Unlocking Learning Potential in Advanced-level Mathematics: AI-Driven Spaced Retrieval for Enhanced Pedagogy

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Wan Sieng Yeo[a,d,*], Mary Jenny Yee Tiing Lim[b], Fethma M Nor[c], Agus Saptoro[d]

[a]Department of Oil and Gas Engineering, Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.
[b]Learning and Teaching Department, Office of Learning and Teaching, Curtin University Malaysia, CDT 250, 98000 Miri, Sarawak, Malaysia.
[c]Mechanical Engineering Department, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, 98000 Miri, Sarawak, Malaysia.
[d]Chemical and Energy Engineering Department, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, 98000 Miri, Sarawak, Malaysia.
**yeows@ums.edu.my*

Abstract
Retrieval practice is an effective learning approach that involves students actively retrieving knowledge from memory after completing the lesson (like lectures, workshops, and labs), which improves memory retention and fosters long-term learning. In short, this study underpins Retrieval Practice Theory. Unlike the pre-test, which involves taking practice tests before learning new information as opposed to afterward, retrieval practice is a strategy where students are tested on questions about unit materials that they have already learned. However, a more interactive spaced retrieval practice using a new platform, such as the highly recommended AI-powered question generators like Edapp, is still limited. This new spaced retrieval practice was implemented two times per semester for mid-semester tests, and then the data was collected for analysis. Based on an engineering first-year unit, namely MATH1020 Calculus for Engineers, after implementing spaced retrieval practices in the first semester of 2024, a significant increase in the passing rate was observed, up to 20.33%. The 95% confidence intervals for the passing rates further reinforce this improvement, showing that the post-intervention cohort's performance was not only higher but also statistically more precise compared to the pre-intervention groups. This substantial improvement demonstrates the effectiveness of the newly proposed intervention.

Keywords: pedagogy, spaced retrieval, AI-driven, mathematics, student-centered approach.

Introduction

First-year engineering courses play a pivotal role in shaping the foundation of future engineers, requiring innovative teaching strategies to engage students, promote deep learning, and improve the courses' passing rates. Retrieval practice involves activities undertaken to activate prior knowledge and enhance students' learning experiences. The effectiveness of retrieval practice has been demonstrated in various educational contexts, including classrooms and online learning environments, in various fields of study (Carpenter, 2023; Van Hoof et al., 2023; Wellmann & Skillicorn, 2024). Encouraging more frequent use of retrieval practice can enhance student achievement (Wang et al., 2023).

Retrieval practice consistently benefits student learning by improving learning outcomes across various educational levels, content areas, experimental designs, final test delays, retrieval, final test formats, the timing of retrieval practice, and feedback (Agarwal et al., 2021). Recently, the efficacy of retrieval practice in university mathematics was investigated by Szabó et al. (2023), and they discovered that it is useful for students with low, average, or high mathematical competence and that it can be an efficient method of learning higher mathematics to be implemented in classes to improve students' performances. This retrieval practice can be conducted via massed practice or spaced practice, as shown in Figure 1.

Massed practice refers to conditions in which individuals practice a task continuously without rest, studying, or learning that takes place all at once over a

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long period. This massed practice is only one practice before the actual test, like a pre-exam. Meanwhile, spaced practice refers to conditions in which individuals are given rest intervals within the practice sessions, studying, or learning that takes place in smaller amounts of time spread out over multiple sessions. Lyle et al. (2022), Lyle et al. (2020), and Hopkins et al. (2016) found that spaced retrieval practice improved mathematical knowledge retention. This is in line with other recent research, including Ebersbach and Nazari (2020), Emeny et al. (2021), and Yazdani and Zebrowski (2006), who demonstrated spacing effects in different forms of mathematics learning.

