Impacts of Rubrics on Secondary Students' Competencies in Quadratic Equations: A Quasi-Experimental Study in Mafinga District, Zambia

Eustasy Mwamba[1]*, Overson Shumba[1,2], Henry Mulenga[1]

[1]School of Mathematics and Natural Sciences, The Copperbelt University, P.O. Box 21692, Kitwe, Zambia

[2] Centre for Academic Development, The Copperbelt University, P.O. Box 21692, Kitwe, Zambia

***Corresponding Author**

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ABSTRACT

Extensive research supports the use of rubrics in assessing mathematics learning outcomes. However, their value in improving student performance is contradictory. This quasi-experimental study investigated the impacts of rubrics on students' algebraic competencies in quadratic equations. Six grade eleven classes (n=149) were randomly sampled from three secondary schools in Mafinga district (Zambia). Three intact classes (n=78) were randomly assigned to experimental groups and used the rubrics to obtain feedback and support self-assessment in the second term of 2024. Three comparison groups (n=71) implemented the same formative assessment practices without rubrics. Students' responses to quadratic equations were analyzed qualitatively based on the Structure of Observed Learning Outcomes (SOLO) taxonomy. The results showed that the students who used rubrics significantly improved their procedural skills in solving quadratic equations, including identifying formulas, analyzing problems, applying logical reasoning, and communicating solutions effectively. These findings demonstrate that by providing timely feedback and promoting students' self-assessment, rubrics can significantly improve secondary students' competencies in solving quadratic equations.

Keywords: algebraic competences, quadratic equations, rubrics, secondary school, SOLO taxonomy

INTRODUCTION

Quadratic equations are equations in the form $ax^2 + bx + c = 0$ where x represents an unknown variable, and a, b, and c represent known numbers, and $a \neq 0$. These equations form fundamental concepts in algebra and mathematics, and their importance goes beyond classroom practices to solving problems involving business, computer sciences, telecommunications, physics, sports, and engineering in the real world. (Murangira et al., 2025). Nevertheless, secondary students in Zambia have continued to face challenges when solving quadratic equations (Examinations Council of Zambia, 2019, 2022b, 2023). These challenges include, but are not limited to, not being able to use and apply the formula; $x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$, including the other ones provided in the question paper (Examinations Council of Zambia, 2022a), graphs of quadratic equations not being smooth, no clear labelling of the axes, wrong scales, and mathematically incorrect (Examinations Council of Zambia, 2023). A study by Mukuka et al. (2020) also found that over 50% of the students (n=300) who completed a mathematics reasoning test had little understanding of the zero-product law to factorize and solve quadratic equations in the form $(x+2)(x-3) = 14$. Similarly, Lopez et al. (2016) also found that secondary students had problems using the completing the squares method even when the question was a perfect square, such as $(81 - x)^2 = 81$, and a misconception that $(a+b)^2$ was equivalent to $a^2 + b^2$ (Fachrudin et al., 2014).

According to previous studies, the challenges faced by students when solving quadratic equations were attributed to the way teachers taught and designed assessment activities (Busaka et al., 2022; Murangira et al., 2025). The teachers often used routine test questions and provided feedback long after the assessment was completed, at which time, the students were no longer interested (Mwamba et al., 2025). These classroom practices resulted in rote learning and mastery of low-level mathematical skills and competencies (Ministry of Education, 2023; Ukobizaba et al., 2021). If the problems were not addressed, students would continue to exit the secondary school system, not being able to think critically and solve real-life problems to contribute to sustainable national development (Ministry of Education, 2023).

LITERATURE REVIEW

In the literature, researchers in the field of classroom assessment advocate for the use of rubrics to improve the assessment of mathematics learning outcomes that include higher-order thinking skills such as critical thinking, problem-solving, and mathematical modelling and representations (Fitriyani & Evendi, 2024; Hattori et al., 2025; Krebs et al., 2022; Toalongo et al., 2022). Usually in the form of a matrix, rubrics are assessment tools that highlight the desired learning outcomes in the first column (the skills that the students are expected to achieve), and the quality levels of performance in the first row correspond to each of the assessment criteria from excellent to poor (Andrade, 2019; Morton et al., 2021). When well-constructed, rubrics communicate learning expectations to students and provide timely formative feedback on strengths and weaknesses, especially when shared with students and used to guide revisions and self-assessment (Brookhart, 2024; Weeda et al., 2020). By considering the appropriateness of pedagogical and instructional strategies, the quality of mathematics lesson plans can also be improved using rubrics (Toalongo et al., 2022), as well as supporting students' understanding of mathematical concepts and their development of procedural skills (Tashtoush et al., 2023).

