



Case study

A comparative case study of a foundation mathematics course for student mathematics teachers before and after the COVID-19 pandemic and implications for low-enrollment programs at regional universities

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Abstract: Australian regional universities have been offering many low-enrollment programs to students living in regional, rural, and remote (RRR) areas as part of their obligation to serve regional communities. However, making these programs sustainable has been a significant challenge due to the small population spread across the vast RRR territory in Australia. There is a lack of studies on the key factors contributing to the difficulty of running specific low-enrollment programs, and more importantly, on possible viable solutions to mitigate the negative impact of these factors on program sustainability. Based on the engagement levels of students in teaching and learning, as well as their performance in solving selected questions in basic trigonometry and triangles, I analyzed three independent groups of students enrolled in three offerings of a foundation mathematics course within a low-enrollment secondary mathematics teaching specialty at an Australian regional university before and after the COVID-19 pandemic. Through statistical analysis, I found that: 1) Relaxing entry requirements for the secondary mathematics specialty did not increase student intake post-pandemic; 2) there was no significant difference in performance between active students before and after the pandemic in solving the selected questions under similar teaching and learning conditions; and 3) some students' unsatisfactory performances in solving the selected questions may have been influenced by learning habits inherited from their secondary education, characterized by 'shallow teaching and learning.' This case study also proposes two new ideas, one focused on a

single institution and the other on multiple institutions to make this low-enrollment program sustainable at Australian regional universities.

Keywords: student mathematics teacher, problem solving, triangles; inverse trigonometry, low-enrollment program, regional university, sustainability, mathematics education

1. Introduction

Australia has a large territory of about 7.7 million km² making it the sixth-largest country in the world, but it has a population of just over 27 million, ranking 53rd out of more than 200 countries [1,2]. According to the classification of Rural, Remote, and Metropolitan Areas, with the five categories of Major Cities, Inner Regional, Outer Regional, Remote, and Very Remote areas [3], the Major Cities and Inner Regional areas have an estimated population of over 24 million, while fewer than 3 million people live in the Outer Regional, Remote, and Very Remote areas [4]. This means that more than 90% of the population live in capital cities and major urban centers, which occupy about 5% of the land, while less than 10% live in the vastly distributed regional areas that make up 95% of Australia's territory (Figure 1). The Outer Regional, Remote, and Very Remote areas, sometimes including parts of the Inner Regional area, are commonly referred to as "regional Australia" or the regional, rural, and remote (RRR) areas of the country.

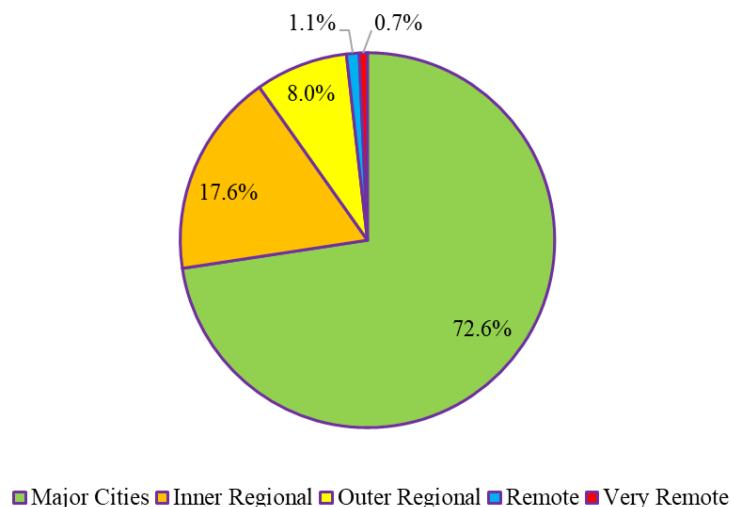


Figure 1. Regional classifications of Australia (redrawn from [4] by the author).

However, regional Australia has made significant contributions to the Australian economy in many ways [5–7]. For instance, mining (minerals, oil, gas, etc.), agribusiness (cropping, horticulture, fishing, wine production, dairy, meat, etc.), and tourism (both domestic and international) are major contributors to the Australian economy, and these sectors are primarily based in the RRR areas. Therefore, despite the small population in these regions, it is crucial to make every effort to sustain a satisfactory standard of living, infrastructure, health, and prosperity for people in regional Australia. The key to achieving this sustainability is to offer affordable, employment-oriented tertiary education to regional students, delivered with convenience and high quality, likely through regional universities near these communities.

Regional universities have been the most popular choice for RRR students who wish to pursue tertiary education. However, offering a wide range of programs to students at regional universities presents unique challenges compared to metropolitan universities [8–11], largely due to the small population of fewer than 3 million spread across 95% of the Australian landmass. Hence, most courses offered in a teaching term in regional universities have a small class size with students from various RRR locations [12,13].

Running many such courses places the institution under tremendous financial pressure. For example, at a metropolitan university, the same course might have over 100, or even hundreds of, enrolled students in one or two venues. The course is typically prepared and delivered by one lecturer, with several casual tutors handling the tutorial sessions. At a regional university, however, the lecturer must prepare and teach the course to 30-40 students online, regardless of attendance, and also more casual tutors are required to conduct face-to-face tutorials with one or a few students at each of the multiple regional campuses that students have selected as their "home campus." Since domestic students pay the same amount of tuition fee for the same course, the efficiency of course delivery at a regional university is much lower than at a metropolitan university. In other words, the cost of teaching and support for delivering the same course at a regional university is significantly higher than at a metropolitan university.

In addition to the higher cost of course delivery at regional universities, there has been a lower rate of participation in tertiary education by school leavers in RRR areas [8–12]. However, encouraging statistics show that once students from RRR areas successfully complete their tertiary programs at a regional university, most graduates are likely to pursue careers in RRR areas after graduation [5–7]. This provides a strong rationale for regional universities to continue offering low-enrollment programs to RRR students.

Thus, ensuring the sustainability of low-enrollment programs has been a significant challenge for regional universities, especially given the severe financial impact of the COVID-19 pandemic and the slow recovery afterward. A typical example is the secondary mathematics specialty in the Bachelor of Education program at Central Queensland University (CQU), a regional university with the largest footprint in Australia.

