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Case study

Design and implementation of multi-purpose quizzes to improve mathematics learning for transitional engineering students

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Abstract: For students who are academically ineligible to enter a bachelor program in engineering but still want to upskill their knowledge in engineering, many universities provide an associate degree program in engineering to these students. The higher achievers from the associate degree program can transfer to a full degree program in engineering. Mathematics courses in such associate degree programs are often challenging to both the teachers and students due to various reasons. This paper presents a small part of a mathematics revitalization project on pedagogical adjustment to scaffold mathematics learning for students in an associate engineering program at Central Queensland University (CQU), a regional university in Australia, from 2018 to 2020. The design and implementation of the online multi-purpose quizzes (MPQ) to improve both the learning environment and outcomes for the engineering students from 2018 to 2020 are reported in this work. Statistically, the online MPQ empowered students to achieve their best possible outcomes by attempting the questions with time flexibility, on a confined set of topics, and with more chances of amending errors than the traditional written assessments. Hence, their performance in the online MPQ was consistently better than that in the written assignments in 2018-2020. The weaknesses of the online MPQ are also discussed.

Keywords: online quizzes, multi-purpose quizzes, engineering mathematics, mathematics learning, pedagogy, engineering curriculum

1. Introduction

Mathematics is an integral and fundamental part of engineering programs in universities over the world. Completion of a bachelor program in engineering would require four or more years of fulltime study in most universities, in which four to six mathematics courses would be chained as a sequence to scaffold the progression of study in different engineering disciplines. Admission into such bachelor programs requires a higher academic standing, particularly the mandatory completion of senor mathematics courses in high schools. For those students who are academically ineligible to enter a bachelor program in engineering but still want to upskill their knowledge in engineering, some universities, particularly regional universities like Central Queensland University (CQU) in Australia, also provide these students with an opportunity to enroll in an associate degree program in engineering. Successful completion of such associate programs not only meets the need of upskilling, but also allows the higher achievers to transfer to a full degree program in engineering if they wish.

Compared with the full engineering degree program, mathematics in the associate degree program is mostly confined to one to three standard courses depending on the duration of the associate engineering program, usually over 2 or 3 years of fulltime study. For example, at CQU the Associate Degree of Engineering (ADEng) is to be completed over 2 years of fulltime study, equivalent to completing 16 standard courses. Prior to the second term (similar to semester) of 2020, ADEng had only one mathematics course, Technology Mathematics (TM), from which students were supposed to gain most necessary mathematical skills and knowledge to support their study of disciplinary courses in the program. Hence, the coverage of TM in a full teaching term of 12 weeks must be stretched over a wide spectrum of topics, including algebra, geometry, trigonometry, all common functions, differentiation, integration, and preferably vectors, complex number, and matrices. These topics would be covered in at least two consecutive mathematics courses in a formal bachelor’s program. Thus, delivering such a wide range of topics in a term over 12 weeks was always an extremely challenging task for the teacher to facilitate effective teaching and learning for the cohort of students whose mathematics preparation was insufficient compared with the students in the engineering bachelor program. Imposed on handling such an extremely challenging task is diversity in the student cohorts, administrative rules, and the assurance of learning equality for all students.

The engineering students enrolled in TM had a wide range in age from eighteen to the 50s, typically around 60% in their 20s or younger and 40% in their 30s or older. The elder students would be likely to have more family commitments in addition to responsibilities for work and study simultaneously. In Australia, a load of 3 or more courses in a term is classified as fulltime study whereas a load of 1 or 2 courses is classified as part-time study. Most students enrolled in TM were in part-time study mode with other concurrent commitments. Some students may be fly-in-fly-out (FIFO) workers with a fortnightly roster in remote mining areas where there was no or limited internet connection. A few others may be travelling tradesmen working on projects over different places for various durations. Many of these students would have to withdraw during the term if the study plan was too rigid to follow through on time.

This mathematics course had been coordinated and taught by junior teachers for more than ten years. As a result, the issues with TM accumulated over the years had not been adequately addressed. For example, engineering students complained about inflexibility of the assessment schedule and difficulty level of individual topics; the lecturers in engineering disciplines requested sufficient coverage of mathematics for the students so that they could better understand engineering contents later in engineering courses. It would be ideal for an experienced senior teacher to take charge of the teaching duty, and more importantly to find appropriate measures or recommendations to resolve the existing issues with TM or even the program, and to redevelop and/or adjust the course accordingly during the process of curriculum restructure and pedagogical adaptation over multiple years. A mathematics revitalization project for TM was initiated from 2018 and completed in 2020, which led to multiple changes to the course structure, corresponding pedagogical design, implementation and refinement, recommendations for curriculum updates, and course redevelopment to realign with the new curriculum.

