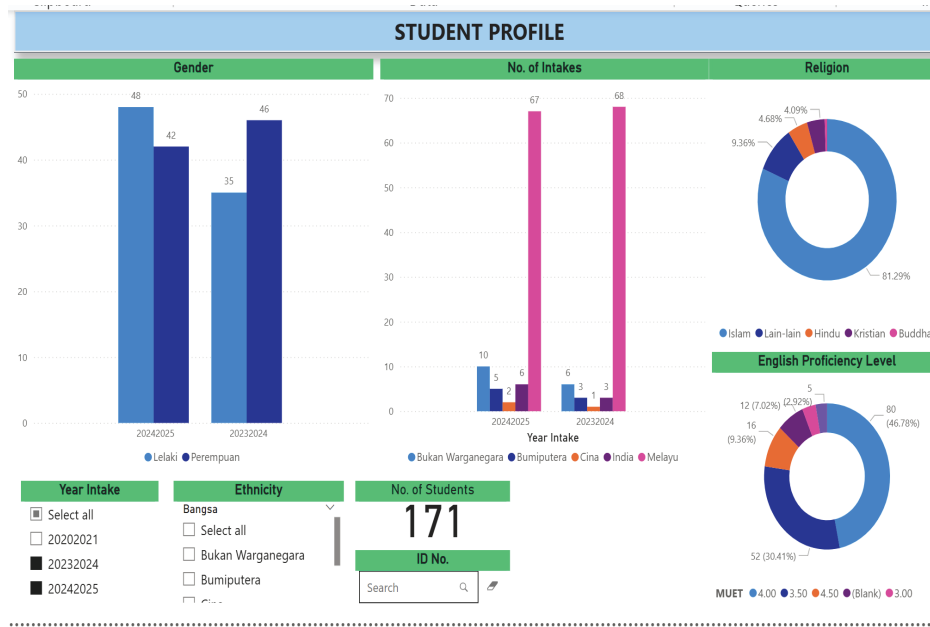


Figure 2: Data model in Power BI

As shown in Figure 3, the majority of students were ethnically Malay, followed by Bumiputera (Sabah and Sarawak), Chinese, Indian, and a small group of non-citizens. Specifically, Malay students made up approximately 84% of the 2023/2024 cohort and 74% of the 2024/2025 cohort. Religious distribution, depicted via a doughnut chart, revealed that 81.29% of students identified as Muslim, followed by Hindu (6.48%), Christian (4.09%), Buddhist (0.58%), and a small percentage who reported no religious affiliation. This reflects the multicultural and multireligious nature of Malaysian higher education, reinforcing the need for culturally responsive teaching strategies.

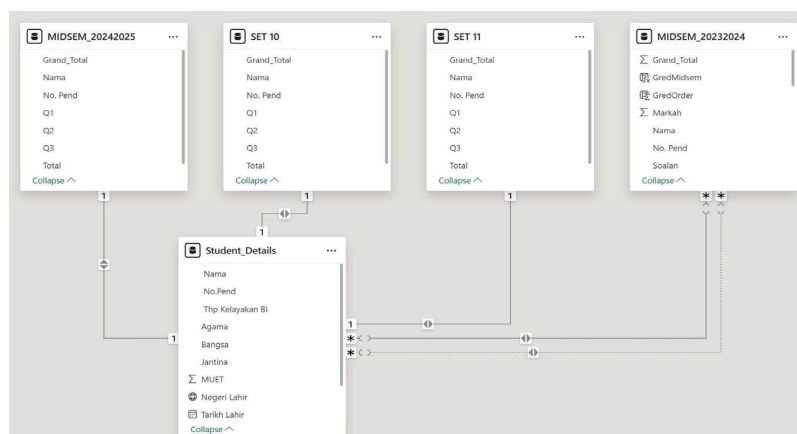


Figure 3: Power BI visualization of student demographics, including gender distribution, year of intake, religion, ethnicity, and English proficiency level (MUET)

English language proficiency was measured using the Malaysian University English Test (MUET) band scores. The distribution indicated that most students possessed intermediate proficiency. Approximately 46.78% scored Band 4.0, and 30.41% achieved Band 3.5. Notably, only five students attained Band 5.0 (advanced proficiency), while 3.51% remained at Band 3.0 (lower intermediate). These data suggest that while most students are adequately prepared for English-medium instruction, a proportion may face challenges in understanding technical terminology in mathematics-related assessments.

Midterm Performance by Gender and Year Intake

Figure 4 presents the second dashboard, which offers a summary of mid-semester examination performance across the two cohorts. The overall average score was 63, with a standard deviation of 5.48. The highest recorded score was 91, and the lowest was 15.56. These values are based on the results of 171 students.

This dashboard enables the filtering of student performance by gender, ethnicity, and academic cohort, allowing for in-depth observation of performance trends. The histogram visualisation shows grade distributions stratified by gender and ethnicity. Grades A and B+ were most prevalent, particularly among female and Malay students.