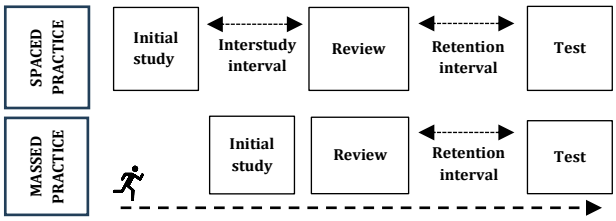

Figure 1. Massed practice and spaced practice before the test

Since students sometimes are unsure where to start, they try to cram all the information they need at the last minute, which leads to hours of wasted time staring at a blank screen, which only causes them more stress. The spaced retrieval practice enhances students' memory, with previous research finding an increased percentage in grades (YeckehZaare et al., 2022) and increasing the retention of STEM knowledge, including mathematics knowledge (Bego et al., 2017; Carpenter, 2023; Hopkins et al., 2016; Lyle et al., 2020; Lyle et al., 2022; May, 2022; Razzaq et al., 2025; Yasar et al., 2019). Honestly, Stavnezer and Lom (2019) reported that the scores for retrieval practice did not differ before and after instruction. Therefore, the effectiveness of the spaced retrieval practice on MATH1020 remains questionable. Thus, this project utilized AI-enhanced applications to improve student engagement by providing an AI-powered question generator for MATH1020 Calculus for Engineers.

Research Methodology

AI-powered online system, EdApp

In this project, the free and highly recommended AI-powered online system, EdApp, was used for the spaced retrieval practice to support the student-centered pedagogy approach in a first-year engineering course, namely MATH1020 Calculus for Engineers. The questions were generated based on the past year's tests and exam papers, and these questions were reviewed and validated by all authors. In EdApp, an action plan is provided after students answer the questions, explaining the fundamental theory behind each question and identifying the relevant teaching materials that students should review.

This project is also introduced to improve the existing online quizzes via the Pearson system and STACK in this unit, which requires the specified syntax for the final answers. The spaced retrieval practices in the project are set as multiple-choice questions, and true or false questions require working steps to get the right answer mapped to the unit learning outcomes (ULOs) and program outcome (PO). The test questions designed in this study primarily assessed students' understanding and analytical skills. Most questions required students to demonstrate conceptual understanding, interpret mathematical information, and apply appropriate solution methods to solve problems. Additionally, other e-learning platforms like Kahoot, the Pearson system, and STACK do not offer the feature to include the action plans for each question in the spaced retrieval practices.

In the meantime, the team members built a total of 20-25 questions related to the unit contents based on the pattern of the past test questions and provided them for each retrieval practice using an AI-powered question generator, namely EdApp. The range of 20–25 questions was used to provide flexibility in aligning the number of questions with the complexity and coverage of each topic. Meanwhile, all students received the same questions. The retrieval practice sessions were conducted twice, with each session lasting one hour, during scheduled revision classes after the completion of specific topics and before the actual test/exam. This activity is considered an active learning strategy because students actively retrieved previously learned knowledge through structured questions. **Figure 2** shows the operational framework of the retrieval practice sessions in this study. These initiatives are to help students prepare for the test by allowing them to practice answering questions under similar conditions to the real test. Additionally, suggested action plans were provided in the system after the spaced retrieval practices. This AI-powered system allows students to generate a certificate of completion, which serves as a complement to their learning and commitments. By utilizing the spaced retrieval practice, it was expected to assess their learning of conceptual theory and fundamental principles in this unit before the actual assessments, and improve the passing rate of the unit.

