ŌTAUTAHI CHRISTCHURCH AOTEAROA NEW ZEALAND
35TH AUSTRALASIAN ASSOCIATION FOR ENGINEERING EDUCATION ANNUAL CONFERENCE
8-11 DEC 2024
THE ENGINEER AND THE WORLD

A Case Study on the Implementation of Retrieval and Spaced Practice in a Third-Year Mechanics of Solids Course to Promote Active Learning

Darson D. Li[a], Zhan Yie Chin[a], Liya Zhao[a], Patrick A. Burr[a] and Susann Beier[a].
School of Mechanical and Manufacturing Engineering, University of New South Wales a
Corresponding Author Email: darson.li@unsw.edu.au

ABSTRACT

CONTEXT

Students must actively engage in the regular practice of knowledge or skills to excel in a field of study. Without innovative delivery and assessment strategies, students often resort to passive learning, leading to a short-lived memory of knowledge in engineering education. Cognitive-science research suggests that two strategies – retrieval practice and spaced practice allow for more effective retention of information. The former requires students to recall knowledge from memory, while the latter requires students to practise the same skill after some forgetting.

PURPOSE OR GOAL

This study aims to examine the effectiveness of innovative teaching methods, such as retrieval and spaced practice, on student performance to promote active learning. This is achieved by adopting different assessment structures for the quizzes of the course MMAN3400 Mechanics of Solids II at UNSW in 2022 and 2023, and by comparing students' results from these two years.

APPROACH OR METHODOLOGY/METHODS

To promote active learning, the number of quizzes in MMAN3400 increased from two in 2022 to eight in 2023 over a 10-week term. All other assessment items remain the same to minimise other factors affecting student performance. Overall and individual assignment grades of the two cohorts were analysed and compared to examine the effectiveness of the strategy implemented. Student feedback was gathered to understand students' satisfaction towards the weekly quizzes.

ACTUAL OR ANTICIPATED OUTCOMES

Results indicate that regular practice from the weekly quizzes in 2023 aided students in achieving higher grades in assignments such as the lab reports and the case-study project, especially for students who are in the Pass-Credit range, where the majority of the class lies. However, students did not perform better in the final exam in 2023, but this is likely due to the broader topics covered, making the exam questions objectively more challenging. Overall, student feedback indicates that they enjoyed completing the weekly quizzes and acknowledged that the quizzes encouraged continuous learning in this course.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The implementation of the weekly quizzes as a form of spaced retrieval practice has shown promising results in stimulating students to retain knowledge. "Practice makes perfect", so future studies will continue to focus on improving this strategy, especially in the realms of workload management and participation encouragement.

KEYWORDS

Engineering education, retrieval-based practice, spaced practice, active learning

Introduction

Mastering engineering disciplines necessitates consistent engagement with the relevant skills and knowledge gained during the course of study. This engagement not only helps students to consolidate their existing knowledge but also to build upon it progressively. However, without well-designed educational activities and corresponding assessment tasks, engineering students may fall into a pattern of passive learning. This pattern often results in surface learning, which is marked by limited involvement, reduced productivity, temporary memorisation through rote learning, and a lack of reflection (Frăsineanu, 2013).

Cognitive science researchers have identified two strategies that aid in the effective encoding and retention of knowledge, thereby enhancing students' learning outcomes. These include retrieval practice, which involves students attempting to recall information from their memory, and spaced practice, where students revisit a skill after a certain period of forgetting has occurred (Brown et al., 2014).

Retrieval practice, a cognitive strategy involving the recall of previously learned information, has been identified as a potent tool for enhancing long-term learning and memory (Roediger & Butler, 2011). A systematic review of nearly 2000 abstracts and 50 experiments revealed that retrieval practice consistently benefits student learning across various education levels, content areas, experimental designs, and final test formats (Agarwal et al., 2021). This practice has been found to be more advantageous for long-term retention than restudying the same information, a phenomenon often termed the "testing effect" or "test-enhanced learning" (Moreira et al., 2019).

The spaced education practice is based on the "spacing effect", a psychological concept that suggests that educational experiences, when distributed and repeated over time (spaced distribution), lead to more effective learning and enhanced memory retention, as opposed to when they are crammed into a single time-point (massed distribution) (Kerfoot et al., 2009; Toppino et al., 1991). The influence of the spacing effect extends beyond the realm of education. A particular study demonstrated that when repeated advertisements were separated by four non-repeated advertisements, participants' recall improved by 18%, compared to when they were separated by a single advertisement. This benefit of spaced learning stands as one of the most solid and applicable discoveries in the field of human memory research (Kahana, 2012).

