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Research Article

Solving word problems involving triangles by transitional engineering students: Learning outcomes and implications

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ABSTRACT

Transitional engineering students are those who are academically ineligible to enter a bachelor's engineering program but are enrolled in an associate engineering program with a university. Successful completion of such an associate engineering program allows the higher achievers to transfer to a full bachelor's engineering program. The associate engineering program is taken commonly by self-employed tradesmen, technical workers, and young apprentices in regional, rural, and remote (RRR) areas. The foundation engineering mathematics course in the associate engineering program, particularly knowledge and skills in solving word problems involving triangles, plays a key role for the smooth transition of these students to the engineering disciplinary courses. However, there is little we have known about the performances of the transitional engineering students in solving problems involving triangles as the associate engineering programs are not among the mainstream of undergraduate programs. This study analyzed the 27 transitional engineering students' performances in solving word problems involving triangles assigned to the students in the foundation mathematics course at a regional Australian university and found that the RRR transitional engineering students demonstrated a higher level of study ethics and achievement in solving word problems involving triangles, compared with the RRR student mathematics teachers. This seems mainly due to the professional experiences in delivering real-world projects prior to the start of their mathematics learning. Further research should be expanded to more areas of mathematics to gauge the overall performances of the transitional engineering students in mathematics learning and progression.

Keywords: foundation engineering mathematics, triangles, Pythagorean theorem, law of sines, law of cosines, regional universities

INTRODUCTION

In regional, rural, and remote (RRR) areas in Australia (and many other countries too), there are many self-employed tradesmen, technical workers, and young apprentices employed by local industries or mining companies in remote areas. Some of these people are keen to enter tertiary programs to improve and enhance their knowledge and skills in engineering either driven by self-motivation or the employer's incentives for professional development. However, many of these people are academically ineligible to directly enter to a bachelor's program in engineering. As a result, many regional universities like Central Queensland University (CQU) in Australia provide these students with an opportunity to start with an associate degree program in engineering (ADE) (Guo, 2022a). Successful completion of such associate engineering programs not only partly meets the need of upskilling, but also allows the higher achievers to transfer to a full degree program in engineering if they wish.

Mathematics is a vital part of engineering programs in universities over the world (Coupland et al., 2008; Levey & Johnson, 2020; Pepin et al., 2021). Mathematics in the associate engineering program usually cover preparatory and foundational topics, equivalent to junior and senior secondary mathematics, for the transitional engineering students to catch up with the required mathematics preparation leading to the engineering calculus courses in a formal engineering bachelor's degree. This is somewhat similar to the preparatory engineering mathematics courses experimented in some universities in the US (Baine, 2020; Newberry et al., 2011; Vercellino et al., 2015).

In the foundation engineering mathematics course in the ADE at CQU, solving problems involving triangles is one of the focused topics due to its importance in engineering (Baine, 2020; Newberry et al., 2011; Ni et al., 2015; Vercellino et al., 2015). However, there is little we have known about the performances of the transitional engineering students in solving problems involving triangles as the associate engineering degrees are not among the mainstream of undergraduate engineering programs. As a loose reference, studies have shown that trigonometry related areas are challenging for many student mathematics teachers. For example, Nabie et al. (2018) found that only 40% of the students were able to fully understand the origin of laws of sines and cosines from the knowledge of right triangles. Walsh et al. (2017) reported that about 20% of the students could not satisfactorily understand and use the properties of right triangles and basic trigonometric rules as the ratios of sides; more than 80% of the participants had difficulties associated with solving obliques triangles; more than 90% were not able to apply laws of sines and cosines to solve a scientific problem described in words, similar to the findings of students' difficulties in dealing with the word problem describing real-life scenarios reported by Dundar (2015) and Fyhn (2017). Hence, it is worthwhile to explore and assess how the transitional engineering students approached and performed in solving word problems involving triangles primarily engaged in distance or online learning environments as a program outside the mainstream.