Regional universities have employed various strategies to encourage as many eligible school leavers as possible to engage in tertiary education and have offered preparatory courses for school leavers and adults who are academically ineligible to enroll in tertiary programs, aiming to provide more potential students with a second chance to participate in tertiary education; hence, to make these programs financially viable. However, the impact of these efforts has been limited, particularly due to disruptions caused by the COVID-19 pandemic in recent years. While a few researchers have briefly addressed the sustainability of low-enrollment programs at regional Australian universities [14,15], there is a lack of detailed case studies on the key factors contributing to the challenges faced by specific low-enrollment programs, and more importantly, viable solutions to mitigate these factors in the future.

Here, I aim to provide a detailed analysis of three offerings of a foundation mathematics course in a low-enrollment secondary mathematics teaching specialty within the Bachelor of Education program at CQU, both before and after the COVID-19 pandemic, conducted by me. The study is based on students' engagement ratios in teaching and learning, as well as their performance in solving two selected questions on basic inverse trigonometry and triangles from their assignments across three independent groups of students. These specific topics were chosen because solving inverse trigonometric and triangular problems is typically a more challenging task in foundation

mathematics, particularly for pre-service mathematics teachers (and for students in other disciplines as well) [16–20]. Solving simple mathematical problems does not adequately reveal students' level of engagement in the learning process. Therefore, only by solving more challenging mathematical problems can students' true effort in engaging with the teaching and learning processes be assessed.

In Section 2, I provide background information on the secondary mathematics teaching specialty and the foundation mathematics course, including details on the three groups of students who took the course before and after the COVID-19 pandemic, as well as the chosen research methodology. In Sections 3 through 5, I present the questions assigned to the 3 student groups, reference solutions, and students' performance in solving these questions. In Section 6, I discuss students' engagement in teaching and learning, the implications of their performance for secondary school mathematics instruction, and the potential realignment of relevant tertiary curricula to improve the sustainability of the foundation mathematics course and, consequently, the secondary mathematics teaching specialty. Finally, in Section 7, I summarize the study.

2. Background information

The mathematics specialty in the Bachelor of Education program at CQU serves the needs of producing mathematics teachers for secondary schools in the RRR areas. The secondary mathematics specialty consists of one statistics course and five mathematics courses across multiple academic levels over three years of full-time study. The academic structure of the courses is illustrated in Figure 2.

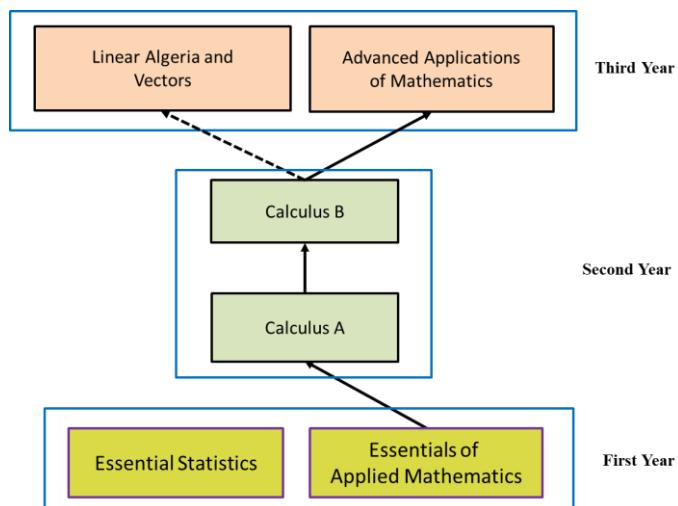


Figure 2. Academic structure of the secondary mathematics specialty based on the CQU Handbook [21].

Except the essential statistics course, which is relatively independent of other mathematics courses, the five mathematics courses are progressively linked in terms of academic progression for the students. All first-year students undertaking this specialty must successfully complete the foundation course (Essentials of Applied Mathematics) as it is the prerequisite for the differential calculus course (Calculus A), which in turn is the prerequisite for the integral calculus course (Calculus B). Both calculus courses are scheduled in the second year, and each is offered in only one

teaching term due to a small number of enrollments. Generally, the integral calculus course is the prerequisite for the two advanced courses in the third year of study, but this is only mandatory for the mathematical modeling course (Advanced Applications of Mathematics). If a student obtained a higher grade in the differential calculus course but has not attempted the integral calculus course, such student may be allowed to undertake the Linear Algebra and Vectors course that is not heavily associated with integration.

The foundation course aims to consolidate basic topics in algebra, geometry, and trigonometry, which students have learned in secondary schools. This course not only helps recent school graduates revise their previously acquired mathematical knowledge and/or bridge gaps in their original mathematics learning but also provides mature adult students who left school more than five years ago with an opportunity to re-engage in mathematics learning from a foundation level to boost their confidence for a smoother progression. The pedagogical goals of this course are achieved through systematic reviews combined with conceptual reasoning, logical articulation, and real-world applications in weekly lectures and tutorials.

Students enrolled in the foundation mathematics course range from 17/18 years old (new school graduates) to 50/60 years old. As this foundation course is the prerequisite for the next mathematics course in the second year, it is offered twice in two teaching terms every year. The first teaching term during March-June usually attracts 40-50 initial enrollments (hence called the major offering), and the second term during July-October typically has around 25 students (hence called the minor offering). Most of the students in a class are likely to live in different RRR areas of Queensland, with a few in other states of the country, and sometimes abroad. History shows that very few students, if any, can frequently attend a scheduled physical or online class for this foundation course. This is because many young RRR students need to take part-time or casual jobs to support their tertiary education due to financial constraints. Other mature students are likely to have family commitments in addition to work and study responsibilities. As a result, this course is delivered through weekly live online classes with or without student participation, but the recorded sessions are uploaded to the course website soon after each session for students to access at their convenience.

Three student groups are selected for this comparative case study. These students undertook the foundation mathematics course in three minor offerings before and after the Covid pandemic. These selections are based on three major reasons. First, these three teaching terms followed the same pedagogical scheme with similar assessment structures, causing some questions assigned to the three cohorts in different terms to be comparable. Second, all the teaching activities and learning assessments were coordinated, conducted, and administered solely by the author, ensuring consistency across the three offerings. Third, the smaller number of enrollments in the minor offering reduced the possibility of multiple students requesting long extensions for assignment submission after the normal due date, which often occurred with larger enrollments in a major teaching term. This fact ensures that all comparisons of student performance are made on as level a ground as possible.