Spaced retrieval, an educational approach that integrates retrieval practice and spaced practice, requires students to actively recall previously learned information at specific intervals after the initial lesson (Australian Education Research Organisation, 2021). This method is intended to reinforce and consolidate the learning process. The essence of this strategy lies in quizzing students on their knowledge, enabling them to identify which areas they can remember and which they need to review. This self-recognition of learned material serves as feedback that can guide students to focus their study efforts on the concepts and skills that require more practice. This feedback-driven metacognition enhances student learning by making them aware of what they know and what they need to learn (Agarwal & Bain, 2019). Without this self-identification of knowledge gaps, students might resort to less effective but commonly used study habits such as rereading study notes or repeatedly practising a single task in a short time span (Brown et al., 2014). However, if learning is facilitated through a well-structured approach, students can learn more efficiently, which ultimately promises to boost their proficiency in the taught skills and knowledge (Beier et al., 2022).

The objective of this project is to evaluate the efficacy of spaced retrieval practice in enhancing student performance and facilitating self-directed study in the field of engineering. The study was implemented in a third-year Mechanics of Solids course at the University of New South Wales. By introducing self-directed weekly quizzes as a spaced retrieval activity for the course content, we aim to measure its impact on student performance. Additionally, we analyse qualitative student feedback to gauge their satisfaction with this activity.

Methodology

MMAN3400 Mechanics of Solids II is a third-year core course for undergraduate students studying mechanical engineering at the University of New South Wales (UNSW Sydney). Topics covered in this course include the theory of elasticity, membrane stress in thin axisymmetric shells, the classical bending, shear and torsion of beam sections, buckling of columns, statically indeterminate structures, and an introduction to fracture and fatigue. This course is offered once each year in Term 1, with an enrolment of 122 students in 2022 and 164 students in 2023.

In an effort to evaluate the efficacy of retrieval and spaced practice in engineering education, a sequence of online quizzes was developed and implemented via the University's Learning Management System, Moodle, for student assessment in MMAN3400 during the years 2022 and 2023. To foster active learning, the number of quizzes was increased from two in 2022 to eight in 2023 over a span of a 10-week term, accompanied by modifications in the assessment structure and behaviour of the quizzes. To control for potential confounding variables, the structure of all other assessment components was kept as consistent as possible between the two cohorts. A comparative analysis of students' overall performance in the course and students' performance in individual assignment tasks of the two cohorts was conducted to examine the effectiveness of the implemented strategy. Additionally, student feedback was gathered to gauge their level of satisfaction with the weekly quizzes. This approach provides a comprehensive understanding of the impact of frequent assessments on student performance and satisfaction in an engineering education context.

Development of quiz activities

The quizzes for the years 2022 and 2023 were both developed utilising STACK, an online evaluation platform for mathematics and STEM disciplines. This system is designed to facilitate students in responding to queries with mathematical expressions, thereby enabling the randomisation of question values. To further enhance the integrity of the assessment, students were presented with varying questions of comparable difficulty, sourced from a "question bank". This strategy was employed to mitigate any potential attempts at collusion. The quizzes thus developed were subsequently integrated with the Moodle page of the course. This approach ensures a robust and fair assessment process, promoting individual understanding and mastery of the course content.

The differences in the quiz activities implemented in 2022 and 2023 are summarised in Table 1.

Table 1: Comparison of quiz activities implemented in MMAN3400 in 2022 and 2023

Year	2022	2023
Number of Quizzes	2	8
Due Date	Friday Week 3 and 5	Friday Weeks 2-5, and 7-10
Question Type	Mixed multiple-choice, short-answer and long calculation questions in each quiz	One long calculation question per quiz.
Time Limit	90 minutes	Untimed
Number of Attempts Allowed	One attempt	Unlimited attempts
Assessment Weighting	20% of course total (10% per quiz)	20% of course total (2.5% per quiz)

The content of the quizzes is synchronised with the weekly lecture material. In 2022, the quiz administered in Week 3 covered topics from the first two weeks, while the Week 5 quiz incorporated topics from Weeks 3 and 4. In contrast, the 2023 structure adopted a weekly quiz format, with each quiz covering the topics discussed in the previous week's lecture. This new approach facilitated students in retrieving and practising their newly acquired knowledge in a spaced manner, aligning with the principles of spaced practice in education. A summary of the topics addressed in each quiz is provided in Table 2.