This paper presents a small part of the mathematics revitalization project on pedagogical adjustment to mitigate the disadvantage of the previous assessment scheme on the elder students who may enrol one or two weeks later after the beginning of a teaching term or have concurrent work and/or family commitments, and the design and implementation of the multi-purpose quizzes (MPQ) to improve engineering student's learning outcomes in 2018 and 2019. The success of the online quizzes saw that a revised format of MPQ has been adopted as part of the pedagogy for the redeveloped TM course in the updated ADEng curriculum since Term 2 of 2020. Section 2 presents a review of the structure and schedule of TM prior to 2018 and the adjustments on the structure, schedules and pedagogy of TM in 2018 and 2019. Section 3 outlines the pedagogical design and implementation of MPQ for TM. Section 4 presents student's learning outcomes and discusses the effectiveness and weaknesses of MPQ in supporting mathematics learning mainly in 2018 and 2019. Section 5 summaries this work.

2. The Previous Course Structure and Adjustments in 2018 and 2019

2.1. Course structure prior to 2018

The TM course had been associated with the ADEng program over 20 years. Prior to Term 2 of 2020, this course was the only mathematics course in this program. The course structure had been steady until the first term of 2018 when the author was tasked with mathematics revitalization for TM. The course structure prior to 2018 is outlined in Table 1. It can be seen that this course covered a wide span of topics over 12 weeks, including basic number and fraction operations, basic geometry, triangles, common functions, introductory calculus and applications, vectors, matrices, systems of linear equations, and statistics. These topics would need at least three courses for sufficient coverage.

Table 1. Weekly topics in TM prior to 2018

Week	Topic
1	Basic algebra and operations
2	Geometry and trigonometric functions
3	Inequalities, functions and graphs
4	Factoring, quadratic functions
5	Oblique triangles and vectors
6	Ratio, proportion, graphs of trigonometric functions
7	Exponential and logarithmic functions
8	Systems of linear equations, matrices and determinants
9	The derivative
10	Applications of derivative
11	Integration and applications
12	Introduction to statistics

There were four assessments to assess students' progression of learning during the course, which are outlined in Table 2. As permitted, students can enrol in a course in a specified term any time before the midnight on Friday of the second week in that term. Meanwhile, any student in a course can withdraw from the course before the census date on Tuesday of Week 4 in that term without both academic and financial penalties. Students remained after the census date are regarded as the officially enrolled students and anyone withdrawn after the census date will be regarded as withdrawn fail, an automatic fail grade. The first written assignment in TM was due in Week 5. Considering the possibility of late enrolment up to two weeks and the FIFO roster for one or two weeks, some students in TM would find themselves in a difficult situation to present a quality submission for the first written assessment on time. This would dampen their confidence in smooth progression in learning, leading to possible late withdrawals or missing majority of the four assessments, which would be regarded as absent fail, another automatic fail grade.

Table 2. Assessment scheme for TM prior to 2018

Assessment	Topic	Due	Weight
Written Assignment 1	Topics covered in Weeks 1-4	Week 5	25%
Written Assignment 2	Topics covered in Weeks 5-8	Week 9	25%
Written Assignment 3	Topics covered in Weeks 9-11	Week 12	10%
Exanimation	All topics	Week 14	40%

2.2. Structural changes to TM in 2018 and 2019

Three key problems were targeted for TM in 2018: a more logical structure for the coverage of the entire course from beginning to the end; increasing duration of learning in calculus for engineering students; providing an alternative assessment scheme to offer more flexible options for students to approach and handle the first assessment. These changes were reflected in the new schedule of weekly topics shown in Table 3. The noticeable changes included the following:

Table 3. The new schedule of weekly topics covered in TM in 2018 and 2019

Week	Topic
1	Basic Algebra (I)
2	Basic Algebra (II) and Basic Geometry
3	Inequalities and Sequences
4	Functions and Graphs
5	Polynomial Functions
6	Exponential and Logarithmic Functions
7	Triangles and Trigonometry
8	Trigonometric and Hyperbolic Functions
9	Essentials of Differentiation
10	Applications of Differentiation
11	Integration
12	Applications of Integration

- Rationalized logical groupings of topics into three blocks: basic algebra, common functions, and calculus;
- Calculus was increased to four weeks in the expenses of vectors, matrices, statistics.

The structure of four assessments was retained but weights for individual items were adjusted. To provide students with flexibility in dealing with the first assessment and hence treating all students as fair as possible, the first written assignment was replaced by a set of twenty online quizzes organized in three subsets on different topics. This allowed the students to complete this assessment bit by bit any time in seven weeks (including the middle-term vacation week between Week 5 and Week 6). The new assessment scheme is shown in Table 4.