The details of these three groups of students are shown in Table 1. The first group of 26 student teachers took this foundation mathematics course in the minor teaching term of 2019, just before the Covid-19 outbreak in early 2020. Students enrolled in 2019 needed to satisfy the preset entry requirement, i.e., either successfully completing Year-12 mathematics or completing a designated preparatory mathematics program equivalent to Year-12 mathematics. Due to the outbreak of

Covid-19 in 2020, both offerings in 2020 were coordinated and delivered by different relief lecturers with altered teaching, learning, and assessment plans, significantly different from the pedagogical scheme followed in 2019. Thus, the cohort of 2020 students is not included in this comparative study. The second group of 13 students took this foundation course in the minor teaching term in late 2021, a year after the peak of Covid-19. Students enrolled in this teaching term followed the normal pedagogical plan and assessment schedule used before the Covid-19 outbreak. The third group of 15 students took this foundation mathematics course in the minor teaching term in late 2022, two years after the peak of Covid-19, following the same pedagogical plan and assessment schedule as the previous year, delivered by the same lecturer.

Table 1. Number of students enrolled in the foundation course in the three minor offerings.

Pre-Covid (2019)	Post-Covid (2021)	Post-Covid (2022)	Total
26	13	15	54

Since teaching, learning, and assessments in mathematics education (and other subjects as well) were substantially affected in high schools in 2020, particularly for senior students in Year 11 and Year 12, students enrolled in this first-year foundation mathematics course in 2021 and 2022 were recommended by individual schools without the need to pass the formal tertiary entrance assessments used in pre-Covid years.

Given the background information described above, I explore potential answers to the following questions:

- How effective was the relaxed tertiary entrance requirement in increasing enrollment numbers in this secondary mathematics specialty post-Covid?
- How much did the influence of Covid-related interruptions affect problem-solving performances of active students before and after the Covid pandemic?
- What are the implications of students' problem-solving performances for teaching and learning adjustments in high school mathematics education?
- What are the potential strategies to sustain the secondary mathematics specialty in a regional university?

To maintain consistency in comparing students' performances in mathematics problem-solving among the three groups, two questions of similar nature were selected from each group's assignments completed in the corresponding teaching term: One question on solving a basic inverse trigonometric problem and the other on solving a word-based triangular problem. The details of the individual questions for the three groups of students are presented in the following sections. Given my purpose of this case study, the most suitable research method is the comparative case study [22], supported by statistics.

3. The first group

3.1. The first question

3.1.1. Information about the group and the question

The first group of 26 student teachers undertook this foundation mathematics course during the

minor teaching term in 2019, just before the outbreak of Covid-19 in early 2020. The questions for the first assignment were made available to all students in Week 1, and the submission was due in the middle of Week 6. The questions were set according to the content covered in lectures and tutorials during Weeks 1-5. Multiple questions on algebra, triangles, and basic trigonometry were included in this assignment, from which only two questions are selected for this comparative case study.

Each question was awarded full marks if the answer was error-free, partial marks if there were some errors, and no marks if it was not attempted or contained too many errors to render the attempt to be without value. To ensure maximum benefit, students were required to present their answers neatly and clearly, with all appropriate work shown.

The first question, referred to as Question 1, was intended to test students' understanding of the non-unique property of angles obtained from inverse trigonometric operations using calculators. It had been explained to the students in lectures, tutorials, and the designated textbook that the angle obtained from any inverse trigonometric function on a scientific calculator is only the principal-range angle for that function. However, there is one more angle within a full 360° turn that can produce the same trigonometric value. Examples of how to determine the other angle using the principal-range angle from calculators were presented in both tutorials and the textbook that also contains a table summarizing the process (e.g., Table 2 below).

Table 2. Summary of principal-range angles of inverse sine, cosine and tangent functions [23].

$\theta = \sin^{-1} z$	Two angles in 360°	$\theta = \cos^{-1} z$	Two angles in 360°	$\theta = \tan^{-1} z$	Two angles in 360°
$0^\circ < \theta < 90^\circ$	θ & $180^\circ - \theta$	$0^\circ < \theta < 180^\circ$	θ & $360^\circ - \theta$	$0^\circ < \theta < 90^\circ$	θ & $180^\circ + \theta$
$-90^\circ < \theta < 0^\circ$	$180^\circ + \theta $ & $360^\circ - \theta $			$-90^\circ < \theta < 0^\circ$	$180^\circ - \theta $ & $360^\circ - \theta $

* θ is the principal-range angle obtained by calculator.

Given $\cos \alpha = -0.5592$ and α is in Quadrant III, determine the angle α .

Question 1. The first problem assigned to the first group of student teachers

3.1.2. The reference solution

Referring to Table 2, the solution to this question can be easily obtained as follows.

Step 1: Use a calculator in degree mode to obtain the principal-range angle by $\theta = \arccos(-0.5592)$.

$$\theta = \arccos(-0.5592) = 124^\circ.$$

Step 2: Use the principal-range angle θ to work out the angle α in Quadrant III by the relationship for cosine summarized in Table 2 as follows.

$$\alpha = 360^\circ - \theta = 360^\circ - 124^\circ = 240^\circ.$$

The angle α is in Quadrant III because cosine is negative in both Quadrant II and Quadrant III.

3.1.3. Performance of the student teachers

Among the 26 students, 21 submitted their assignments. Five students, or about 19% of the total,

failed to submit anything. Of the 21 who submitted, 14 students solved the problem correctly, meaning that two-thirds of the students who attempted the problem obtained the correct answer by following the process demonstrated in the reference solution. Two other students followed the correct procedure but made careless mistakes in obtaining the principal-range angle by entering a number different from -0.5592 , resulting in their answers being regarded as partly correct. Nevertheless, these 16 students adhered to the instructions provided in the lectures, worked examples in the textbook, and tutorials.

However, 5 students simply used calculators to find the principal-range angle $\theta = 124^\circ$ as their solution, without considering that the required angle should be in Quadrant III, resulting in an incorrect answer for this question. The overall performance of the student teachers in solving this problem is summarized in Table 3.

Table 3. The overall performance of the first group of students in solving Question 1.

Outcome	Number	Percentage (%) of all	Percentage (%) of attempted students
Correct	14	53.9	66.7
Partly correct	2	7.7	9.5
Incorrect	5	19.2	23.8
No attempt	5	19.2	—
Total	26	100	100

3.2. The second question

3.2.1. The question

The second problem, referred to as Question 2, was a worded problem related to applying the Pythagorean theorem and basic trigonometric functions associated with right triangles. The problem aimed to test students' understanding of the Pythagorean theorem and basic trigonometric functions, as well as their ability to use these rules to solve an authentic problem described in words with a clear strategy.