Empirically, the use of rubrics by the students has been shown to contribute to improved mathematics learning outcomes (Fitriyani & Evendi, 2024; Hattori et al., 2025), and motivation to learn among the students (Fraile et al., 2023). Previous studies report that the students who used rubrics as a guide when completing assignments significantly achieved higher performance gains and greater accuracy than the students who did not use rubrics (Richiteanu-Nastase & Mihaila, 2023; Shirawia et al., 2024; Smit et al., 2023). This is also confirmed by students, who generally expressed positive attitudes towards the use of rubrics and indicated that they used the rubrics to understand the teachers' expectations better and to obtain detailed feedback on strengths and weaknesses to improve performance in mathematics (Gallego-Arrufat & Dandis, 2014).

Theoretically, the use of rubrics when learning mathematics aligns with the social constructivist learning theory (Vygotsky, 1978), which prioritizes active learning and practical experiences to support student learning through social interactions (Fitriyani & Evendi, 2024; Ukobizaba et al., 2021). By providing clear expectations, the use of rubrics facilitates a shared understanding of mathematics learning outcomes between the teachers and the students, and improves student engagement in the learning process through interactive learning experiences of mathematical concepts (Krebs et al., 2022). Through the zone of proximal development (ZPD), the students who try to explain concepts and those who seek help from their peers tend to improve their conceptual understanding by scaffolding (Ukobizaba et al., 2021).

Although previous studies agree that the use of rubrics supports student learning (Auxtero & Callaman, 2021; Fitriyani & Evendi, 2024), their impact on mathematics learning competencies is contradictory (Tejeda & Gallardo, 2017; Willey & Gardner, 2009). The contradictory findings are reported concerning whether rubrics were shared with students or not (Panadero et al., 2023), used in formative or summative assessments (Panadero & Jönsson, 2013), and the criteria assessed compared to others, e.g., accuracy and completeness compared to grades or test scores (Krebs et al., 2022). For some studies, secondary students needed more time to familiarize themselves with the use of rubrics before they could start getting the benefits, than higher education and older students (Andrade, 2019). Nevertheless, these contradictions present opportunities to design better studies and ultimately strengthen the rubric's potential to support student learning. Therefore, this study investigated the impacts of using rubrics on secondary students' algebraic competencies associated with solving quadratic equations. One research question guided the investigation: What are the impacts of using rubrics on students' algebraic competencies associated with solving quadratic equations, such as algebraic graphing skills, algebraic reasoning skills, and algebraic representation skills?

METHODOLOGY

Research design

This study used a quasi-experiment, non-equivalent comparison group with a pretest-posttest design. This design allowed the researcher to investigate the impacts of rubrics in real-time classroom contexts, where randomization may not be possible due to practical constraints (Mukuka et al., 2021).

Population and Sample

The target population comprised 422 grade eleven students in eighteen classes and their teachers of mathematics from nine secondary schools in Mafinga district, Zambia. The district was more suitable because it was more convenient for the researchers. Convenience sampling was employed because it was more cost-effective than other sampling techniques (Golzar & Noor, 2022). Then, by using simple random procedures (Golzar & Noor, 2022), three secondary schools were randomly selected. From each school, two grade eleven classes were randomly sampled and were assigned to experimental groups or comparison groups at random. Thus, three classes and their teachers of mathematics formed experimental groups (n = 78, 40 males and 38 females), and the other three classes formed comparison groups (n = 71, 38 males and 33 females). The sample comprised 149 grade eleven students from six classes and six teachers of mathematics. The students in this study were taught quadratic equations for the first time.

Due to the lack of an established ethics committee, the procedures for getting ethical clearance were waived by the author’s institution. However, the research was conducted in accordance with ethical standards as laid down in the 1964 Declaration of Helsinki (DoH) and its later amendments.

Intervention

A total of fifteen lessons were conducted across six weeks. In each lesson, the teachers introduced quadratic concepts through think-pair-share activities that encouraged the students to discuss, share ideas, and to learn from each other in order to improve their understanding of quadratic equations through peer feedback. Thereafter, the students worked on the same task in small, manageable groups. The group work took 15–25 minutes and allowed students to discuss the strengths and weaknesses of their own work. Upon completion, pairs of groups exchanged solutions and assessed the other group’s work without assigning scores (peer assessment). This group assessment took an extra 10–15 minutes and enabled the students to provide oral feedback on the other group’s work, debating on the strengths and areas to improve (peer feedback). Following that, the teachers provided feedback to each group on the needy areas with nuanced information on how to improve in future assignments (teacher feedback). The only difference was that the teachers from experimental groups used the rubrics as a basis for communicating their objective feedback to the students, thereby preventing assessment judgments from becoming arbitrary.

Finally, the students completed the same classwork individually. Upon completion, the teachers asked the students to assess their own work before submitting it to the teacher. The students from experimental groups used the rubrics to score their own performance from pre-structural level (0) to extended abstract label (4) and recorded the score at the end of each task. Upon submission, the teachers checked the correctness of the completed work and provided feedback to the students on areas that needed improvement. The teachers also used feedback from the analysis of students’ work and from one-on-one conversations to align instructions with assessment activities and the desired learning outcomes to improve teaching and learning. Unlike the feedback without rubrics, the teachers from experimental groups provided rubric-based feedback by indicating the level of performance achieved by the student from 0 to 4, which encouraged the students to practice the algebraic skills where they scored low marks (0–2). The teachers further assured the students that the self-scores would not influence their final grade, but rather, the scores would be used to guide studying, revisions, and self-monitoring of the learning progress.