Table 4. New assessment scheme for TM in 2018 and 2019

Assessment	Topic	Due	Weight
Online quizzes	Algebra, inequalities, sequences, linear & quadratic functions	Week 6	20%
Written assignment 1	Triangles, exponential, logarithmic, trigonometric functions	Week 9	20%
Written assignment 2	Calculus covered in Weeks 9-11	Week 12	20%
Exanimation (invigilated)	All topics	Week 14	40%

3. Design and Implementation of the Multi-purpose Quizzes (MPQ) for TM in 2018

3.1. Background for the design of MPQ

Online quizzes have been long used as a flexible means in pedagogical design and practices in tertiary education, particularly in assisting the transition from traditional distance learning to online learning from the early 2000s [1–3], accelerated by the wide adoption of modern teaching and learning management systems such as Moodle, Blackboard, and others from 2010s [4–6]. In STEM courses, different forms of online quizzes have been tried by many educators. Dimas et al. [7] experimented online quizzes in the actual face-to-face classroom to observe the live learning behaviours and collect the interactive learning performances of students who were expected to have watched the pre-recorded lecture before the start of the live class. The teacher was able to provide instant feedback to students according to the answers students provided anonymously to the online quiz. Although not decisive, some improvements on student's learning were observed in the study, which was backed by similar studies for different cohorts of students reported in recent experiments [8,9].

Setting up online quizzes became relatively easier with Moodle since the mid-2010s. Martins [10] experimented online multiple choice questions (MCQs) in engineering mathematics courses as weekly optional assessments for students. If students did not want to attempt the quizzes, they could still succeed the course by completing all other regular assessments. For those students who attempted all the quizzes, they would have a chance to include their scores from the quizzes (capped to10%) into their final grade if they obtained more than 45% in their regular assessments. It was found that nearly all the students who attempted the quizzes felt the quizzes being useful for them to achieve a better grade. This outcome seems encouraging but many would argue whether such approach is fair to the whole class, particularly those students who did not attempted the quizzes but still passed the course.

Pre-class MCQs were used as conceptual questions to test student's preparation level on the knowledge that would be taught in the face-to-face class immediately after the MCQs in an electromagnetics course for electrical engineering students [11]. The MCQs focused on the understanding of key concepts in electromagnetics that would be delivered in the live class. The special features of these MCQs included that no calculus or other sophisticated calculations were required to answer these questions, and that all students would need to complete this timed quiz session before the live class began. Such measures ensured that all students in the classroom completed the necessary reading before attending the class. As a result, student's learning outcomes, including the performance in the examination, were substantially improved by this pedagogical approach. A similar experiment called the preparatory quizzes or pre-quizzes conducted by Gyllen et al. [12] in an introductory mechanical engineering course also demonstrated a significantly better course average achieved by those students who engaged with the pre-quizzes than those who did not participate in the pre-quizzes. Both studies are promising in improving student's learning outcomes for the students who engaged in the live face-to-face classes where the pre-class quizzes would be relatively easier to administer. The applicability of this approach in terms of academic equality remains unclear for the mixed cohorts of students in the live face-to-face class, in the telecasted online live class, and in asynchronous distance learning in different time zones or countries.

In contract with the ungraded pre-class quizzes, a comparative trial of replacing formal exanimations by weekly homework and graded quizzes for an engineering mathematics course was reported in [13]. The students had face-to-face live class on a specific topic or chapter on Monday of a week and then completed a homework of 8-12 exercise questions by Friday of that week, followed by the quiz session consisting of four questions. Students could attempt all ten quiz sessions and the best eight sessions were used to calculate the final grade. Compared with the two control groups of students who undertook the traditional assessments with examination, the class mean of the trial group was 25 and 32 marks better than that of the two control groups. Unfortunately, this study did not share the detailed information on how the quiz sessions were structured and administered and how the difficulty levels of quiz questions were benchmarked with that of the examination. Hence, the extraordinarily higher class mean seems unlikely to be unbiased. The other fact is that the weekly homework-quiz sequence would be hardly replicable for many distance students from different counties or time zones.

Gero and Stav [14] applied two-tier MCQs to an electric circuits course. A two-tier MCQ included two items in sequence: the first item was a fact-based question and the second was a reasoning-based question associated to the answer to the first item. The first item was more similar to the traditional pre-class MCQs whereas the second item was more like a question in a traditional engineering assignment. Surprisingly, this study found that there was no significant difference in the student's overall performances in the test for both groups of students who participated in the one-tier MCQs with the first item only and the two-tier MCQs respectively, despite the fact that some students agreed the two-tier MCQs being helpful for an in-depth study of theory.

These strategies of using online quizzes to support students learning in STEM subjects in face-to-face teaching, either pre-class quizzes or in-class quizzes, would not be applicable to TM as our engineering students study this course online by distance mode from the whole nation in different time zones. Pre-recorded videos were available online for students to access whenever they found time and wherever there was internet connection. Unlike any traditional quizzes, the quiz questions in this newly structured course should not only be graded as part of the formal assessment with the highest possible flexibility, but also be an effective means to empower students to better understand the basic mathematical concepts and more effectively apply the essential mathematical techniques to solve problems. For students who have known the foundation mathematics well, the online quizzes would provide them with a unique way of self-evaluation on their existing knowledge and skills in basic mathematics. For students who learned the foundation mathematics years ago but currently lost their pre-learnt mathematics knowledge partly or entirely, the online quizzes would be a new measurable opportunity to review and re-assess what they had learned in the past.