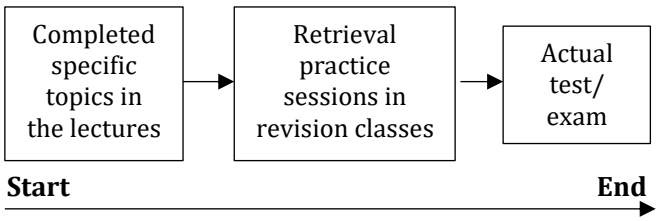

Figure 2. Operational framework of the spaced retrieval practice sessions in this study

Data collection and analysis

Data collection was conducted for semesters in the years 2023 and 2024 before and after the retrieval practices: i) the total number of students, ii) mid-semester test marks, and iii) the passing rates. To be more specific, the sample sizes were 61 students in Semester 1 of 2024, 28 students in Semester 1 of 2023, and 25 students in Semester 2 of 2023. Basically, this study used a quantitative approach to evaluate the impact of spaced retrieval practice on student performance. A quasi-experimental research design for semesters in the years 2023 and 2024, before and after the retrieval practices, was used to assess the effectiveness of the retrieval practice. The following data was collected to understand the students' activities, engagement, and learning behavior. All the collected data from learning activities were tabulated to understand their trends and patterns.

In the analysis, the relationships between sets of data and the passing rate were analyzed and compared. The percentage error, PE, displayed in (1), was used to compare the data collected before the spaced retrieval practices. Factors that affect the passing rate of the unit were identified. Moreover, the root causes of problems faced and solutions were also justified.

$$PE = \left|\frac{V_a - V_b}{V_a}\right| \times 100\% \quad (1)$$

where V_a and V_b refer to the average test marks and passing rates after and before the spaced retrieval practices, respectively.

Anonymous questionnaire survey

An online anonymous questionnaire survey for the spaced retrieval practice in the clinic classes was conducted in July 2024 for 3 weeks, and it was voluntary. The purpose of this online anonymous questionnaire survey is to gather student feedback on how they experience the spaced retrieval practice in the clinic classes of the semester. It took roughly 8 minutes to complete all questionnaire survey questions, and there is only one survey for a semester in this study. And all the participants' details remain confidential and were not collected, are non-identifiable, and are analyzed. Hence, this research project has no foreseeable risks since the participants' information was not collected or analyzed.

Results and Discussions

This study was conducted in Semester 1, 2024, on an engineering first-year unit, MATH1020 Calculus for Engineers. This unit has a lower passing rate, a high number of repeat students, and is traditionally a complex or difficult unit. The initiative of this study is to support the learning and teaching of this teaching unit so that students perform better and have a better learning experience. The following subsections are the results of the data analysis and the anonymous questionnaire survey.

Results of the data analysis

The results of the data analysis in this study are summarized in **Table 1**, which highlights the variation in students' performance due to different teaching strategies and learning approaches. As mentioned earlier in the methodology section, the numbers of students in Semester 1 of the year 2024 and Semesters 1 and 2 of the year 2023 are 61, 28, and 25, respectively. It is worth noting that the number of students in a semester did not impact the analysis, as the means of the marks were used to standardize the result data regardless of the number of students (Glass & Hopkins, 1996), ensuring fair comparisons across different groups (Wright, 2008). Hence, the student numbers were not a factor in data analysis.

From **Table 1**, the mean for the mid-semester test mark, which is out of 100 in Semester 1 in the year 2024, is higher than both Semesters 1 and 2 in the year 2023. The mean of the marks exceeding 50% indicates that students are performing above the minimum passing threshold, suggesting a generally satisfactory level of understanding and competence in the teaching unit. This concept is further supported by Kamaruddin et al. (2023), who discussed how the means of the marks are used to indicate student performance and understanding. In this study, these three-semester students have a mean of marks of 60.60-70.66, all exceeding 50 out of 100, or 50%, indicating above-average performance on the test. Nevertheless, in Semester 1 of 2024, the spaced retrieval practices facilitated better performance, with an improvement of 14.14%-14.24% in the mean of the marks compared to Semesters 1 and 2 of the year 2023. These findings support the correlation of the spaced retrieval practices and their retention benefit, where these findings are consistent with the study from Roediger III and Karpicke (2006). They adopted a similar approach to retrieval practices and demonstrated a scaling improvement in student average performance. This consistency in results suggested that the spaced retrieval approach could benefit long-term retention and understanding.