In regional universities in Australia, students enrolled in tertiary programs are typically engaged with online learning in part-time study mode due to various personal, family, and professional issues (Fraser et al., 2019; Guo, 2022b; Murphy et al., 2019; Wilson et al., 2013). A typical mathematics course offered in a semester or term in a regional university has about 15-30 students enrolled from different geographical locations, predominantly the RRR areas that the regional university serves, with a few from major cities or other local communities nationwide. It is interesting to see how the RRR transitional engineering students would approach solving word problems involving triangles through distance or online learning. Specifically, the aims of this case study are to explore

1. How the RRR transitional engineering students approached solving word problems involving triangles?
2. What factors may affect the performances of these transitional students in RRR areas in solving word problems involving triangles and trigonometry?

To achieve these goals, this study analyzed the 27 transitional engineering students' performances in solving three problems described in words involving triangles assigned to the students in the foundation mathematics course at CQU before the COVID-19 pandemic. The chosen word questions targeted solving the problems using a right triangle, an oblique triangle, and mixed triangles, respectively. Given the nature of this exploratory study based on students' performances in solving the assigned problems, comparative case study is adopted for this work (Christensen et al., 2020), supported by simple statistics analysis. As there is no existing output on the performance of similar engineering students in solving word problems involving triangles, the outputs from the RRR student mathematics teachers on solving similar triangular problems are used as a reference in the comparison of this study.

In the rest of this work, first introduced are the word problems involving solving triangles along with students' performances. Students' results are then analyzed, and the implications are discussed. Finally, a conclusion is presented at the end of this study.

THE WORD PROBLEMS AND STUDENTS' PERFORMANCES

The First Problem

This word problem was related to the Pythagorean theorem and basic trigonometric functions associated with right triangles. The problem aimed at testing students' understanding of the Pythagorean theorem and basic trigonometric functions, and their ability to use these basic rules to solve an authentic problem

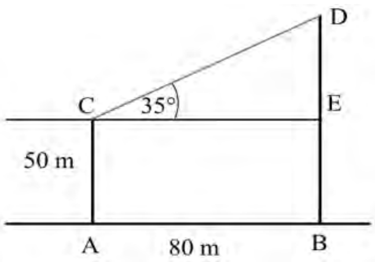


Figure 1. The diagram depicting the scenario of the first word problem (Source: Author)

Table 1. Overall performances of students in solving the first problem

Outcome	Number	Percentage (%)
Correct	25	92.6
Incorrect	2	7.4
Total	27	100.0

described in words with a clear strategy. By the teaching and learning plan, students should have completed these topics and all the required exercises at least three weeks before submitting their assignments.

Problem 1. The first word problem

The first word problem is, as follows:

> Two buildings with flat roofs are 80 meters apart. The shorter building is 50 meters high. From the roof of the shorter building, an angle of elevation to the edge of the roof of the taller building is 35°. How high is the taller building?

This problem is basically a direct use of trigonometric ratio in a right triangle. The student would be expected to draw a diagram to depict the described scenario with the known figures as a guide to craft a reference for solving the problem, similar to the sketch shown in **Figure 1**, in which BD represents the height of the taller building.

$BD=BE+DE=AC+CE\times \tan 35^o=AC+AB\times \tan 35^o=50+80\times \tan 35^o\approx 106\ m$.

25 out of the 27 students solved this problem correctly. One student presented an incorrect solution mainly due to obvious errors in calculating the trigonometric values. The other student had problem in understanding the trigonometric relationship between any two of the three sides for the right triangle. In other words, the student only knew how to use the Pythagorean theorem $c^2=a^2+b^2$ if the two sides of a right triangle were given. The overall performances of the students in solving this problem by right triangles summarized in **Table 1** indicate that most transitional engineering students were able to properly deal with applications involving solving right triangles.

The Second Problem

The second word problem was primarily related to solving oblique triangles. The problem aimed at testing students' understanding of law of cosines and their ability to use this rule to solve an authentic problem described in words with a clear strategy. By the teaching and learning plan, students should have completed all the required exercises in solving oblique triangles at least two weeks before submitting their assignments.