3.2. Pedagogical design for the online MPQ

The key pedagogical consideration for the online quizzes in TM was that the quiz questions must play the role of a formal assignment to assess both the understanding of mathematical concepts and efficacy in applying mathematical techniques in foundation mathematics covered in Weeks 1–5. To achieve this goal and resolve some problems raised earlier for TM, the concept of the two-tier MCQs reported in [14] would be partly useful for our online quizzes. However, our online quizzes would consist of questions assessing the conceptual understanding of a topic, the technical efficacy, reasoning for problem solving, and combinations, rather than separating one from the other. Hence, the new quizzes were named the multi-purpose quizzes (MPQ) for TM.

Shown in Figure 1, for instance in one set of MPQ, Question 1 was to test the understanding of domains for the given function; Question 2 was to assess the efficacy of solving the given absolute inequality; Question 3 targeted reasoning for problem solving; Question 4 was to test both understanding of the characteristics of linear functions and technical efficacy for determining the linear function.

1. Determine the domain of function $y = \dfrac{\sqrt[3]{2x-3}}{\sqrt{x-5}}$.
2. Solve the absolute inequality $|3x-1| > |3-x|$.
3. The gas rates of a residential home are based on a unit rate plus a base charge of $90. Suppose the total charge of 300 units of gas for a home is $150. Find a linear function between the gas charge (y) and the unit rate (x).
4. One straight line is normal to $y = 2x-1$ and passes through (2, 8). Find the expression of this straight line.

Figure 1. Examples of MPQ for TM

Each question was worth one mark and no partial marks were available. Because some of the questions would require deep reasoning or combinative approaches for problem solving, all the quiz questions were made available at the time the online quizzes were opened, less the choices for potential solutions. The pedagogical purpose of this measure was to encourage students to work on the questions with their best effort before attempting the online quizzes guided by own solutions, hence, to discourage random attempts to the quizzes before making meaningful effort on the topics and the problems. Such measure was proven to be a mastery act as, for example, only one case of random attempt to quizzes was recorded in the Moodle log for all students who completed the quizzes in six terms from Term 1 of 2018 to Term 2 of 2020. One set of the quiz questions for TM is shared in Appendix 1.

Once a quiz session began, each question and the five associated answers would appear on Moodle and only one choice was correct among the five answers (Figure 2). To empower students to achieve their best possible performance in the online quizzes, students had up to three attempts for each quiz question without time restriction and the last attempt was recorded as their final score, which was summarized as a list of correct or incorrect choice against the chosen option for each of the quizzes without disclosing the correct answer (Figure 3). A reshuffle would be automatically enforced in both the order of the quiz questions and the order of the five choices to a quiz in the next repeating session for the student.