In addition, the median of the mark in Semester 1, 2024, after the spaced retrieval practices is higher than before these practices in Semesters 1 and 2, 2023, by about 14.91% and 12.38%, respectively. Moreover, note that the medians of Semester 1, 2024, are slightly higher than their means, indicating that the bulk of students achieved relatively high scores and performed well. Besides that, Table 1 shows that the passing rate of the mid-semester test in Semester 1 of the year 2024 was over 80%, which improved significantly from Semesters 1 and 2, 2023, by 15.52% and 20.33%, respectively. These significant improvements in student passing rate further verify statistically the effectiveness of spaced retrieval practice approaches on student capability to retain and apply knowledge over time.

Table 1. The obtained results *before and **after the spaced retrieval practice for the mid-semester test

Learning mode	Face-to-face learning mode				
Semester/ year	****S1 2024**	***S1 2023**	***PE (%)***	***S2 2023**	***PE (%)***
Total number of students	**61**	28		25	
Mean of the mark (Total: 100)	**70.66**	60.67	14.14	60.60	14.24
Median of the mark (Total: 100)	**71.25**	60.63	14.91	62.50	12.28
Passing rate (%)	**80.33**	67.86	15.52	64.00	20.33

*S1 and S2 are Semesters 1 and 2, respectively.

Furthermore, **Table 2** summarizes the computed 95% Wilson confidence intervals (CIs) for passing rates of the mid-semester test. In Semester 1, 2024, which is after retrieval practice, the passing rate was 80.33%, with a 95% CI ranging from 68.69% to 88.37%. This result indicates that the true passing rate of the population lies within this interval. The relatively narrower interval reflects the larger sample size (n = 61), which provides a more precise estimate. Moreover, in Semester 1, 2023 (before retrieval practice), the passing rate was 67.86%, with a 95% CI of 49.34% to 82.07%. The range of CIs is wider because of the smaller sample size (n = 28), indicating greater uncertainty in the estimated passing rate. Also, for Semester 2, 2023 (before retrieval practice), the passing rate was 64.00%, and the 95% CI was 44.52% to 79.75%. Like Semester 1, 2023, the smaller sample (n = 25) also results in a wide interval, showing less precision. In conclusion, based on our findings, it is worth noting that such retrieval practices do not merely enhance short-term memorization but foster deeper learning and understanding, leading to better academic outcomes.

Table 2. The obtained 95% confidence intervals for passing rates *before and **after the spaced retrieval practice for the mid-semester test

Semester/year	95% CI (Wilson)
****S1 2024**	68.69 – 88.37
***S1 2023**	49.34 – 82.07
***S2 2023**	44.52 – 79.75

Furthermore, to address the limitation of other e-learning platforms that do not offer the feature to include the action plans for each question in the spaced retrieval practices, EdApp, used in this study, can provide the suggested action plans in the system after the spaced retrieval practices. In this study, these action plans enable students to recap their lectures to have a better understanding of the teaching materials and allow students to focus their study efforts on those weaker areas, improving overall comprehension and knowledge. Moreover, these action plans provide immediate, tailored qualitative feedback on students' questions' responses, which explain the correct answers, highlight key concepts, and direct students to specific lecture notes for more detailed studies. Hence, these action plans reinforce their memory by re-emphasizing the key concepts and providing a deeper insight, and are less likely to be forgotten. This approach ensures that all students receive valuable knowledge in different contexts that solidify their gaps in the materials and guide them to additional learning sources and experiences.

Results from the anonymous questionnaire survey

Besides the quantitative improvements, qualitative feedback from students also provides further insight into the benefits of spaced retrieval practices. As shown in **Figures 3(a)** and **3(b)**, respectively, the survey reveals that up to 52% found these approaches exceptionally effective (very and extremely effective shown in **Figure 3(a)**) for their learning, while 72.5% of students enjoyed the spaced retrieval practices in clinic classes, which are like revision sessions (absolutely shown in **Figure 3(b)**).