Problem 2. The second word problem

The second word problem is, as follows:

> A radar speed camera is placed at point C outside of a road. It takes two readings of time in seconds at points A and B, respectively for a moving vehicle (**Figure 2**). If the time difference between A and B for vehicle X is 0.5 seconds whereas the time difference for vehicle Y is 0.4 seconds, determine the speed of X and Y, respectively.

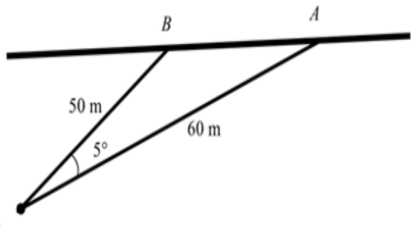


Figure 2. The second word problem (Source: Author)

Table 2. Overall performances of students in solving the second problem

Outcome	Number	Percentage (%)
Correct	24	88.9
Incorrect	3	11.1
Total	27	100.0

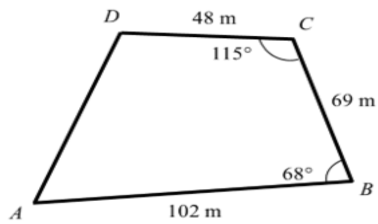


Figure 3. The third word problem (Source: Author)

Referring to the oblique triangle ABC in **Figure 2**, the distance from A to B (AB) can be found by using the law of cosines directly, as follows.

$$AB = \sqrt{AC^2 + BC^2 - 2AC \times BC \times \cos C} = \sqrt{60^2 + 50^2 - 2 \times 60 \times 50 \times \cos 5^\circ} = 11.083\ m.$$

The average speed for vehicles X and Y can be calculated, respectively by

$$v_X = \frac{AB}{t} = \frac{11.083}{0.5} = 22.166\ m/s = 79.8\ km/h$$

$$v_Y = \frac{AB}{t} = \frac{11.083}{0.4} = 27.707\ m/s = 99.7\ km/h.$$

24 out of the 27 students solved this problem correctly. One of the three incorrect solutions was due to obvious errors in calculating the law of cosines. Two others applied the Pythagorean theorem directly to the oblique triangle, including the student who only knew the formula of Pythagorean theorem in solving the first word problem. These two students actually did not know how to use law of cosines to solve the oblique triangles at all. The overall performances of the students in solving this problem by obliques triangles summarized in **Table 2** indicate that most transitional engineering students were able to properly deal with applications involving solving a single oblique triangle.

The Third Problem

The third word problem was designed to test students' ability to integrate their knowledge and skills in solving a problem involving composite right and oblique triangles. Students have options in choosing different composite approaches to solve the problem described in words with a clear strategy. By the teaching and learning plan, students should have completed these topics and all the required exercises at least two weeks before submitting their assignments.

Problem 3. The third word problem

The third word problem is, as follows:

> Find side AD in the quadrilateral shown in the **Figure 3**. Keep 1-decimal place (1D) for angles and 2-decimal places (2D) for sides.

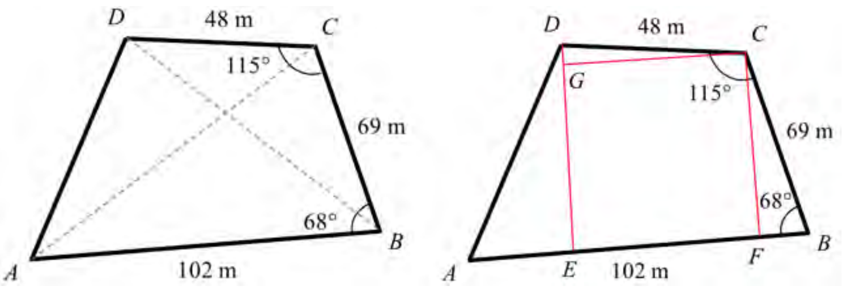


Figure 4. The diagram depicting the scenario of the third word problem: (a-left) by oblique triangles, and (b-right) by right triangles (Source: Author)