During the intervention, the researchers provided in-service support to individual teachers through collaborative lesson planning. This practice ensured the fidelity of the intervention by minimizing teacher bias. The teachers taught quadratic equations in parallel sessions three times a week in the second term of 2024, covering different methods of solving quadratic equations in the same sequence: the graphing method, the factorization method, the completing squares method, and the formula method. The duration of each lesson was 80 minutes.

Data collection tools

The researchers analyzed the learning outcomes associated with solving quadratic equations in the Zambian secondary school ordinary level mathematics syllabus (Ministry of Education, 2013, 2023), and developed a quadratic equations competence test with four questions. The questions assessed students' understanding of quadratic equations based on the criteria: algebraic graphing skills, algebraic reasoning skills, and algebraic representation skills.

Initially, five questions were developed. Then ten subject matter specialists rated each test question independently by indicating zero (0) "the question was not necessary" or one (1) "the question was necessary". The content validity ratio (CVR) was manually computed as: $\mathrm{CVR} = \frac{\left(\mathrm{Ne} - \frac{N}{2}\right)}{\left(\frac{N}{2}\right)}$ where *Ne* is the number of specialists indicating the item was necessary, and *N* is the total number of specialists. One question with a CRV less than 0.62 was excluded based on Lawshe's (1975) minimum critical value threshold. The content validity index (CVI) of the entire test was then computed as the average of the CVRs and was exceptionally high (CVI = 0.95), indicating that the test measured what it was intended to measure with no improvements to the test questions required (Mohajan, 2017).

With four questions, a rubric, and a scoring strategy based on the SOLO (structure of observed learning outcomes) taxonomy (Mukuka et al., 2020a), were developed (see Appendix 1). Previous literature (Panadero et al., 2023), advance guidelines for designing and implementing classroom rubrics, such as defining desired learning outcomes and assessment criteria, determining levels of performance, and deciding on the scoring scale. While other frameworks, such as Bloom's cognitive taxonomy (Anderson & Krathwohl, 2001) focuses largely on the cognitive processes, such as applying and analyzing, the SOLO taxonomy was used because it focuses on the structure of the student's response, showing the quality and complexity of understanding, and how well the students applied or analyzed mathematical concepts (Adeniji et al., 2022). The SOLO taxonomy also provides the teachers with the opportunity to implement specific strategies that lead the students' new level of understanding from the lower level (pre-structural level) to the higher level (extended abstract) (Valenzuela-Gonzalez et al., 2021). By highlighting different levels of understanding based on the SOLO taxonomy, different raters can also achieve a higher inter-rater reliability (Yazici, 2013).

Thereafter, five subject matter experts were asked to independently scrutinize the 'behavioral descriptors' at each level of performance in the rubric to ensure that the rubrics provided enough evidence to assess different levels of performance of quadratic equations from the pre-structural level to the extended abstract level. This is called criterion validity evidence (Brookhart & Chen, 2015). Language was also rephrased so that the rubric included observable skills and competencies. The experts' differences were resolved through a discussion.

In addition, a pilot test was administered to ten students who were selected from the target population. Students' responses in the pilot test, along with rubrics, were photocopied and shared among four independent raters, and the inter-rater agreement was calculated using Fleiss' kappa (κ). Fleiss' kappa coefficients are widely used to evaluate inter-rater reliability for multiple raters (Brookhart & Chen, 2015). The Fleiss' kappa, $\kappa = 0.831$, was found to be high and significant, $p < 0.5$, suggesting the instruments' reliability to yield reliable results consistently (Creswell, 2018).

Before and after the intervention, students from both the comparison groups and the experimental groups completed the quadratic equations competence test. The duration of the test was one hour and thirty minutes. During the posttest assessment, the students from the experimental groups used the same rubrics to assess their own work before it was submitted to the teacher. On the other hand, the students from the comparison groups completed the same posttest without rubrics. Upon completion, the researchers received the test scripts from all teachers and marked them.

Data analysis

Students' responses to quadratic tasks were analyzed qualitatively using the SOLO taxonomy that described the levels of understanding from pre-structural level (no understanding), uni-structural level and multi-structural level (surface understanding), relational level (deep understanding), to extended abstract level (conceptual understanding). A value was assigned to each level: 0 = pre-structural level, 1 = uni-structural level, 2 = multi-structural level, 3 = relational level, and 4 = extended abstract level, and analyzed using percentage frequencies. Frequency tables were generated to summarize the proportion (%) of students on each SOLO level in relation to algebraic graphing skills, algebraic reasoning skills, and algebraic representation skills. The proportion of students who were classified under the relational (3) and extended abstract level (4) demonstrated higher-order thinking skills (HOTS) while the uni-structural (1) and multi-structural levels (2) demonstrated lower-order thinking skills (LOTS). Students under the pre-structural level (0) demonstrated no understanding, indicating that the student missed the point. The Statistical Package for the Social Sciences (SPSS) version 25 was used to analyze the data.