An observer stood on top of a cliff 255 m above sea level. The observer first saw a boat at point A in the sea with an angle of inclination of 64° . Two minutes later, the observer saw the boat at point B with an angle of inclination of 33° . Assuming the boat traveled in a straight line, what was the average speed of the boat? (Keep one decimal place for the final result.)

Question 2. The second problem assigned to the first group of student mathematics teachers

According to the teaching and learning plan, students should have completed these topics and all the designated exercises before attempting this question. A similar example is also presented in the designated textbook [23].

3.2.2. The reference solution

As demonstrated in [20], there are two general strategies to solve this problem: using right triangles alone or by mixing right and oblique triangles. Both methods require students to draw a diagram to

accurately represent the described scenario with the known and derived figures to assist in solving the problem. A diagram representing the described scenario is shown in Figure 3. Point C indicates where the observer was standing during the observation.

By right triangles

Referring to the right triangles DAC and DBC in Figure 3, the distance from A to B (AB) can be found through the following process.

$$DA = CD \tan 26^\circ \longrightarrow DB = CD \tan(31^\circ + 26^\circ) = CD \tan 57^\circ$$

$$AB = DB - DA = CD \tan 57^\circ - CD \tan 26^\circ = CD(\tan 57^\circ - \tan 26^\circ)$$

The average speed of the boat over two minutes (or 120 seconds) is calculated by

$$v = \frac{AB}{t} = \frac{CD(\tan 57^\circ - \tan 26^\circ)}{t} = \frac{255(\tan 57^\circ - \tan 26^\circ)}{2 \times 60} = 2.236 \text{ m/s} = 8.05 \text{ km/h.}$$

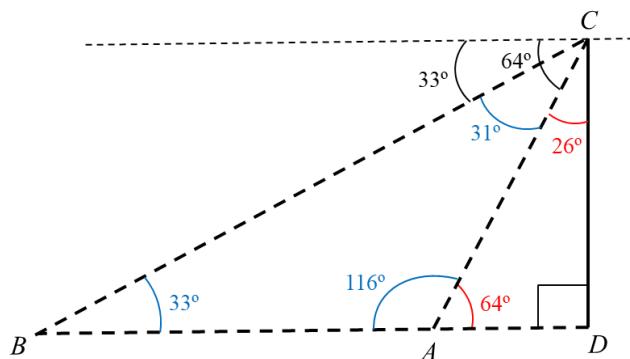


Figure 3. The diagram depicting the scenario of the second question.

By mixing right and oblique triangles

Referring to the right triangle DAC or DBC and the oblique triangle ABC in Figure 3, the distance from A to B (AB) can be found through the following process.

$$AC = \frac{CD}{\sin 64^\circ} \left(= \frac{CD}{\cos 26^\circ} \right) \text{ or } BC = \frac{CD}{\sin 33^\circ} \left(= \frac{CD}{\cos 57^\circ} \right) \longrightarrow \frac{AB}{\sin 31^\circ} = \frac{AC}{\sin 33^\circ} = \frac{BC}{\sin 116^\circ}$$

$$AB = \frac{AC \sin 31^\circ}{\sin 33^\circ} = \frac{CD \sin 31^\circ}{\sin 33^\circ \sin 64^\circ} \left(= \frac{CD \sin 31^\circ}{\sin 116^\circ \sin 33^\circ} \right)$$

The average speed of the boat can be calculated similarly as above.

3.2.3. Performance of student teachers

Excluding the 5 students who did not submit their assignments, 16 of the 21 students who submitted solved this problem correctly, accounting for about 76% of the students who attempted the problem, or approximately 62% of all the students. Two students presented partly correct solutions,

primarily due to errors in calculating the associated angles or trigonometric values while employing a correct strategy to solve the problem. Three students were completely incorrect, which seemed more related to their inability to understand the scenario described in words. The overall performance of the student teachers is summarized in Table 4.

As reported in [20], using right triangles was the overwhelming choice for 18 of the 21 students who attempted this problem. Only 3 students used the strategy of mixing triangles to solve the problem and all obtained the correct solution.

Table 4. The overall performance of student teachers in solving Question 2.

Outcome	Number	Percentage (%) of all	Percentage (%) of attempted students
Correct	16	61.5	76.2
Partly correct	2	7.7	9.5
Incorrect	3	11.5	14.3
No attempt	5	19.2	—
Total	26	99.9	99.9

4. The second group

4.1. The first question

4.1.1. Information about the group and the question

The second group of 13 students undertook this foundation mathematics course in the minor teaching term in late 2021, a year after the peak of Covid-19. Students enrolled in this teaching term followed the normal pedagogical plan and assessment schedule, similar to those before the outbreak of Covid-19. Since teaching, learning, and assessments in high schools were also affected, particularly for senior students in Year 11 and Year 12, students enrolled in this first-year foundation mathematics course in 2021 were recommended by individual schools without formal state-wide assessments as the entry requirement.

Considering the potential negative impact of the Covid outbreak in 2020 on this group of students who were in Year 12 during the pandemic, the teaching pace for this foundation mathematics course was significantly slowed down. Topics such as triangles and basic trigonometry were moved to the second half of the teaching term. Additionally, the difficulty level of the assignment questions was slightly adjusted to encourage as many students as possible to continue progressing positively. The assignment questions were made available to all students in Week 1, with submission due in the middle of Week 11. The questions were set according to the content covered in lectures and tutorials during Weeks 6-10. The two questions chosen from the assignment for this case study are similar to those for the other two groups, with the same assessment criteria. The first question, referred to as Question 3, was intended to test students' understanding of the non-unique property of angles obtained from inverse trigonometric operations using calculators, similar to the purpose of the first question for the first group of students.

Given $\sin \alpha = ? .8910$ and α is in Quadrant III, determine the angle α .

Question 3. The first problem assigned to the second group of student teachers

4.1.2. The reference solution

Referring to Table 2, the solution to this question can be easily obtained as follows.

Step 1: Use a calculator in degree mode to obtain the principal-range angle by $\theta = \arcsin(-0.8910)$.

$$\theta = \arcsin(-0.8910) = -63^\circ.$$

Step 2: Use the principal-range angle θ to work out the angle α in Quadrant III by the relationship for sine summarized in Table 2 as follows.

$$\alpha = 180^\circ + |\theta| = 180^\circ + 63^\circ = 243^\circ.$$

The angle α is in Quadrant III because sine is negative in both Quadrant III and Quadrant IV.