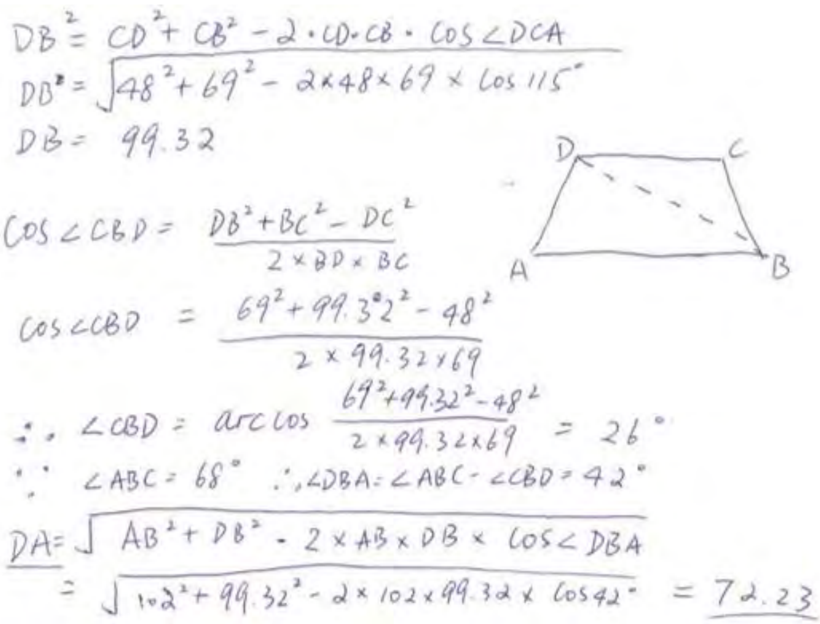


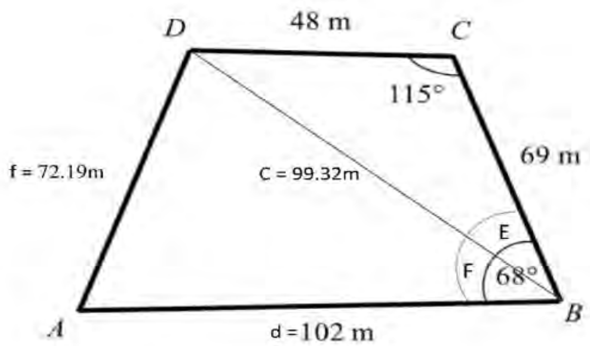
Figure 5. Recaptured work of student A by using oblique triangles (Reprinted with permission of the student)

There are multiple ways to solve this problem. In general, these approaches can be classified into two broad strategies: by oblique triangles or by right triangles. No matter which strategy was chosen by a student to solve this word problem, the student should firstly draw a diagram to depict the described scenario with the known and derived figures as a guide to craft a plan for solving the problem. The diagrams representing these two strategies are shown in **Figure 4**. Because each approach may have different variations, no standard solutions are presented here. Instead, a few typical examples of solving this problem from students will be briefly discussed next.

By oblique triangles: The length of side AD can be determined by using law of cosines multiple times as shown by the work of student A in **Figure 5**. The student first used law of cosines to triangle BCD to work out the length of diagonal DB, then used law of cosines again to work out angle ∠CBD, from which angle ∠DBA was determined. Finally, the students applied law of cosines again to triangle ABD to find the length of side AD.

The length of side AD can also be determined by combining law of sines and law of cosines together as shown by the work of student B in **Figure 6**. The student first used law of cosines to triangle BCD to work out the length of diagonal DB (or c), then used law of sines to work out angle ∠CBD (or E), from which angle ∠DBA (or F) was determined. Finally, the student applied law of cosines again to triangle ABD to find the length of side AD (or f).

By right triangles: The length of AD can also be solved by using right triangles as shown in **Figure 4(b)**, which was demonstrated by the example from student C shown in **Figure 7**. The student first solved the right triangle on the right side, then did the same for the right triangle on the top, and finally applied Pythagorean theorem to the right triangle on the left side to find the length of AD.