RESULTS

Analysis of results before the intervention

Students' performance on each of the competence areas associated with solving quadratic equations before the intervention is presented in Table 1.

Table 1. Students' performance before the intervention [Comparison group, CG(n=71), Experimental groups, EG(n=78)]

SOLO	Graphing skills		Reasoning skills		Representation skills	
Level	CG (%)	EG (%)	CG (%)	EG (%)	CG (%)	EG (%)
Pre-structural	100	100	95	90	97	97
Uni-structural	0	0	4	10	3	3
Multi-structural	0	0	1	0	0	0
Total (Higher-Order Thinking)	0	0	0	0	0	0

Table 1 results show that before the intervention, the students (100%) from the comparison groups (n=71) and the experimental groups (n=78), respectively, demonstrated lower-order thinking skills (LOTS) in all competence areas assessed. These students were classified under the lowest levels of performance (pre-structural level or uni-structural level). These findings show that the students demonstrated little/no knowledge of finding the roots ($x - values$) of quadratic equations, $x^2 - 2x = 0,\ -x^2 + 4 = 0, and\ x^2 - 2x = -x^2 + 4$, using the same axes (graphing skills). The student's responses were also characterized by the absence of a table of values, inappropriate scaling, no clear labelling of the axes, incomplete and incorrectly plotted points, and graphs not being smooth and mathematically incorrect (see Figure 1).

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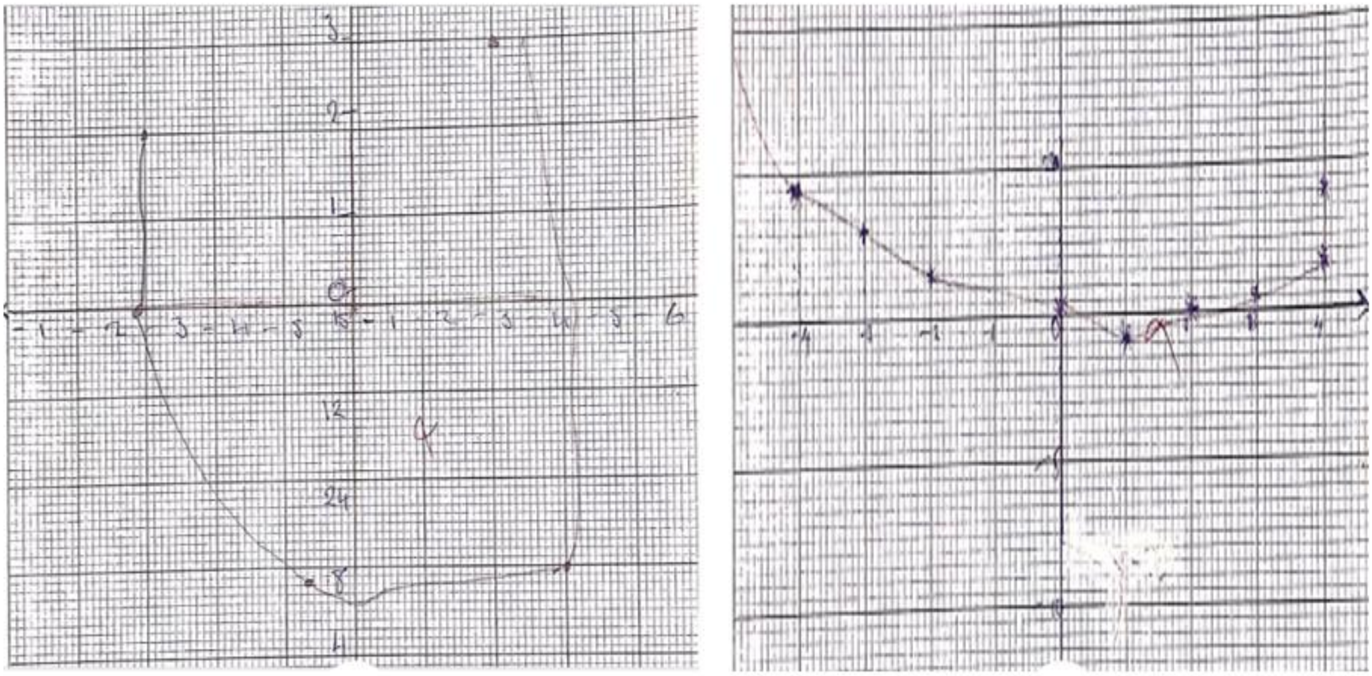

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Figure 1. Sample of students' graphs from the comparison groups (i) and the experimental groups (ii) before the intervention

Secondly, the students' ability to reason and communicate solutions to quadratic equations in written form was analyzed. Students were provided with three suggested solutions to the quadratic equation, $2m^2 - 5m = 12$ (see Figure 2) and were asked to analyze, identify, and justify their reasons whether each answer was correct or wrong.