4.1.3. Performance of the student teachers

Among the 13 enrolled students, only 8 submitted their assignments, while five did not submit anything. Of the eight who submitted, five students, or about 62% of those who attempted the problem, obtained the correct answer by following the process demonstrated in the reference solution. One student made a small mistake in obtaining the principal-range angle using the calculator, leading to an erroneous angle in Step 2. However, the general procedure was correct, so this student received half of the full marks. Two students obtained incorrect answers by simply using calculators to get the principal-range angle as the solution, without considering that the required angle should be in Quadrant III. The overall performance of the student teachers in solving this problem is summarized in Table 5.

Table 5. The overall performance of the second group of student teachers in solving Question 3.

Outcome	Number	Percentage (%) of all	Percentage (%) of attempted students
Correct	5	38.5	62.5
Partly correct	1	7.7	12.5
Incorrect	2	15.4	25.0
No attempt	5	38.5	—
Total	13	101	100

4.2. The second problem

4.2.1. The question

The second question, referred to as Question 4, was a simple word problem related to applying the Pythagorean theorem to an isosceles triangle. The problem aimed to test students' understanding of the general properties of isosceles triangles and their ability to use the Pythagorean theorem to solve a word problem with a clear strategy.

The area of an isosceles triangle is 24 cm^2 and its height based on the unequal side is 6 cm . Find the length of the equal sides of this isosceles triangle. (Keep one decimal place in the final result.)

Question 4. The second word problem assigned to the second group of student teachers

4.2.2. The reference solution

To assist in solving this problem, it is helpful to sketch an isosceles triangle with labels for reference, as shown in Figure 4. With this diagram, the question can be solved as follows. Other methods can also be used to solve the problem with additional steps.

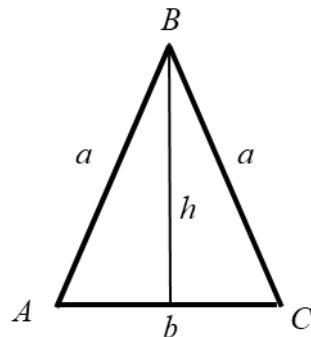


Figure 4. The diagram depicting the scenario of Question 4.

Step 1: Assume the length of the unequal side is b and the height from this base to point B should be $h = 6$ cm for this isosceles triangle. Area (A) of this isosceles triangle should be

$$A = \frac{1}{2}bh = 24 \longrightarrow b = \frac{2A}{h} = \frac{2 \times 24}{6} = 8 \text{ (cm).}$$

Step 2: Since two other sizes are equal in length (a), the height and half of the base form a right triangle, which leads to determining the size a by the Pythagorean theorem.

$$a^2 = h^2 + \left(\frac{b}{2}\right)^2 \longrightarrow a = \sqrt{h^2 + \left(\frac{b}{2}\right)^2} = \sqrt{6^2 + 4^2} = \sqrt{52} = 7.2 \text{ (cm).}$$

4.2.3. Performance of student teachers

Excluding the 5 students who did not submit their assignments, 6 of the 8 students who submitted the assignment solved this problem correctly. One student followed the correct procedure but made a mistake in calculation. Another student did not draw a sketch to assist with the solution and used the entire base (rather than half of the base) in the Pythagorean theorem, leading to an incorrect answer. This type of mistake often occurred among students who disengaged from the explicit teaching and learning practices recommended by the lecturer [24]. The overall performance of the student teachers is summarized in Table 6.

Table 6. The overall performance of the second group of student teachers in solving Question 4.

Outcome	Number	Percentage (%) of all	Percentage (%) of attempted students
Correct	6	46.1	75.0
Partly correct	1	7.7	12.5
Incorrect	1	7.7	12.5
No attempt	5	38.5	—
Total	13	100	100

5. The third group

5.1. The first question

5.1.1. Information about the group and the question

The third group of 15 students undertook this foundation mathematics course in the minor teaching term in late 2022, two years after the peak of Covid-19. Most students enrolled in this teaching term had experienced the transition from on-campus study to online teaching and learning during 2020 and 2021 in their Year 11 and Year 12 studies.

Similar to the minor teaching term in 2021, students in this term followed the normal pedagogical plan and assessment schedule as in the previous year, delivered by the same lecturer who also taught the first two groups of students. The assignment questions were made available to all students in Week 1, with submission due in the middle of Week 11. Questions were set according to the content covered in lectures and tutorials during Weeks 6-10. The two questions chosen from the assignment for this case study are similar to those used for the first and second groups, with the same assessment criteria. The first question, referred to as Question 5, was intended to test students' understanding of the non-unique property of angles obtained from inverse trigonometric operations using calculators. This question is similar to Question 1 assigned to the first group of students.

Given $\cos \alpha = -0.2079$ and α is in Quadrant III, determine the angle α .

Question 5. The first problem assigned to the third group of student teachers

5.1.2. The reference solution

Referring to Table 2, the solution to this question can be easily obtained as follows.

Step 1: Use a calculator in degree mode to obtain the principal-range angle by $\theta = \arccos(-0.2079)$.

$$\theta = \arccos(-0.2079) = 102^\circ.$$

Step 2: Use the principal-range angle θ to work out the angle α in Quadrant III by the relationship for cosine summarized in Table 2 as follows.

$$\alpha = 360^\circ - \theta = 360^\circ - 102^\circ = 258^\circ.$$

The angle α is in Quadrant III because cosine is negative in both Quadrant II and Quadrant III.

5.1.3. Performance of student teachers

Among the 15 enrolled students, only 9 submitted their assignments, while 6 did not submit anything. Of the 9 students who submitted, 4, or about 44% of those who attempted the problem, obtained the correct answer by following the process demonstrated in the reference solution. One student made a small mistake in obtaining the principal-range angle using the calculator, which led to an erroneous angle in Step 2. However, 4 students obtained incorrect answers by simply using calculators to get the principal-range angle as the solution, without considering that the required angle should be in Quadrant III. The overall performance of the student teachers in solving this problem is summarized in Table 7.

Table 7. The overall performance of the third group of student teachers in solving Question 5.

Outcome	Number	Percentage (%) of all	Percentage (%) of attempted students
Correct	4	26.7	44.4
Partly correct	1	6.7	11.1
Incorrect	4	26.7	44.4
No attempt	6	40.0	—
Total	15	100.1	99.9

5.2. The second question

5.2.1. *The question*

The second problem, shown in Question 6, was a simple word problem related to applying the Pythagorean theorem in the context of an isosceles triangle. The problem aimed at testing students' understanding of the general properties of isosceles triangles and their ability to use these properties to solve a problem described in words with a clear strategy. Note that Question 6 is somewhat similar to Question 4 assigned to the second group of students in 2021, but is relatively easier as it does not require the use of the Pythagorean theorem.