ANSWER:

(i) First divide the quadrilateral shape into separate 2x oblique triangles between DAB and DCB.

(ii) Next, use the Law of cosines to find side 'c' as per below:

Find 'c':

$c = \sqrt{a^2 + b^2 - 2abcosC}$ $\qquad c = 99.32m$

(iii) Then divide Angle B into Angles E & F. Find Angle E using Law of Sines:

$\frac{c}{sinC} = \frac{e}{sinE}$ $\qquad sinE = \frac{sin115 \times 48}{99.32}$ $\qquad sinE = 0.43$

$\frac{99.32}{sin115^0} = \frac{48}{sinE}$ $\qquad sinE = \frac{sin115 \times 48}{99.32}$ $\qquad E = Sin^{-1}0.43$

$E \approx 26^0$

(v) With Angle F found, use Law of cosines again with the sides 'c' and 'd' to solve for side AD (f):

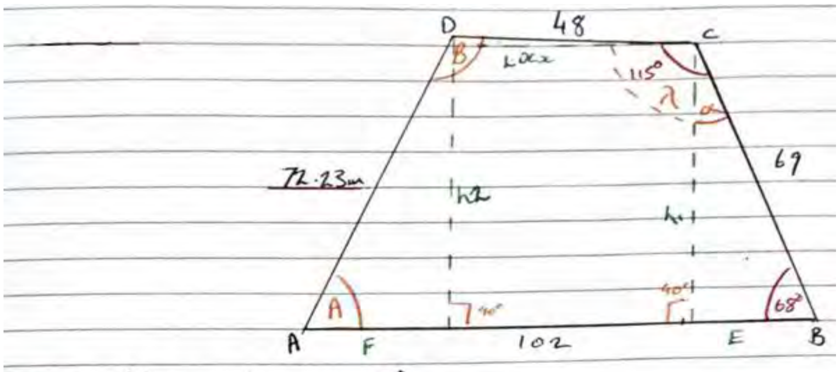
$f = \sqrt{c^2 + d^2 - 2cdcosF}$

$f = \sqrt{99.32^2 + 102^2 - 2 \times 99.32 \times 102cos42}$

$f = \sqrt{99.32^2 + 102^2 - 2 \times 99.32 \times 102cos42}$

$f = 72.19m$

Figure 6. Recaptured work of student B by using oblique triangles (Reprinted with permission of the student)



$h_1 = 69 \sin 68° = 63.98 m$

$E = 69 \cos 68° = 25.85 m$

$\alpha = 90 - 68 = 22°$

$\lambda = 115 - 22° = 93°$

$LDcx = 48 \cos(93 - 90) = 47.93 m$

$F = 102 - 47.93 - 25.85 = 28.22 m$

$h_2 = h_1 + 48 \sin(3) = 63.98 + 2.51 = 66.49 m$

Angle $A = Tan^{-1}\left(\frac{66.49}{28.22}\right) = 67°$

Angle $B = 360 - 115 - 68 - 67° = 110°$

Side $AD = \sqrt{66.49^2 + 28.22^2} = 28.22 \div Cos 67° = \cancel{66.49 \div Cos t}$

$= 72.23 m$

Figure 7. Recaptured work of student C by using right triangles (Reprinted with permission of the student)

Table 3. Overall performances of students in solving the third problem

Outcome	Number	Percentage (%)
Correct	19	70.4
Incorrect	8	29.6
Total	27	100.0

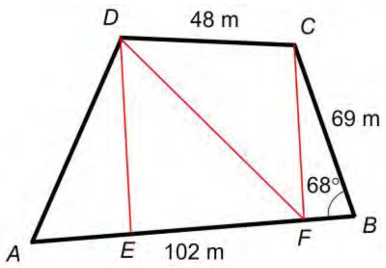


Figure 8. A wrong conceptual frame of four right triangles for the quadrilateral (Source: Author)

Table 4. Effect of different strategies on the performances in solving the third word problem

Method	Correct	Incorrect	Subtotal
Right triangles	16 (73%)	6 (27%)	22
Oblique triangles	3 (60%)	2 (40%)	5

Note. The percentage inside the parentheses is the relative value against the corresponding subtotal

19 out of the 27 students solved this problem correctly, which was about 70% of the total (**Table 3**), significantly lower than the overall percentage of correctness students achieved in solving the two simpler problems previously. Among the eight students who solved the problem incorrectly, only two were due to errors in calculation with a correct strategy. Six students were wrong from the beginning in terms of conceptual understanding of trigonometric representations of the described scenario.