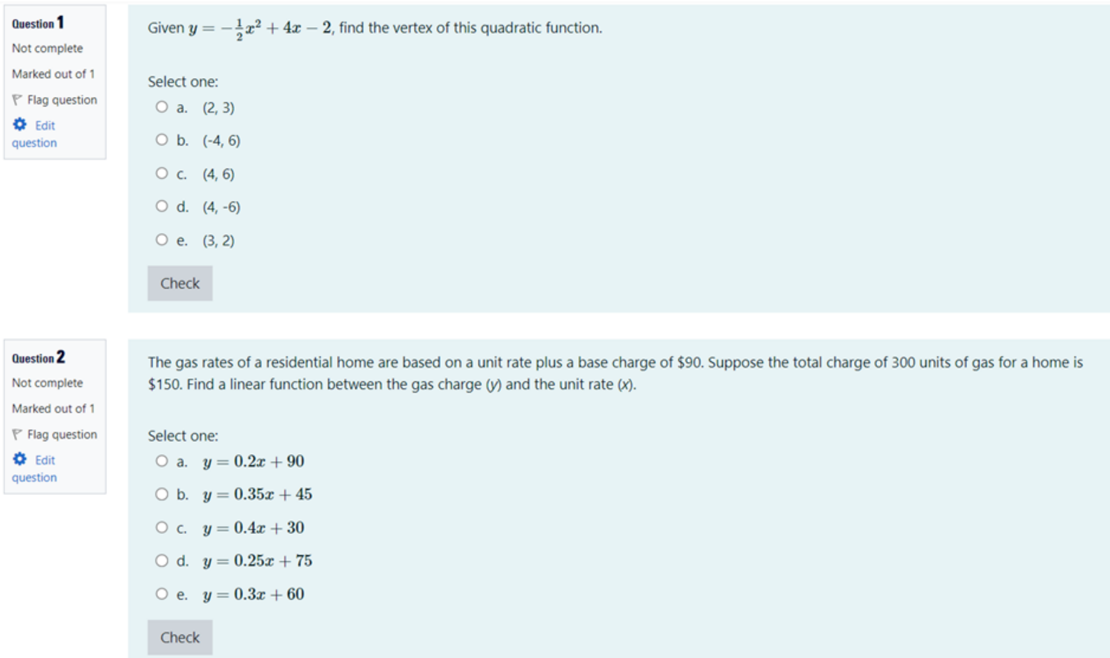

Figure 2. Examples of online MPQ in TM

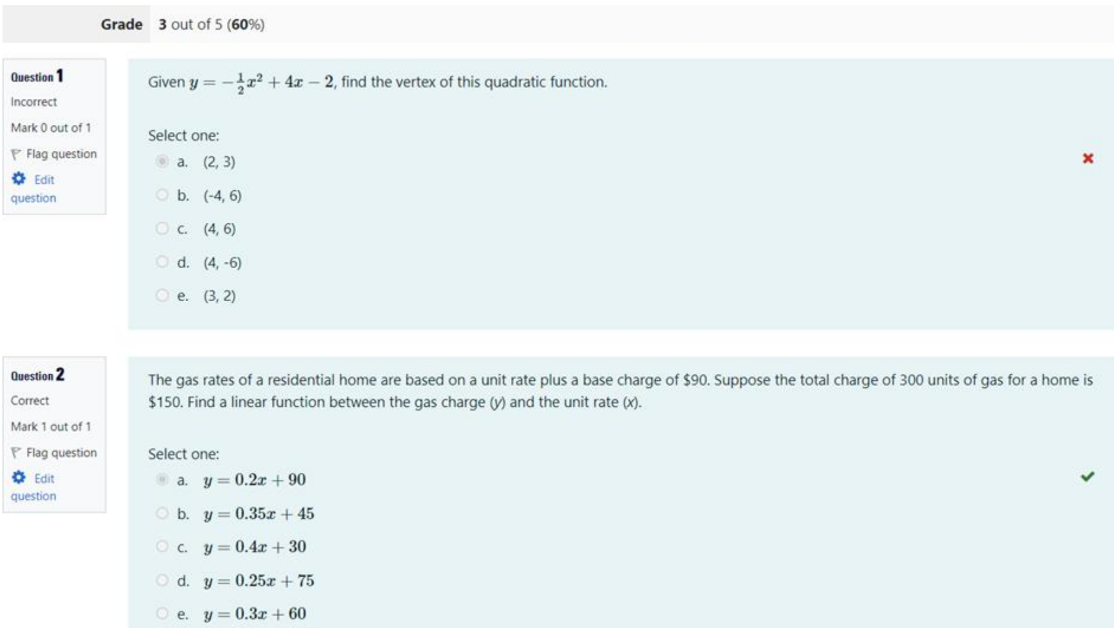

Figure 3. Part of the summary after completing one attempt to online MPQ in TM

The timeline of the online quizzes would have a significant influence on student's participation and performance. Firstly, for those students who enrolled late in the course, an earlier opening of the online quizzes would be a disadvantage for them. As the late enrolment is due by the end of Week 2, the online quizzes were designed to be open from Monday of Week 3 and be closed by Sunday of Week 6. This timeline should offer all the students the same period of time to access the online quizzes. Secondly, for those students who are on FIFO rosters without adequate internet access up to two weeks, they could complete the online quizzes anytime during the five weeks from Week 3 to Week 6 including one vacation week before Week 6. To further leveling the field for all students, the quiz questions were made available less the choices for solutions when the online quizzes were opened in Week 3 so that students could work on the questions on paper first before attempting the online quizzes.

To provide more flexibility for the students who may be affected by their work and/or family commitments irregularly, the sequencing of MPQ was based on the concept of 'micro learning and assessment' [15,16], which allows a student to attempt one section of quizzes that only relate to the subset of topics just studied by the student, rather than waiting to the completion of all topics in foundation mathematics covered from Week 1 to Week 5 in TM. Accordingly, the twenty quiz questions were segmented into three parts associated with different topics covered in different weeks as follows.

- Part I: 8 questions to test the learning outcome of basic algebra covered in Weeks 1–2;
- Part II: 7 questions to test the learning outcome of inequalities, arithmetic and geometric sequences, general properties of functions and graphs covered in Weeks 3–4;
- Part III: 5 questions to test the learning outcome of linear, quadratic, and other polynomial functions covered in Week 5.