The area of an isosceles triangle is 24 cm^2 and its perimeter is 32 cm . If the height measured from the unequal side is 8 cm , find the length of the two equal sides of this isosceles triangle (keep 1 decimal place in the final result).

Question 6. The second problem assigned to the third group of student teachers

5.2.2. *The reference solution*

To assist in solving this problem, it is helpful to sketch an isosceles triangle with labels, similar to Figure 4, for reference during the solution process. The problem can be solved as follows (other methods may also be used, potentially involving additional steps):

Step 1: Refer to Figure 4. By the base b and height h , the area of this isosceles triangle should be

$$A = \frac{1}{2}bh \longrightarrow b = \frac{2A}{h} = \frac{2 \times 48}{8} = 12 \text{ (cm)}$$

Step 2: The perimeter (P) of this isosceles triangle should be

$$P = 2a + b = 32 \longrightarrow 2a + 12 = 32 \longrightarrow 2a = 20 \longrightarrow a = 10 \text{ (cm)}.$$

Alternatively, once b has been obtained in Step 1, the equal side can be found using the Pythagorean theorem as follows.

Step 2^{*}: By the Pythagorean theorem

$$a^2 = h^2 + \left(\frac{b}{2}\right)^2 \longrightarrow a = \sqrt{h^2 + \left(\frac{b}{2}\right)^2} = \sqrt{8^2 + 6^2} = \sqrt{100} = 10 \text{ (cm)}.$$

Thus, the length of the equal sides of this isosceles triangle is 10 cm . The known perimeter

simplifies the process but can be used for verification if needed.

5.2.3. Performance of student teachers

By excluding the 6 students who did not submit their assignments, 6 of the 9 students who did submit solved this problem correctly. Among these, 3 used the Pythagorean theorem, 2 used the perimeter of the isosceles triangle, and 1 used both approaches. Two students made simple errors in calculations in Step 1, leading to incorrect answers in Step 2, and were marked as partially correct. One student did not draw a sketch and mistakenly treated the isosceles triangle as a right triangle, resulting in an incorrect answer. The overall performance of the student teachers is summarized in Table 8.

Table 8. The overall performance of the third group of students in Question 6.

Outcome	Number	Percentage (%) of all	Percentage (%) of attempted students
Correct	6	40.0	67.7
Partly correct	2	13.3	22.2
Incorrect	1	6.7	11.1
No attempt	6	40.0	—
Total	15	100	100

6. Discussion

6.1. Entry requirement and student's commitment to learning

Visually, there is a clear difference in the proportion of students who did not attempt the assignments in this foundation mathematics course before and after Covid-19, as shown in Figure 5. In 2019, less than 20% of students did not attempt the assigned questions, but this ratio doubled to about 40% for students enrolled in both 2021 and 2022. These students had experienced online teaching and learning during the peak of Covid-19 in 2020 and 2021 in Years 11 and 12 than traditional face-to-face education. The total enrollment in each of these two post-Covid years was about half of that in 2019, yet the number of non-attempts was at the same level as in 2019. Given the small number of enrollments and the similarity in the numbers of submissions and non-submissions, Table 9 combines the numbers and ratios of attempts and non-attempts for these two post-Covid years.

With the frequencies of student attempts and non-attempts before and after Covid-19 given in Table 9, the similarity in patterns of attempts versus non-attempts before and after Covid-19 can be assessed using a chi-square test at a significance level of $\alpha = 0.05$ [25]. The chi-square value for the post-Covid pattern compared to the pre-Covid pattern is 4.214, which is greater than the critical value of 3.841 (see Table 10), or the p -value of 0.04 is smaller than $\alpha = 0.05$. This indicates that the patterns of student attempts and non-attempts on the assignments before and after Covid-19 are statistically different from each other.

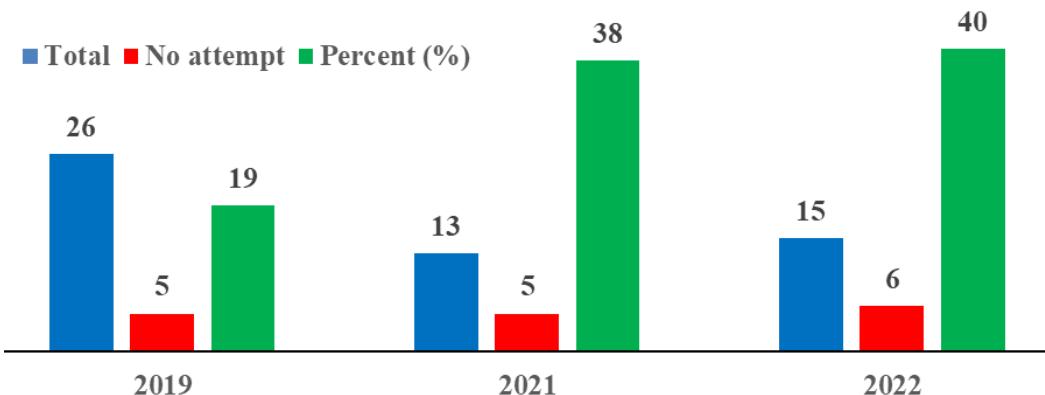


Figure 5. Distribution of numbers of total (blue), no-attempts (red) students and the ratio (Green).

Table 9. Frequencies of attempts and non-attempts by student teachers before and after Covid-19.

	Pre-Covid (2019)	Post-Covid (2021-2022)	Total
Attempt	21	17	38
No attempt	5	11	18
Total	26	28	54

Table 10. Results of chi-test on patterns of student's attempts before and after Covid-19.

Chi-square	p-value	Critical chi-square ($df = 1; \alpha = 0.05$)
4.214	0.040	3.841

The higher rate of non-attempts among the 2021-2022 cohort may be attributed to several factors associated with the negative impact of the Covid pandemic on student engagement in mathematics learning. For instance, students might have been inadequately prepared due to a lower standard of authentic learning through online delivery and a lack of formal and invigilated assessments during 2020-2021 in Years 11 and 12, compared to the standards of on-campus learning. Additionally, family or personal financial constraints following the pandemic might have forced more students to take on multiple casual or part-time jobs, reducing their time for mathematics study, particularly for students in regional, rural, and remote areas.