Table 2: Topics covered in each quiz implemented in MMAN3400 in 2022 and 2023

2022		2023	
Quiz 1 (Week 3)	Theory of Elasticity Classical Bending of Beam Sections	Quiz 1 (Week 2)	Theory of Elasticity
		Quiz 2 (Week 3)	Classical Bending of Beam Sections
		Quiz 3 (Week 4)	Shear and Torque of Beam Sections
		Quiz 4 (Week 5)	Shear Centre of Beam Sections
Quiz 2 (Week 5)	Shear and Torque of Beam Sections	Quiz 5 (Week 7)	Membrane Stress in Thin Axisymmetric Shells
		Quiz 6 (Week 8)	Buckling
		Quiz 7 (Week 9)	Principles of Virtual Work
		Quiz 8 (Week 10)	Introduction to Fracture and Fatigue

The revised quiz structure in 2023 was strategically designed to stimulate active and sustained engagement among students, a pedagogical approach based on the principles of retrieval practice and spaced practice strategies in education. The retrieval-practice strategy posits that the act of recalling information shortly after its acquisition significantly enhances the learning process. By instituting a regimen of more frequent, weekly quizzes, students were incentivised to engage consistently with the course material, thereby fostering a culture of continuous learning. This approach effectively discourages the tendency to cram information at the last minute before a high-stakes assessment such as the final exam. The spaced-practice strategy, which involves spreading out study activities over time, further enhances the long-term retention of knowledge. Consequently, the increased frequency of quizzes served a dual purpose: not only as an evaluative tool but also as a potent instrument for learning. This underscores the transformative potential of frequent assessments in enhancing student engagement and learning outcomes, particularly in the realm of engineering education.

Other assessments in the course

To control for potential confounding variables, the structure of all other assessment components was kept as consistent as possible between the two cohorts. These assessment items included two lab reports, a case study project, and a final examination.

This course incorporates two laboratory experiments. The completion of these experiments is mandated for students during Weeks 5 and 6, followed by the submission of two corresponding laboratory reports in Weeks 7 and 8, respectively. These laboratory reports contribute to 20% of the total course grade.

The third assignment task in this course is a case study project which integrates all theories and concepts introduced throughout the course. This provides students with an opportunity to apply the acquired knowledge from this course to the design of a practical engineering structure. The case study project constitutes 20% of the total course grade.

The final assessment in this course is a two-hour final examination. It consists of four in-depth calculation questions, accounting for 40% of the total course grade. The 2022 final examination focused on topics from the latter half of the course that were not covered in the two quizzes. Conversely, the 2023 final examination covered all topics that were taught throughout the course.

Results and Discussions

The effectiveness of the weekly quizzes, implemented as part of the spaced-retrieval strategy, was evaluated by collecting, analysing, and comparing data on student grades from all individual assessments over two years. Additionally, student feedback was gathered via an anonymous university-wide feedback survey to assess student satisfaction with the quizzes.

Student performance

Figure 1 presents histograms comparing the results from 2022 and 2023 for each individual assessment item, including quizzes (a), lab reports (b), the case study project (c), and the final exam (d). The course total is shown in subplot (e), and the course total excluding quizzes is in subplot (f). To ensure comparability of results, the vertical axis of each subplot represents the percentage of the total student number, not the actual number of students, as the number of actively enrolled students varied between 2022 (122 students) and 2023 (164 students). These figures exclude inactive students who enrolled but did not complete any course assessment, resulting in zeros in all assessments. Figure 2 contains a box plot showing the statistical metrics of student results. The box represents the interquartile range (the middle 50% of the data). The whiskers extend to the smallest and largest values within 1.5 times the interquartile range. The median is indicated by the vertical line inside the box, and the notch provides a visual indication of the 95% confidence interval of the median. Statistical outliers are shown as dots.

As seen in Figure 1(a), students performed significantly better in the quizzes in 2023 compared to 2022, which is expected given that the quizzes were untimed and allowed unlimited attempts. Consequently, the quiz grades are not a suitable measure of this study's outcome. The focus of student performance measurement should be on the other assessments. For this reason, Figure 1(f) is a more accurate measure of overall student performance than Figure 1(e), as it excludes the quiz grades.