3.3. The implementation of MPQ on Moodle

The MPQ design was implemented by the author on Moodle using its quiz functions in 2018. The major features of the implementation on Moodle included

- The quiz questions for each Part were the same but the order of the questions would be reshuffled once a new attempt was started on Moodle. The five choices for each quiz were the same but the order of the choices would be reshuffled once a new attempt was started on Moodle. This was to make the student work on own solution to the quiz question, rather than the index number of the quiz, so as to reduce the possibility of collusion among some students.
- Students should have up to three attempts for each of the questions. Once finished the whole Part, the student should be able to see the correctness of each question for this Part immediately. However, the system should neither disclose the correct answer nor remember the choice to the quiz for the student. The system should only record the results from the student's last attempt as the final score for the Part. This was to discourage random attempts to the quizzes and to minimize the possibility of exploiting the system by multiple attempts, so as to guide students to focus on solving problems through mathematical procedures.
- Students were not allowed to redo within the same round of attempt but may have multiple options to exit the entire quiz session without recording the attempts in the system. This was

to provide students with more flexibility to amend or redo the questions without fears of losing the three formal attempts, hence, to motivate students to achieve their best.

Since the online quizzes were the first time for most students to experience in TM, a detailed instruction was provided to students in a word document as shown in Appendix 2, which was also displayed on the front page of the quiz session on the Moodle course site.

In 2020, ADEng was updated to include a preparatory mathematics course as the prerequisite of TM. The TM course was then redeveloped as the advanced mathematics course in ADEng to cover more on calculus, vectors, complex numbers, and matrices commencing from the second term of 2020. This arrangement was to accommodate the offerings of the preparatory mathematics course in the first and second terms in a year for all new students commencing from 2020, followed by the redeveloped TM course in the second and third terms of the year. The author was again tasked with redevelopment of the advanced TM course and taught the new TM course in its inaugural offering in the second term of 2020. The MPQ was implemented as three subsets almost evenly distributed over the term to cover all topics from Week 1 to Week 12 because the students in the new TM course must have had a better preparation in mathematics after successfully completed the preparatory mathematics course. To offer the similar flexibility to students in the new advanced TM course same to the old course, the first quiz session was due in six weeks. This realignment proved to be a success as all 21 students who went through this advanced TM course in that term passed this course. Although the old TM course was still offered in the first term of 2020, it was offered only to several existing students who needed to complete the old program in 2020.

4. Results and Discussion

The TM course was offered twice in 2018 and 2019 with the first term as the major offering with more students. The minor offering usually attracted one-third or a half of the number of students enrolled in the major term. The 2020 offerings were transitional with significant variations to TM over three terms. Hence, the results from the major terms in 2028 and 2019 are the focus of discussion in this work. There were 29 and 26 engineering students who completed at least the first two assessments in the first term in 2018 and 2019 respectively. Statistics of student's results from the online MPQ (OQ) in these two terms are shown in Table 5. The results of the first written assessment (WA1) on common functions are also shown in the table as an indirect reference of different styles of assessments. Both had the same weight of 20% or 20 marks out of 100 for the course. [*Note that different sets of assessment questions were used in 2018 and 2019 respectively, but the difficulty levels for the questions were same with each other.*] These two assessments are chosen for discussion because the Part III of the online quizzes was already part of the common functions. As the third assessment on calculus was more advanced than the online MPQ and the examination was timed and invigilated or was a vastly different style of assessment, these two assessments are not included in the discussion.

Table 5. Statistics of results from the first two assessments in Term 1 of 2018 and 2019

Year	Number of students	OQ		WA1	
		Mean	SD	Mean	SD
2018	29	18.345	3.687	15.862	3.729
2019	26	18.923	1.294	14.827	3.564

The average score of the online quizzes (OQ) was between 18 and 19 out of 20 in both offerings. The mean of the first written assignment (WA1) was around 15 out of 20, about 17% lower than that of the quizzes. Such difference in the mean scores between OQ and WA1 is statistically significant at $\alpha = 0.025$ level by *t*-test in each offering and consistent over both offerings (Table 6).

Table 6. The *t*-test results between OC and WA1 for TM in 2018 and 2019

Year	*d.f.*	Critical *t*-value ($\alpha = 0.025$)	*t*-value for OQ-WA1
2018	56	±2.003	2.550
2019	50	±2.009	5.508

One may argue that the difficulty levels of contents in OQ and WA1 may be a factor contributed to the difference in the mean scores between OQ and WA1 because OQ was more on basic mathematics whereas WA1 was on functions and triangles. This may be true to some extent but hardly measurable directly. As an indirect reference, in Term 2 of 2020, TM became an advanced mathematics course on top of a new preparatory mathematics course in the updated ADEng program. Common functions, calculus, vectors, complex numbers, and matrices became the main focuses of the redeveloped TM course by the time. The online quizzes and two written assignments, each bearing 20% of the course total, were staged in the new course before the final examination. The online quizzes were implemented as three subsets almost evenly distributed over the entire term to support student learning on all topics over the course. Hence, the quizzes would cover all topics appeared in both written assignments (WA1 & WA2). The difference in the mean scores between OQ and either WA1 or WA2 (Table 7) is still statistically significant at $\alpha = 0.025$ level by *t*-test from the newly developed TM course in Term 2 of 2020 (Table 8). Therefore, it is fairly confident to claim that students were likely more comfortable in attempting questions more flexible in time and more focused on a confined set of topics with more chances of amending errors offered by the online quizzes than the traditional written assessment.