Another significant factor is the removal of formal entry requirements for tertiary programs for the 2021-2022 cohorts, especially for secondary mathematics teaching. Teaching secondary mathematics is arguably one of the most challenging career choices for school leavers aspiring to become high school teachers. Unlike subjects in other natural or social sciences that are primarily based on factual description, elaboration, life experiences, social norms, or regulations with minimal formulation and algorithmic processes, mathematics focuses on logical reasoning and technical procedures involving various topics. The ultimate goal of mathematics education is to enable students to use mathematical reasoning and techniques to solve both practical exercises and real-world problems with confidence. Thus, tertiary mathematics relies on a solid foundation of basic mathematics established during secondary education. While tertiary mathematics may review foundational concepts, it focuses on strengthening and expanding mathematical knowledge beyond what was covered in secondary schools. There is no capacity within the tertiary mathematics curriculum to simply repeat the basic mathematics taught over six years in secondary school.

Therefore, reintroducing formal entry requirements for tertiary programs in secondary mathematics teaching is crucial. This would better support well-prepared students in becoming competent secondary mathematics teachers and prevent under-prepared students from incurring financial loss and academic penalties due to course failures.

6.2. Student engagement and performance in problem solving

For students who attempted the assignment questions, the statistics revealed no significant difference in performance between the two small groups enrolled in 2021 and 2022. The chi-square values were smaller than the critical value of 5.992 at a significance level of $\alpha = 0.05$ (see Table 11), indicating that these two cohorts can be combined into one post-Covid group. Consequently, the performance of the pre-Covid and post-Covid groups in terms of correct, partly correct, and incorrect solutions is summarized in Table 12.

Table 11. Results of chi-test on students' performances for the 2021 and 2022 cohorts.

Test item	Q3-Q5	Q4-Q6	Critical chi-square ($df = 2; \alpha = 0.05$)
Chi-square (p -value)	1.250 (0.535)	0.500 (0.779)	5.992

Table 12. Performances in solving the questions by the student cohorts before and after Covid-19.

Question	Pre-Covid			Post-Covid			
	Correct	Partly correct	Incorrect	Question	Correct	Partly correct	Incorrect
Q1	14	2	5	Q3/Q5	9	2	6
Q2	16	2	3	Q4/Q6	12	3	2
Total	30	4	8		21	5	8

Based on the frequencies of student performances in solving the corresponding questions presented in Table 12, the chi-square test at a significance level of $\alpha = 0.05$ indicates no statistical difference in performance patterns between the pre-Covid and post-Covid groups for both inverse trigonometric problems (Q1-Q3/Q5) and triangular problems (Q2-Q4/Q6). The chi-square values were below the critical value of 5.992 (see Table 13), suggesting that students who attempted the assignments achieved similar levels of success or failure in solving these problems, with minimal impact from the Covid pandemic.

This finding implies that the consistency in teaching and assessment for this foundation mathematics course was largely maintained by the same lecturer before and after the Covid pandemic, despite an increase in the number of students who did not attempt the assignments post-pandemic.

Table 13. Results of chi-test on students' performances before and after Covid-19.

Test item	Q1-Q3/Q5	Q2-Q4/Q6	Critical chi-square ($df = 2; \alpha = 0.05$)
Chi-square (p -value)	2.944 (0.229)	2.167 (0.338)	5.992

Several students in both cohorts obtained completely incorrect answers to the questions. While these students may have made a reasonable effort, it did not necessarily reflect engagement with the

explicit teaching and learning practices that the instructor had developed over time to foster more effective and efficient mathematics learning. Engaged learning, driven by the students themselves, is crucial for effectively building mathematical knowledge, regardless of the teaching approach [24]. For instance, nearly all students who followed the prescribed procedure for obtaining the correct angle from the principal-range angle using calculators (as outlined in Table 2) achieved the correct answer for the inverse trigonometric problem. In contrast, those who disregarded this procedure ended up with incorrect answers.

6.3. Implication for school mathematics education

Since no statistical difference was found in the pattern of solving assigned questions among students who attempted the questions before and after the Covid pandemic, these two groups can be combined into a larger cohort of 38 students for further statistical analysis of performance on inverse trigonometric and triangular questions (see Table 14). The chi-square test indicates a significant difference between performances on inverse trigonometric questions and triangular questions for all 38 students who submitted their assignments. This is evidenced by the chi-square value of 8.293, which exceeds the critical value of 5.992, or the p -value of 0.016, which is smaller than the significance level $\alpha = 0.05$ (see Table 15). Therefore, students performed statistically better for triangular questions compared to inverse trigonometric questions.

In this study, triangular questions were generally less challenging for students who had a solid understanding of right triangles. Given that right triangles and their applications form the foundation for learning more advanced topics like obtuse triangles and trigonometry, and that these topics are extensively covered in secondary education, solving right triangle-based problems should have been relatively straightforward for most students. Except for a few who made careless calculation errors, course logs indicated that students who struggled with triangular questions often lacked active engagement in the course throughout the term. These students might have been able to solve simple triangular problems using calculators but faced difficulties in accurately representing scenarios described in words and logically connecting multiple steps to solve the problems. In other words, their ‘shallow mathematics learning’ followed ‘shadow mathematics teaching’ in secondary school were insufficient for handling such problems without full engagement in their first tertiary mathematics course.

Table 14. Students’ performances in solving the inverse trigonometric and triangular questions.

Question	Correct	Partly correct	Incorrect	Subtotal
Inverse trigonometry (Q1/Q3/Q5)	23	4	11	38
Triangle (Q2/Q4/Q6)	28	5	5	38
Total	51	9	16	76

Table 15. Results of chi-test on students’ performances in different types of questions.

Test item	Triangle-Trigonometry	Critical chi-square ($df = 2$; $\alpha = 0.05$)
Chi-square (p -value)	8.293 (0.016)	5.992

The inverse trigonometric questions further highlighted the inadequacies of the ‘shallow teaching and learning’ prevalent in many secondary schools. It has become a standard practice for

mathematics teachers to instruct students on how to use scientific calculators to ‘solve’ mathematical problems from the early stages of secondary schooling and even primary school [26–28]. This calculator-dependent approach has led to many high school graduates being able to perform basic arithmetic operations like addition or subtraction of fractions using calculators but unable to carry out these tasks using mathematical procedures. This issue arises from shallow teaching that focuses on ‘how’ to obtain results rather than ‘why and how’ these results are derived.