A shift towards higher grades in 2023 is noticeable in Figure 1(b-c), suggesting that the weekly quizzes have helped prepare students for the lab reports and case study projects. This is further supported by the grade distribution of these two assessment items shown in Figure 2, which shows a significant increase in both the interquartile range and median values in 2023.

However, there is no evidence to suggest that the weekly quizzes prepared students for the exam in 2023, as indicated in Figure 1(d) and the slight decrease in statistical metrics of exam grades shown in Figure 2. This can be attributed to two factors. First, the 2022 final exam focused on topics taught later in the course term (topics not covered in the two quizzes), leading to better performance due to fresher memory of these topics. In contrast, the 2023 final exam covered all topics taught throughout the term, where some knowledge forgetting is expected. This suggests the potential benefit of including earlier topics in later-term quizzes to help students prepare for the final exam. Additionally, the 2023 final exam questions were intentionally made more challenging to offset the significant increase in student marks in the quiz assessment.

Nevertheless, Figure 1(f) suggests that the weekly quizzes have contributed to the improvement of overall performance of students in other assessments, particularly for mid-performing students (those in the pass-credit range). This finding is also supported by the metrics of "course total excluding quizzes" in Figure 2.

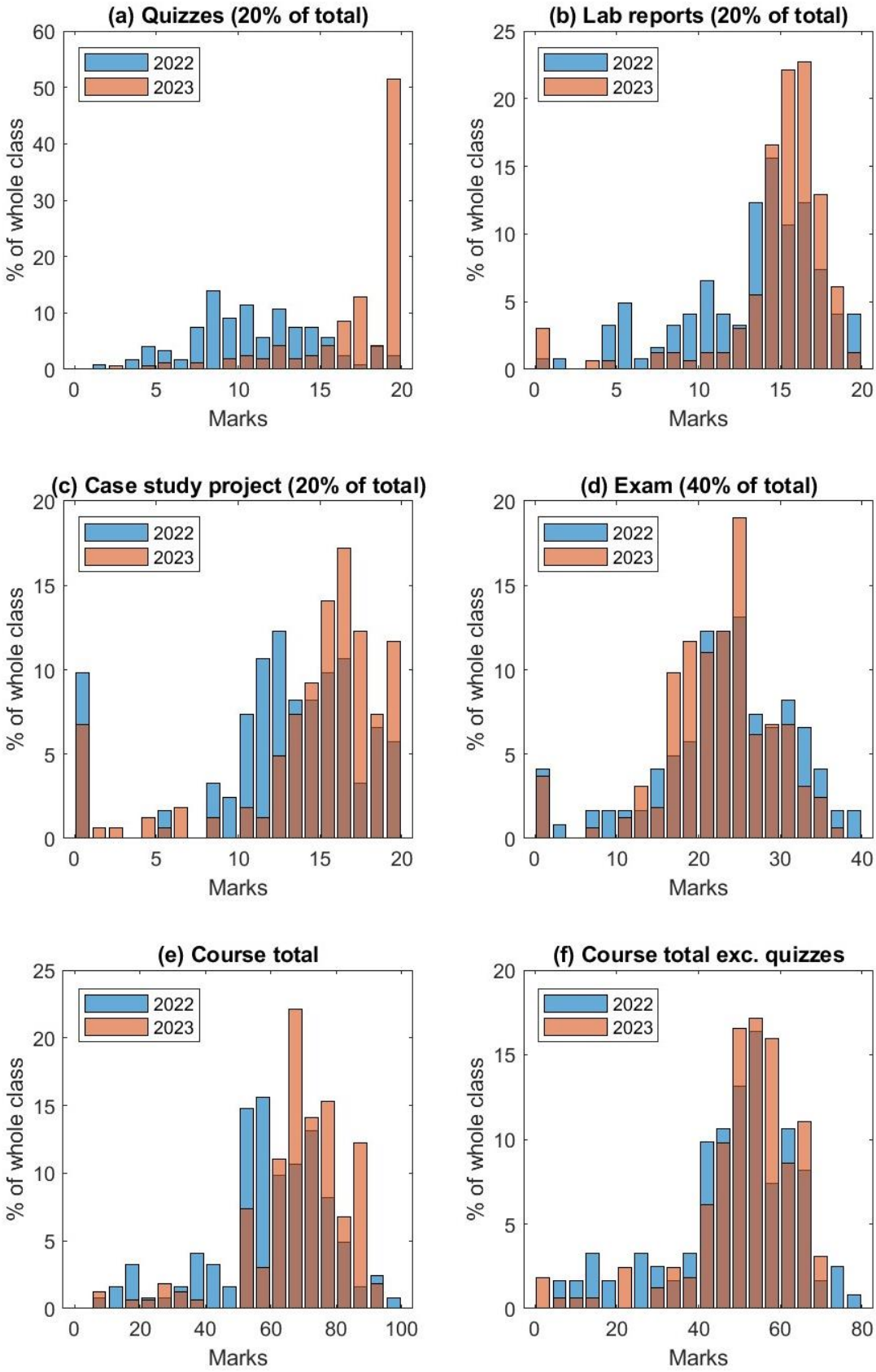

Figure 1: Histogram of student results of 2022 vs 2023: (a) Quizzes; (b) Lab reports; (c) Case study project; (d) Exam; (e) Course total; and (f) Course total excluding quizzes.

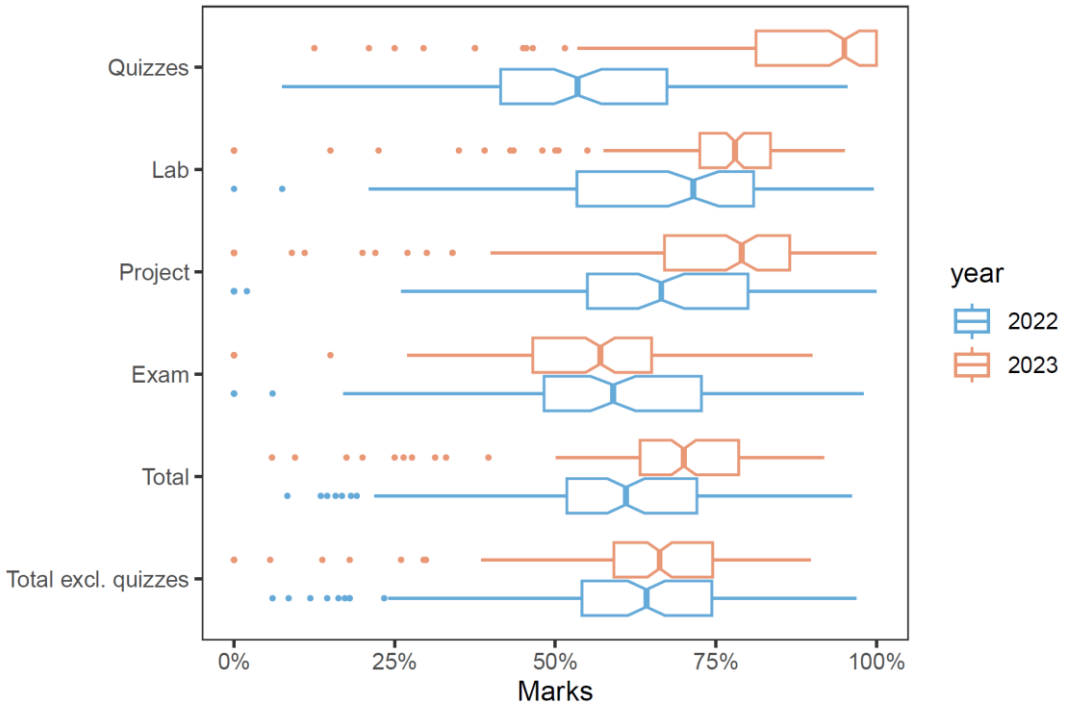

Figure 2: Normalised distribution of student results in assessment items. The box denotes the interquartile range (middle 50% of data), the vertical line inside the box marks the median, and the whiskers show the range within 1.5 times the interquartile range. The dots are statistical outliers, and the notches indicate the 95%confidence intervals of the median.

Student feedback and satisfaction

Beyond the assessment grades, it's crucial to take into account the students' feedback and their satisfaction with the quizzes. An anonymous feedback was conducted through a university-wide initiative called "myExperience". This was scheduled after the end of the term but before the final exam period, and results are not released to academics until after all exam marks are returned to students. In 2022, 123 students (88.6% of the total cohort), and in 2023, 140 students (85.4%) participated in this voluntary feedback process to share their views on the course content/assessments and their instructors, including lecturers and demonstrators/tutors.