Table 7. Statistics of results from OQ, WA1 and WA2 for TM in Term 2 of 2020

Number of students	OQ		WA1		WA2	
	Mean	SD	Mean	SD	Mean	SD
21	19.476	0.981	17.047	3.232	15.690	3.376

Table 8. The *t*-test results between OQ and WA1 or WA2 for TM in Term 2 of 2020

Year	*d.f.*	Critical *t*-value ($\alpha = 0.025$)	*t*-value for OQ-WA1	*t*-value for OQ-WA2
2020	40	±2.021	3.296	4.947

Although the average scores from the written assignments for TM may vary noticeably over these three years, online quizzes employed in TM, no matter as the only foundation mathematics course in 2018 and 2019 or the advanced mathematics course in 2020, seemed consistently accomplished by the students. The hypothesis *t*-test indicates at the significance level $\alpha = 0.025$ no statistical difference exists in the mean scores of online quizzes between 2018 and 2019 or 2018 and 2020 (Table 9). In other words, the student's performance in online quizzes was consistently better than that in the written assignments in Term 1 of 2018, Term 1 of 2019, and Term 2 of 2020.

However, the weaknesses associated with using online quizzes as formal assessments should be understood. The main weakness must be a lack of transparency of the mathematical procedure students attempted to answer the online quizzes. Since lecturers have no chance to see student's working for obtaining the solutions to all quiz questions, there is no chance for the lecturers to provide specific feedback targeting the wrong process behind any incorrect answer to the quiz question. For the same reason, the lecturers will not be able to detect any academic misconduct, such as collusion among some students or contract cheating using solutions from a third-party.

Table 9. The *t*-test results between OQ for TM in 2018 and OQ in 2019 and 2020

Year	*d.f.*	Critical t-value ($\alpha = 0.025$)	*t*-value for Q-Q
2018-2019	53	±2.006	-0.758
2018-2020	48	±2.011	-1.368

Another weakness is that setting up online quizzes with the required quality in both academics and online presentation is time-consuming initially. Imposed on this tedious work is that the reusability of the previous quizzes would be restricted by the potential circulation of the quiz questions already released to the previous students to new students. One solution to deal with this weakness could be increasing the number of quiz questions in the test bank, from which a new set of quizzes can be drawn for a cohort of new students. However, creating a large number of new quizzes is time-consuming itself, and all the effort would be wasted if a course changes shortly, like the transition of TM from 2018 to 2020.

The most advantageous aspect of online quizzes is the instant feedback to students in terms of the correctness of their choices against the questions. Due to technological constraints, the current system is not able to accommodate online quizzes that require in-depth mathematical reasoning for sophisticated solutions. Hence, the options of online quizzes for mathematics would be limited until new systems are able to support the efficient creation of more advanced online quizzes in mathematics.

Random attempt to online quizzes is common for some students to exploit the system. However, the way of the online MPQ designed and implemented for TM saw only one student over six terms from 2018 to 2020 randomly attempted the online quizzes. That student failed to finish this course eventually.

5. Conclusions

The online quizzes designed and implemented for the TM course in 2018-2020 was a success in terms of achieving the main purposes. The flexibility of the online quizzes featured in TM from 2018 to 2020 was signalled out as the best aspect of TM by multiple students in their course evaluation. One FIFO student was able to complete the online quizzes during the week when he was accompanying his wife in the hospital in a local city. He worked on the quiz questions on paper in spare times during his on-site duty and then attempted the online quizzes in the lounge room of the hospital when accompanying his wife. He shared his personal experience with the author during an online tutorial especially set up for him joined from the hospital lounge room.

Statistically, the online quizzes empowered students to achieve their best possible outcomes by attempting questions with time flexibility, on a confined set of topics, and with more chances of amending errors than the traditional written assessments. Hence, their performance in online quizzes was consistently better than that in the written assignments during 2018–2020.

However, online quizzes have a number of weaknesses in terms of scaffolding more aspects of mathematics learning and teaching in a broad scale, such as a lack of transparency in student's problem solving processes, time-consuming in creating online quizzes and their reusability, and difficulty in accommodating mathematical online quizzes with sophisticated solutions. Hence, online quizzes are only part of the solutions in better supporting student learning and improving learning outcomes in mathematics. Consequently, pedagogical improvement is only part of any success in supporting student learning. Maintaining the quality standard achieved and even improving further for any course requires sustainable efforts from instructors and active engagement with learning from the students [17].