Similarly, students who did not actively engage in the teaching and learning of this course often ended up with incorrect answers for the inverse trigonometric questions by simply accepting the angles returned directly by calculators. They were not taught by their secondary school mathematics teachers that an angle obtained via inverse trigonometric functions is merely the ‘principal-range angle’ and that there can be another angle within 360 ° that produces the same trigonometric value. In fact, some in-service mathematics teachers themselves might not fully understand ‘why and how’ the result should be obtained, as noted by a few in-service teachers during a workshop hosted by the author a few years ago.

Therefore, while students must be actively engaged in the mathematics teaching and learning process, it is equally important for school mathematics teachers to continuously improve their technical skills. Teachers need to not only show students how to use calculators or other mathematical software to find answers but also to clearly explain the underlying mathematical concepts, the rationale behind specific procedures, and the appropriate contexts in which these procedures can be applied to solve real-world problems.

6.4. Sustainability of tertiary mathematics education in regional Australia

There has been a significant decline in enrollments in the foundation mathematics course in the minor teaching term following the Covid-19 pandemic. Before the pandemic, approximately 40 students enrolled in the major teaching term and around 25 students in the minor teaching term for this course at the regional Australian university. Ideally, to ensure financial viability and sustainability of the secondary mathematics teaching specialty, offering this foundation course once per year to all first-year students would be the most economical choice for a regional university, given the higher running costs compared to metropolitan institutions. However, people and families living in regional, rural, and remote areas in Australia face numerous uncertainties, such as employment instability, job mobility, and environmental factors like floods and droughts. Consequently, RRR students and their families may be more cautious about committing to tertiary education compared to their metropolitan counterparts.

Offering the foundation mathematics course twice a year not only maximizes the number of students entering their desired specialty in secondary mathematics teaching but also provides a second chance for those who failed in the major term to retake the course without delaying their progress by a year. A year-long wait to retake the foundation course as a prerequisite for subsequent mathematics courses could lead many RRR students to drop out of mathematics study or tertiary education altogether. Thus, regional Australian universities often prioritize supporting as many students as possible in their educational pursuits over financial concerns, fulfilling their social obligations. However, the long-term sustainability of such programs can be jeopardized during prolonged periods of financial constraint, particularly when revenue from other programs declines.

The impact of the Covid pandemic exacerbated the challenge of maintaining the minor teaching

term due to the reduced number of students. The simplest option might be to offer the foundation mathematics course only once per year, but canceling the minor term could lead to further reductions in student numbers. This reduction in students progressing to second-year mathematics courses could continue into third-year courses. Increasing first-year enrollments in regional Australia has proven difficult, despite persistent efforts by recruitment departments using various strategies over the past decade. While continuing successful recruitment strategies is essential, exploring new ideas is crucial to ensure the sustainability of programs for training future generations of competent secondary mathematics teachers.

At the university level, the foundation mathematics course is mandatory for the mathematics education specialty, while engineering programs have separate foundation courses for different specialties. Many science (e.g., chemistry, physics, biology, agriculture, environment) and technology programs (e.g., information technology, communication systems, information systems) do not mandate mathematics courses, although students may choose them as electives. Basic mathematics underpin numerous operations in these science and technology fields; thus, making the foundation mathematics course a core requirement for all first-year students in STEM specialties could be beneficial for their subsequent studies and professional lives. With higher enrollment numbers, offering this course twice or even three times a year would become viable. Increased pass rates in the foundation course might lead some students initially enrolled in other STEM programs to transfer to the mathematics specialty or pursue double majors or minors, thus contributing to the sustainability of the mathematics program.

Beyond a single regional university, collaborative efforts among multiple regional institutions could address low enrollment issues. Such cooperation would allow each university to focus on developing and delivering specific courses within a joint program. For example, if three regional universities in Queensland collaborate on the secondary mathematics specialty, they could divide responsibilities: One university could develop and deliver statistics and one of the third-year mathematics courses, another university could handle the foundation mathematics course and the other third-year mathematics course, and the remaining university could take charge of the two second-year mathematics courses. The quality assurance of these courses would be managed by a joint program committee to ensure adherence to national academic standards. However, such collaboration would require significant additional work in administration, finance, management, and technical support from all participating institutions, in addition to academic responsibilities.

7. Conclusions

This comparative case study sheds light on the major factors affecting the sustainability of low-enrollment programs and offers potential strategies to address these challenges. The findings revealed that the Covid-19 pandemic significantly reduced enrollments in the minor offerings of the foundation mathematics course compared to before the pandemic. Additionally, relaxing entry requirements did not increase student intake in the post-pandemic minor teaching term. Instead, a higher proportion of new students failed to submit assignments, contributing to increased attrition.

Despite these challenges, I found no significant difference in the performance of active students before and after the pandemic when they were subject to similar teaching and learning conditions. This suggests that the impact of Covid on learning was minimal for students who maintained engagement with their studies. However, this also highlighted that some students' unsatisfactory

performance might be linked to ineffective learning habits inherited from their secondary education, characterized by ‘shallow teaching and learning’. This underscores the need for adjustments in high school mathematics education to foster more effective learning habits early on.

Given the difficulty in dramatically increasing student numbers for low-enrollment programs in regional universities due to the dispersed population and other challenges faced by potential students and their families, new strategies are needed to ensure the sustainability of these programs. Using the secondary mathematics teaching specialty at CQU as a case study, two potential strategies are proposed:

1. A single regional institution can make the foundation mathematics course mandatory for all first-year students in as many STEM programs as possible. This approach would not only benefit students in their future studies and careers but also increase the likelihood of some students considering a secondary mathematics teaching specialty as a minor.

2. Multiple regional institutions could collaborate to co-offer low-enrollment programs. Such a joint program would allow institutions to share the development and delivery of courses, thus pooling resources and enhancing program viability.

Ensuring the sustainability of low-enrollment programs at regional universities presents a significant challenge. This requires a collaborative effort from all levels of government, universities, schools, teachers, families, communities, organizations, and industries in regional, rural, and remote areas. Students must also be prepared to make the necessary effort to overcome the challenges of their educational journey. As emphasized in [20], tertiary education is not only a right but a privilege that equips individuals to serve society professionally. For pre-service mathematics teachers, this is particularly crucial as their competence impacts not only their own teaching but the mathematics learning of future generations. Without effective measures, low-enrollment programs risk becoming unsustainable, wasting valuable resources, and hindering educational opportunities.

Conflict of interest

The authors declare there is no conflict of interest in any part of this article.

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Ethics declaration

The author declared that the ethics committee approval was waived for the study.

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