LEARNER A

$2m^2 - 5m = 12$

$m(2m-5) = 12$

Either

$\underline{m = 12}$

Or

$(2m-5)=12$

$2m=12+5$

$2m=17$

$m=\frac{17}{2}$

LEARNER B

$2m^2-5m-12=0$

$m= b \pm \frac{\sqrt{b^2-4ac}}{2a}$

$a=2, b=-5, c=-12$

$m= -5 \pm \frac{\sqrt{-5^2-4(2\times-12)}}{2(2)}$

$m=-5\pm \frac{\sqrt{-25+96}}{4}$

$m=-5\pm \frac{\sqrt{71}}{4}$

$m=-5 \pm \frac{8.4261}{4}$

$m=-5 \pm 2.106525$

Either

$m= -5 +2.106525$ Or $m= -5 - 2.106525$

$m=-3.106525$ Or $m=-7.106525$

$\underline{m=-3.107 \text{ Or } m=-7.107}$

LEARNER C

$2m^2-5m-12=0$

$2m^2-5m=12$

$2m^2-5m + \left(\frac{-5}{2}\right)^2 =12+ \left(\frac{-5}{2}\right)^2$

$2m^2-5m+\left(\frac{-5}{2}\right)^2=12+ \frac{25}{4}$

$\left(2m - \frac{5}{2}\right)^2 =12 + \frac{25}{4}$

$\left(2m - \frac{5}{2}\right)^2 = \frac{73}{4}$

$\sqrt[2]{\left(2m - \frac{5}{2}\right)^2} = \pm \sqrt[2]{\frac{73}{4}}$

$2m - \frac{5}{2} = \pm \frac{8.5440}{2}$

$2m = \frac{5}{2} \pm \frac{8.5440}{2}$

Either

$2m= \frac{5}{2} + \frac{8.5440}{2}$ Or $\frac{5}{2} - \frac{8.5440}{2}$

$2m=\frac{13.5440}{2}$ Or $\frac{-3.5440}{2}$

$2m= 6.772$ Or -1.772

$m= \frac{6.772}{2}$ Or $\frac{-1.772}{2}$

$\underline{m=3.386 \text{ Or } -0.886}$

Figure 2. Suggested solutions of the quadratic equation: $2m^2-5m=12$

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The results in Table 1 show that the students (100%) demonstrated an inability to verify and communicate correctly the methods used to find solutions to quadratic equations. The qualitative analysis of responses showed that the students were not able to state and apply the quadratic formula correctly: $x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$, had very little understanding of the zero product rule: $x.y = 0 \; if \; and \; only \; if \; x = 0 \; or \; y = 0$, and were not able to complete the squares of the quadratic equations. In addition, the students did not even attempt to verify whether the suggested solutions satisfied the given quadratic equation or not. Thus, the students' attention to detail and their logical reasoning were lacking (see Figure 3).