Figure 4: Power BI visualization of midterm performance in Engineering Mathematics

A funnel chart ranks grade frequencies from highest to lowest, highlighting that 33 students obtained Grade A, followed by 28 with B+, and 20 each with B- and C. This indicates that a substantial proportion of students performed at a moderately high level. The dashboard thus serves as a valuable diagnostic tool for identifying at-risk groups and guiding instructional support.

Item-Level Performance and Discrimination Analysis of Midterm Questions

The third dashboard (Figures 5 and 6) visualises item-level performance across three midterm questions (Q1, Q2, and Q3). Boxplots, grouped by gender, illustrate the distribution of scores and support the identification of patterns in student responses.

A key observation (see Figure 5) is the relatively narrow distribution of scores for Q2, suggesting consistent student performance, either due to the question's uniform difficulty or its limited discriminatory power. In contrast, Q1 and Q3 display wider score distributions, indicating greater variation among students. Notably, Q1 includes a wider upper range, with several high-performing students, potentially signalling its effectiveness in distinguishing stronger candidates. This aligns with assessment best practices, where a spread of scores is indicative of effective discrimination

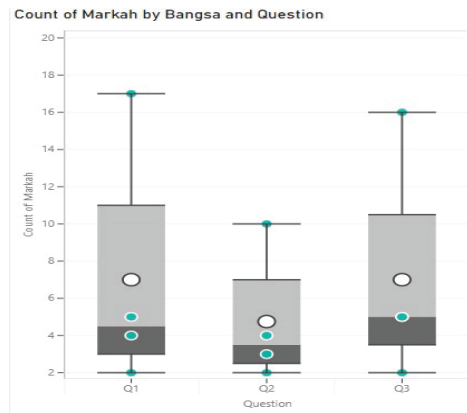


Figure 5: Boxplot visualisation of midterm performance

Further analysis (Figure 6) reveals that Q1 and Q2 had similar difficulty levels, with approximately 41% of students answering each correctly, classifying them as moderately difficult. Q3, however, had a correct response rate of only 18%, making it the most difficult item. Despite its difficulty, Q3 recorded the highest discrimination index (0.72), meaning it effectively distinguished between high and low performers. Q1 and Q2 also showed strong discriminatory power, with indices of 0.70 and 0.68, respectively. These findings are significant for assessment quality assurance, as they inform whether questions accurately reflect differences in student understanding.



Figure 6: Comparison of item difficulty and discrimination indices for each midterm question in Linear Algebra

Collectively, the item-level analysis emphasizes the importance of combining difficulty and discrimination indices to inform test design and ensure alignment with curricular goals. For instance, the finding that Q3 was the most discriminating item suggests it was the most effective in assessing a higher-order LO, namely the ability to apply linear algebra concepts to solve non-routine, and complex problems (mathematical thinking) compared to Q1 and Q2, which likely assessed foundational conceptual understanding or direct computation. This link supports curriculum refinement.

Conclusion

This study successfully demonstrates the potential of an interactive Power BI dashboard to support item-level analysis of student performance in engineering mathematics. By integrating demographic profiles, midterm performance trends and detailed item statistics, the dashboard enables educators to assess both student learning outcomes and the effectiveness of assessment instruments.

The demographic findings revealed a relatively balanced gender distribution, with a high proportion of Malay and Muslim students. English language proficiency was generally at the intermediate level, although a minority of students may face linguistic challenges in technical subjects. These observations emphasised the need for culturally inclusive and linguistically accessible teaching strategies.

In terms of performance, most students achieved Grade A or B+, with clear patterns observed across gender and ethnic lines: female and Malay students tended to perform better overall. These findings suggest avenues for further pedagogical exploration and the development of targeted academic support initiatives.

At the item level, Question 3 was identified as the most difficult but also the most discriminating, effectively distinguishing between students with varying levels of understanding. Although Questions 1 and 2 were less difficult, they still achieved acceptable discrimination indices. These results reinforce the value of using both difficulty and discrimination indices to evaluate test quality and refine assessment design.

Overall, this study affirms the usefulness of business intelligence tools such as Power BI in enhancing evidence-based teaching. By enabling detailed, visual, and real-time performance analysis, Power BI empowers educators to make data-informed decisions that support continuous instructional improvement, student feedback, and curriculum development, particularly in mathematically intensive fields.

Beyond the immediate context of a single course, the Power BI dashboard model presents a scalable framework for institutional integration. Given Power BI's compatibility with diverse data sources, this approach can be readily adapted for other mathematically intensive courses (e.g., Vector Calculus, Differential Equations) or integrated longitudinally to track student performance across an entire engineering programme. Crucially, the dashboard reinforces the formative assessment and feedback loop. By offering educators targeted, item-level diagnostic feedback, it shifts focus beyond mere summative reporting. Future work should investigate integrating this dashboard directly into university Learning Management Systems (LMS) to provide real-time, actionable analytics for all users. This adaptability mirrors broader applications of Power BI in industry, where it has supported project management and workflow automation (Attar et al., 2025), highlighting its cross-domain versatility.

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