Many students testified that the spaced retrieval approach built their confidence and had better prepared them for tests. Spaced retrieval practices offer consistent review and "run through" sessions integrated into their exam preparation, where students regularly challenge themselves, learn from the mistakes, improve competency by being procedurally fluent, and continuously accumulate successes. As such, it allows and provides collective evidence of their capabilities and eventually builds a foundation of self-trust to override their self-doubt. While all these denote psychological effects and are scientifically supported and agreed upon by researchers from Singh et al. (2022), this physiological benefit is the one in which the level of confidence could foster a positive attitude towards learning and encourage active participation. Moreover, students' perceptions of their preparedness are closely linked to their academic success. When students feel prepared, they are more likely to perform well, which creates a positive feedback loop of confidence and achievement. This relationship between preparedness and success has been extensively documented in educational research, underscoring the importance of effective study strategies like spaced retrieval practices.

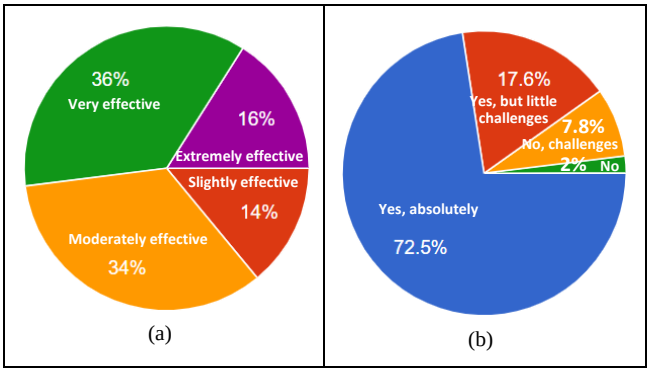

Figure 3. Survey questions for the spaced retrieval practice in the clinic classes (a) How effective has the spaced retrieval practice in the clinic classes been for you? and (b) Do you enjoy the spaced retrieval practice in the clinic classes?

Besides that, the positive reception of spaced retrieval practices also highlights their effectiveness in reducing test anxiety. These positive student perceptions suggest that the approach not only improved academic performance but also enhanced learning motivation. As students experienced better understanding and greater confidence, they became more motivated to engage consistently with the course content. Consistently engaging with the unit materials reduces the fear of the unknown or of potential failures and feeling overwhelmed by the content volume to be studied in a short range of time closer to the test dates. These ongoing engagements reframe students' perception and focus on performance rather than worry, making the learning process more manageable and less stressful.

Conclusions

In conclusion, spaced retrieval practices involve a systematic review of previously learned unit materials at increasing time intervals, suggesting that constantly recalling information by studying it multiple times over a longer period is more effective in knowledge retention than repetitive, short-term cramming. Our study has supported both quantitatively and qualitatively the benefit of integrating the spaced retrieval approach into the institutional curriculum. Our findings demonstrated a statistically significant improvement in the passing rate of the mid-semester test, indicating its reliable outcome in students grading improving instead of merely being a result of chance.

First of all, this growing body of evidence in educational psychology supports that spaced retrieval practices are a better learning strategy compared to the conventional method of massed practice, or cramming. Secondly, the spaced retrieval practices offer long-term benefits for students by establishing a habit of regular review and self-assessment. Hence, students could develop more effective study skills throughout their educational journey and beyond.

These practices provide students with a concrete knowledge base, allowing new information to be integrated and applied in the best possible way. However, this limitation of the study was investigated in a semester, which could not represent the complete success of the proposed approach as in this study. Hence, further research on the spaced retrieval practice sessions involving more semesters needs to be carried out to investigate the consistency of the findings. And eventually, this approach can be implemented in other units if the findings are promising.

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Conflict of Interest

The authors declare no competing interests.

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