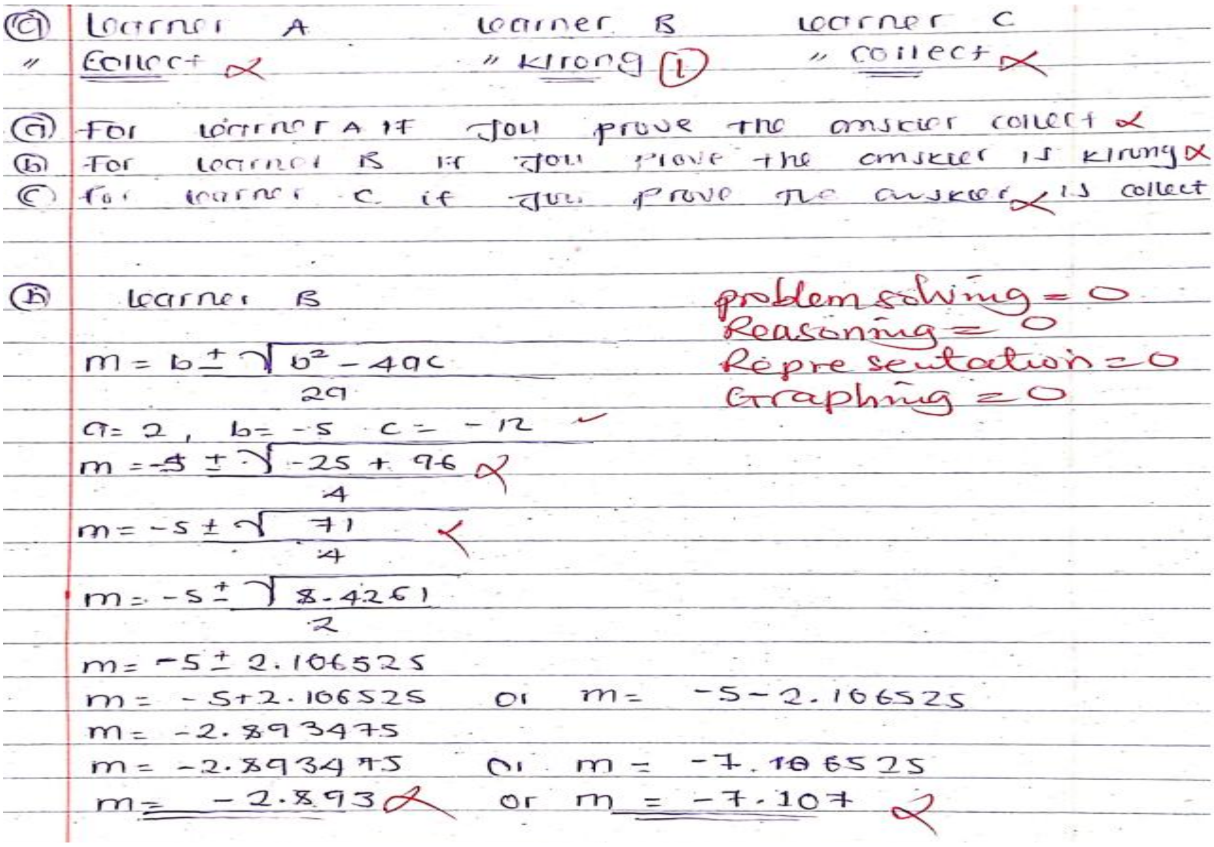

Figure 3. Sample of students' mode of justifications of suggested solutions to the quadratic equation $2m^2$-5m=12 before the intervention

These results demonstrate the students' inability to interpret the information supplied in the problem statement and their lack of basic understanding of solution strategies for solving quadratic equations.

Finally, students were asked to construct mathematical equations from mathematical statements and use the constructed equations to solve mathematical problems. For example;

Given that Mary is older than James. If the sum of their ages is 25, their product is 156. Find their ages, showing all necessary steps.

The results in Table 1 show that before the intervention, the students (100%) demonstrated an inability to construct and interpret word problems to solve related and real-life problems. Thus, the students were classified under the lowest level of performance: the pre-structural level or the uni-structural level. Evidence from the analysis of students' answer scripts revealed that word problem questions were the most omitted questions because of the failure to translate word problems into mathematical equations. Thus, the students lacked persistence in solving challenging equations.

Analysis of results after the intervention

Students' performance on each of the competence areas associated with solving quadratic equations after the intervention is presented in Table 2.

Table 2. Students' performance after the intervention [Comparison group, CG(n=71), Experimental groups, EG(n=78)]

SOLO level	Graphing skills		Reasoning skills		Representation skills	
	CG (%)	EG (%)	CG (%)	EG (%)	CG (%)	EG (%)
Pre-structural	52	17	46	18	80	56
Uni-structural	12	9	25	19	14	17
Multi-structural	14	6	21	12	6	4
Relational	15	12	7	21	0	7
Extended abstract	7	56	1	30	0	16
Total (Higher-Order Thinking)	22	68	8	51	0	23

Table 2 results show that 68% and 22% of students from the experimental groups (n=78) and the comparison groups (n=71), respectively, demonstrated higher-order graphing skills (HOTS) and were classified under the highest levels of performance: relational level or extended abstract level. These students were able to draw and label the graphs of the quadratic equations correctly $x^2 - 2x = 0$, $-x^2 + 4 = 0$ on the same exes, and use interpolation to find the roots of the equations $x^2 - 2x = -x^2 + 4$ without simplifying the quadratic equation. The students' attention to detail sufficiently improved after the intervention, ensuring accuracy in plotting the points and connecting them using a smooth curve. Nevertheless, the majority of the students who demonstrated better higher-order graphing skills came from the experimental groups (68%) compared to the comparison group (22%) (see Figure 4).