A typical example was that the student simply assumed that the quadrilateral could be divided into four right triangles shown in **Figure 8**. For the two students who did not know how to use law of cosines to solve the second word problem, their approach was simply applying the Pythagorean theorem to the two known sides of oblique triangle BCD to decide the diagonal BD, then to repeat the Pythagorean theorem to the known diagonal BD and side AB to decide side AD.

Overall, twenty-two students used the strategy of right triangles to solve this problem, and sixteen or 73% of them were correct. Only five students used the strategy of oblique triangles to solve this problem, and three or 60% of them were correct. It seemed that most students preferred to choose right triangles over oblique triangles to solve the problem (**Table 4**).

DISCUSSION

The Overall Performance in Solving Word Problems Involving Triangles by the Transitional Engineering Students

For the three problems involving triangles, the transitional engineering students achieved a rate of correction over 70%, particularly in solving a problem involving a single triangle. This is significantly higher than the overall performances in solving problems involving triangles by student mathematics teachers with a correct rate between 20-60% reported in many studies (Guo, 2022b; Nabie et al., 2018; Walsh et al., 2017). Many of the transitional engineering students have been professional workers or tradesmen and had some experiences in working with various triangular objects and/or apparatus or in using engineering or scientific software packages. They can use their experience to draw a correct diagram for a given scenario described by words like the first word problem, or craft a correct procedure to solve a complicated problem step by step, similar to the work demonstrated in **Figure 6** by student B. These professional experiences would be lacked by the student mathematics teachers.

Looking back to the learning journey many transitional students underwent in learning triangles and trigonometry systematically in this foundation mathematics course, the professional experiences in dealing

Table 5. Effect of different strategies on the performances in problem solving

Method	Correct	Incorrect	Subtotal
Right triangles	41 (83.7%)	8 (16.3%)	49
Oblique triangles	27 (84.3%)	5 (15.7%)	32

Note. The percentage inside the parentheses is the relative value against the corresponding subtotal

Table 6. Results of Chi-test on student's results by using different strategies

	Chi-value	Critical Chi-value	df
Right-Oblique triangles	0.007	6.635 (α=0.01)	1

with triangles had helped their learning immensely. Their previous experience in how to deal with problems involving triangles can be seamlessly articulated to not only why the problem should be handled in the way they have already known, but also how the same problem could be solved by alternative ways. Hence, their efficacy and confidence in dealing with triangular problems would be greatly improved.

Most transitional engineering students would keep trying to complete all the assessments for this foundation mathematics course regardless of the outcomes of their individual assessments during the course. There were only about 7% of the enrolled students who withdrew from the course in exceptional circumstances associated with work commitments and/or family emergencies. This is a stark contract to the student mathematics teachers from the RRR areas, among whom the no attempt or automatic fail rate was about 27% in their foundation mathematics course on average (Guo, 2022b). This difference might indicate that the existing professional experiences in handling real-world projects by the most transitional engineering students may make them more resilient to pressures associated with learning, work, and looking after family, and hence more dedicated to the completion of the course, just like to complete a real-world project under different kinds of challenges.

The Effect of Different Strategies on the Performance

The results from the third problem indicated that the transitional engineering students would prefer to choose the strategy based on right triangles over that based on oblique triangles should such options be available. Under such preference, it seemed that the strategy based on right triangles led to a higher rate of correction for solving the same problem compared with the strategy based on oblique triangles (**Table 4**). This may be true for the third problem specifically, but it must be cautious to draw a conclusion that the students were more efficacious in using right triangles than oblique triangles to solve relevant problems.