In 2022, students found the two quizzes "very difficult", and they wanted "more resources" and "more time" to help them with their "preparation". One student specifically mentioned that "*Weekly quizzes with mark weighting would have helped me get an exposure to all aspects of the course. The lack of regular assessed content gave less incentive to keep up with content.*"

After the change was implemented in 2023, all student feedback that contained the keyword "quiz" or its variations is summarised in Table 3. Overall, students responded positively and appreciated the weekly quizzes, acknowledging their role in promoting continuous learning and helping them stay current with the course content. Conversely, some students felt overwhelmed by the course's assessment workload, and a few thought the quiz questions were too simplistic.

The collected feedback clearly demonstrates that the implementation of weekly quizzes has been instrumental in establishing a learning environment that leverages the principles of spaced retrieval for students. However, the confluence of weekly deadlines with other assessment deadlines within this course may be overwhelming for students. This highlights the necessity for recalibrating the quizzes or other assessments to ensure a more manageable workload. Considerations for achieving this balance could include moving lab report deadlines earlier in the term or developing an innovative strategy to consolidate all assessment items into a single weekly evaluation point. Moreover, it is crucial to convey to students that the quizzes should be used as a tool to test their understanding of the course content and promote learning. It should not be interpreted as "free marks" or substitutions for tutorial questions or lecture examples.

Table 3: Every student feedback comment containing the keyword "quiz" or its variations.

Question	What were the best things about this course?	What could be improved?
2023 Student responses	• "*I really liked the assessment layout for this course, I learnt much from the weekly quizzes and they kept me on top of the theory. I also enjoyed the labs, the concepts seemed simple but provided a good practical aspect to the course."* • *"The quizzes being open note, not timed, and available for retakes was helpful to make it more of a learning experience than stressful test environment."* • *"Weekly quizzes keep me up to date with content"* • *"I personally appreciated the change towards the quiz system compared to last year where it changed from 2 large mid terms into weekly quizzes. It became way less punishing and gave more opportunity to learn and practise the fundamentals of the course before putting it into the test in marked assessments."* • *"Continual learning through weekly quizzes"*	• *"The one–question per week quiz is a bit of a strange point. On one hand it is good (I suppose) that it is easy, but on the other it means that I'm not made to practice as much."* • *"Assessment are too condensed towards the back end of the course, weekly quizzes and two labs and case study due in weeks 7,9,10 is too condensed."* • *"There was an excessive amount of assignments, especially due to the fact that there were already weekly quizzes. I believe the lab assignments were sufficient but the case study project was a bit over the top."*

Conclusions

The implementation of spaced retrieval practice through weekly quizzes in the MMAN3400 Mechanics of Solids II course at the University of New South Wales has proven to be a beneficial strategy. The positive impact on student performance, especially among mid-performing students, highlights the effectiveness of these quizzes in promoting a culture of continuous learning and engagement. The open-book, untimed nature of the quizzes, coupled with the unlimited attempts policy, has been well-received by students, who appreciate the reduced stress and enhanced learning opportunities these methods provide. This approach has also been instrumental in improving content retention and mastery of course concepts.

While there is room for improvement in preparing students for the final exam, the overall student feedback is encouraging. The quizzes are seen as a valuable addition to the learning process, offering a more relaxed and supportive environment compared to previous assessments. Although some students have expressed concerns about the assessment workload, this feedback is an opportunity to refine our approach and ensure that quizzes serve their intended purpose as a learning tool.

In summary, the introduction of weekly quizzes has had a positive effect on student performance and satisfaction. It is recommended that future research continues to explore ways to optimise quiz frequency and format, integrate earlier topics into later-term quizzes, and develop strategies to manage the assessment workload effectively. These efforts will further enhance the application of cognitive science principles in engineering education and contribute to improved student engagement and learning outcomes.

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Acknowledgements

The authors wish to acknowledge the financial support provided by the GROW Grant, awarded by the Faculty of Engineering at the University of New South Wales (UNSW Sydney).

Ethics consideration

Ethics approval for this study was obtained from the UNSW Human Research Ethics Advisory Panel H: Science/Engineering and the UNSW Human Research Ethics Committee, approval number HC200391.

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