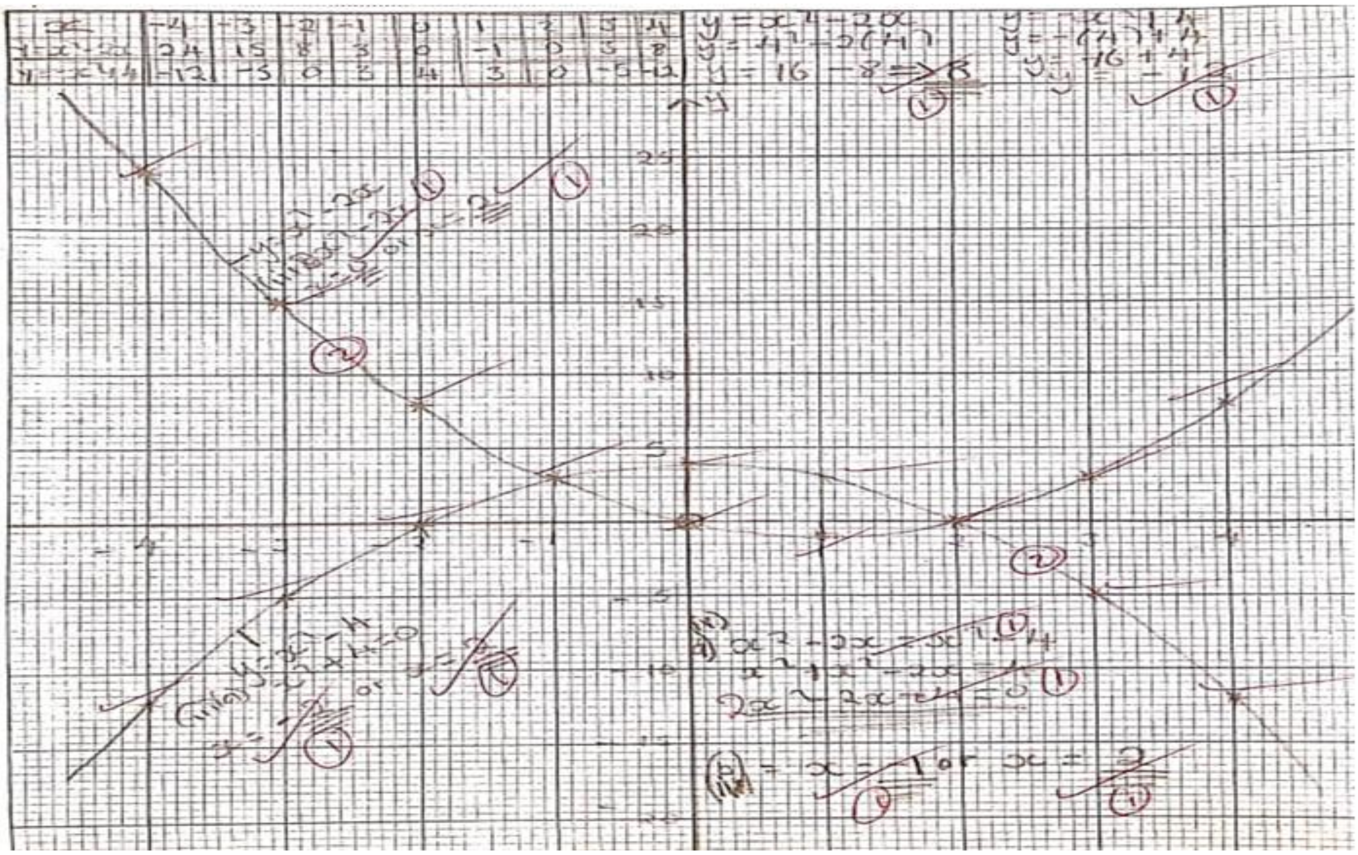

Figure 4. Selected students' responses to quadratic equations using the graph after the interventions

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Table 2 results also indicate that 17% and 52% of the students from the experimental groups (n=78) and the comparison groups (n=71), respectively, were classified under the pre-structural level of performance after the intervention (no understanding). These results suggest that more than 50% of the students from the comparison groups, compared to 17% from the experimental groups, were not able to find the solutions to quadratic equations using the graph, despite having learned the whole topic in full.

Secondly, Table 2 results show that 51% and 8% of students from the experimental groups (n=78) and the comparison groups (n=71), respectively, demonstrated higher-order reasoning skills (relational or extended levels) after the intervention. These students were able to identify, communicate in writing, and justify the use of different solution strategies correctly to solve quadratic equations (see Figure 5).