Acknowledgments

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Appendix 1: Quiz Questions (2018)

Part I (8 questions):

1. Evaluate

$$8\times 3\times \frac{1}{4}\div 2\div \frac{3}{4}$$

2. Evaluate

$$\frac{x-3}{5}\div\frac{3-x}{20}+\frac{3-x}{x-1}\times\frac{1-x}{x}\times\frac{2x}{x-3}$$

3. Rationalise the following fraction:

$$\frac{\sqrt{6}}{\sqrt{3}-\sqrt{2}}$$

4. Expand and simplify the following algebraic expression:

$$\{\sqrt{3ab}-[(ab^2+3ab)/\sqrt{3ab}]\}\sqrt{3ab}$$

5. Factorise the following algebraic expression:

$$2x^2+5xy+3y^2$$

6. Evaluate

$$\frac{x^2+2x-3}{x^2-2x+1}-\frac{x^2+4x-5}{x^2-1}$$

7. Solve the following equation:

$$\sqrt{2x^2-7}+2=x+1$$

8. Solve the following system of linear equations using either substitution or elimination:

$$\begin{cases}\frac{1}{2}x-\frac{1}{3}y=3\\ x+y=1\end{cases}$$

Part II (7 questions):

9. Solve the following abstract inequality:

$$|2x+1|\le|4-x|$$

10. Given the third and fourth terms of an arithmetic sequence as a_3 = 33 and a_4 = 44, find the sum of the first 8 terms of this arithmetic sequence.
11. A new car is currently valued at $20000. It is expected the value of the car is depreciated by 10% each year. Find the value of the car after 5 years.
12. Determine the domain of the following function.

$$y=\sqrt[3]{27\sqrt{x+5}}$$

13. Find the combined function of the following functions.

Given $f(x)=\sqrt{x-1}$ and $g(x)=\sqrt{2x+1}$, determine $h(x)=g(f(x)^2)$.

14. Given $y=f(x)=x^2-4$, determine its inverse function.

15. In the 3D Cartesian space, determine the distances between the following two points respectively.

$A(0,0,1),\ B(2,3,-1);$

$C(3,1,2),\ D(1,0,3);$

Part III (5 questions):

16. One straight line is parallel to $y = -2x + 1$. Find the expression of the linear function that is normal to this line and passes through (2, 3).
17. The rates of a rental car are based on the $55 per day plan plus a base charge. Suppose the total charge of a seven-day rent for a customer is $500. Find a linear function between the rent charge (*y*) and the daily rate (*x*).
18. Given $y = 2x^2 - 8x + 3$, find the vertex of this quadratic function.
19. The vertex of a quadratic function is located at *V*(2, 3) and its *y*-intercept is 1. Find the expression of this quadratic function.
20. Find the points of intersection between $y = \frac{1}{2}x^2 + x - 2$ and $y = x + 6$.

Appendix 2: Instruction on online quizzes (2018)

1. This quiz covers topics studied in Weeks 1-5. The quiz has 20 questions in total and each question is worth one mark. No partial parks are available for each quiz.
2. You have up to three (3) attempts for each quiz question. The last attempt will be recorded as your final answer.
3. The quiz consists of three independent parts:
   a) Part I has 8 questions and tests your learning outcome from Weeks 1-2;
   b) Part II has 7 questions and tests your learning outcome from Weeks 3-4;
   c) Part III has 5 questions and tests your learning outcome from Week 5.
4. Remember in each part:
   a) Try to solve the quiz questions provided in the quiz document. Check and write your answers in your notebook.
   b) You should begin attempting the quiz questions on Moodle only after you have solved ALL questions in that part.
   c) With ALL answers with you, then start the first attempt by ticking one out of the five choices to each question AND clicking the **CHECK** button of that question to lock in your answer. Repeat for all other questions until all questions in that part are answered.
   d) Click **FINISH ATTEMPT** button to move to the Summary page. You have to click **SUBMIT ALL AND FINISH** button to complete this round of attempt.
   e) You then see the results of your answer to each of those attempted questions on a new page. If you got ALL correct, you would not need to do anything further in that part. Well done!
   f) If you do have one or more incorrect answers, you need to check with your notebook and tick off the ones answered correctly and MARK those **questions** answered incorrectly, **not the question number and choice letter**. The question number and choice letters will be reshuffled in your next attempt.
   g) In your next attempt, all questions will be reshuffled, and **you have to pick a choice for each of these questions again regardless of your previous attempt**. Make sure you choose

the correct answer to a question according to the record in your notebook, **not the question number and choice letter appeared in the previous attempt.**

5. This is an individual assignment. No one should communicate any result or process with other student in any public medium, including the **General Discussion** and **Q & A** forums on the Moodle site.

Author's biography

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