By combining the results of solving the third problem by right triangles with the first problem that was focused on using right triangle and combining the results of solving the third problem by oblique triangles with the second problem that was focused on using oblique triangles, the reclassified performances in applying right triangles and oblique triangles to solving the problems are shown in **Table 5**. Effectively, both methods had the same correct rate of around 84%. The Chi-test also confirmed there was no statistical difference in the correct rate between the two methods at significance α=0.01 (**Table 6**). This statistical result is similar to that exhibited by the RRR student mathematics teachers in solving word problems involving triangles in their foundation mathematics course (Guo, 2022b).

Performance with Respect to Willingness to Engage with Learning

Whilst most students progressed well with the weekly learning activities, very few students, usually one to four, were not going with the required study pace in every teaching term. It was often observed that some students would have a short period of interruptions in learning, usually one to three weeks, due to emergencies in their work or family commitments in a teaching term. The negative impact of such interruptions on their study could be mitigated through various learning supports, such as extension to the assessment, deferring examination, one-to-one online tutorial if required, and rescheduling for assessments (Guo, 2022a). However, for the few students who did not make necessary and meaningful efforts on their learning, this foundation mathematics course becomes the obstacle of overall progression in their degree study. Hardly the instructors had any effective means to motivate such students to actively engage with learning.

The negative impact from such students was not only on own learning outcomes, but also on the sustainability of the course in which all the students were enrolled. Such students were often the regular participants in the course evaluation where they would complain about every aspect of the course (Guo et al., 2017), for example, the instructor, the assessments and feedback, the learning resources and supports, textbooks, even though they were not bothered to open their marked assignments and standard solutions. It would be even worse if the course committee takes a bureaucratical approach to deal with any matter raised in student feedback, in the name of 'student centric'. Such would see a healthy course be forced to make unnecessary changes by wasting already limited human resources severely impacted by the COVID-19 pandemic in recent years. The current technology should be able to identify such students and hence to remove their biased feedback from the course data analysis.

CONCLUSION

The foundation mathematics for the transitional engineering students serves the similar role as the preparatory mathematics for the first-year engineering students in some universities in the US (Baine, 2020; Newberry et al., 2011; Vercellino et al., 2015). It was found that this preparatory mathematics course has significantly improved the basic mathematical skills for those students who started the engineering program with a weaker mathematical background, which allowed many of these students to progress to the 'usual' engineering mathematics courses and subsequent engineering courses with confidence. It was also observed that the matured students among all the students were more resilient to the pressure and challenges during mathematics learning. Although this current study only focused on the performances of the transitional engineering students in solving real-world problems involving triangles, most of the transitional engineering students exhibited the same level of resilience to challenges and pressures during their mathematics learning, mainly attributed to their professional experiences with delivering real projects prior to the start of their mathematics learning. This is a stark contrast to the RRR student mathematics teachers on attempting the similar problems where about 30% of the student teachers gave up on attempting the problems.

The same professional experiences possessed by most of the transitional engineering students were also extremely helpful for them to both correctly interpret the scenarios described in words and properly capture the scenarios visually in diagrams, leading to the appropriate applications of trigonometric rules accordingly, particularly the Pythagorean theorem for right triangles and laws of sines and cosines for oblique triangles. Hence, their average performances in solving word problems involving triangles are significantly better than the RRR student mathematics teachers in dealing with the similar problems (Guo, 2022b).

If different strategies exist for solving a word problem involving triangles, the transitional engineering students would prefer to choose the strategy based on right triangles over that based on oblique triangles. However, statistically the students were equally efficacious in using both the right triangles and oblique triangles to solve the problem in terms of the rate of correctly solving the problem. This is similar to that exhibited by the RRR student mathematics teachers in solving word problems involving triangles in their foundation mathematics course (Guo, 2022b).

The RRR transitional engineering students demonstrated a higher level of study ethics and achievement in mathematics learning, compared with the RRR student mathematics teachers. In further research, the scope should be expanded to other areas of mathematics to gauge the overall performances of the transitional engineering students in mathematics learning and progression

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