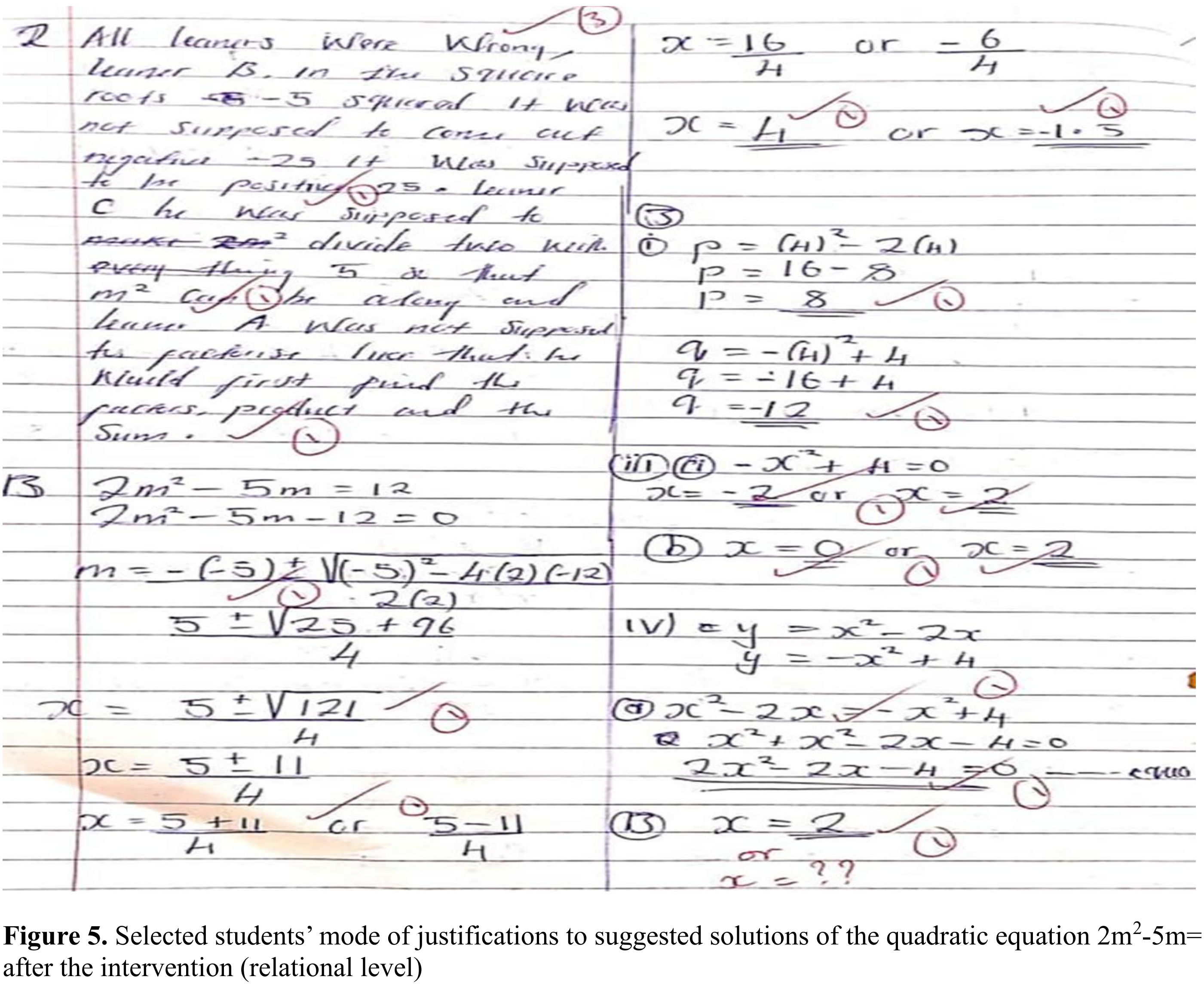

Figure 5. Selected students' mode of justifications to suggested solutions of the quadratic equation $2m^2$-5m=12 after the intervention (relational level)

The analysis of students' responses further showed that 60% of the students from the experimental groups (n=78) and 43% from the comparison groups (n=71) identified learner A correctly as being wrong and provided the correct justification for their answer: "learner A was not supposed to factorize like that, he would first find the factors, product and the sum" (S003; Experimental group). These students demonstrated the complete understanding of the null factor property that $x = a \text{ or } x = b \text{ if and only if } (x-a)(x-b) = 0 \text{ for all real numbers } a \text{ and } b$. Analysis of responses also showed that, 73% of the students from the experimental groups (n=78) and 42% from the comparison groups (n=71) identified learner B correctly as being wrong because the quadratic formula was incorrect, the expected response. These students identified the factual errors committed by learner B correctly such as the leading $(+\boldsymbol{b})$ in the quadratic formula, $m = (+\boldsymbol{b}) \pm \frac{\sqrt{b^2-4ac}}{2a}$, was supposed to be negative as $(-\boldsymbol{b})$; "Learner B, the answer also was wrong, because the quadratic formular is given by $\frac{-b\pm\sqrt{b^2-4ac}}{2a}$, but he wrote $m = b \pm \frac{\sqrt{b^2-4ac}}{2a}$" (S008; Experimental group). The students also identified the procedural and the computational errors in the substitution as $-5^2 = -25$ instead of $(-5)^2 = 25$. One student wrote that "Learner B was wrong because he failed to multiply the squares…, it was not supposed to come out negative 25. It was supposed to be positive 25" (S050; Comparison group), and another student wrote that, "Learner B made mistakes on the square root, it was negative five squared, when you multiply negative five times negative five, it's supposed to be positive twenty-five. Now it was negative twenty-five again" (S009; Experimental group). Additionally, the analysis of students' responses revealed that, 53% of the students from the experimental groups (n=78) and 11% from the comparison groups (n=71) identified learner C correctly as being wrong and rightly pointed out the correct procedures and steps for solving quadratic equations using the completing squares method, such as making the coefficient of *m-squared* as positive one (1). The sampled excerpts illustrate; "This is completing the squares; here we are supposed to look for the half of negative 5 over 2. Instead, he or she wrote, negative 5 over 2 which was wrong. He did not make m^2 to be independent" (S007; Experimental group), another student wrote, "First step, after we correct the like terms, we are supposed to divide the number on m^2. Here they were supposed to divide, now they did not divide the 2, now that's why, and the half of that sum term, he did not." (S072; Comparison group). These students further provided their own correct solution using a method of their choice. Thus, students' ability to analyze the problem and identify the patterns was more developed in the experimental groups than in the comparison groups.

Finally, Table 2 results show that 23% of the students from the experimental groups (n=78) demonstrated higher-order representation skills (relational or extended levels) after the intervention. These students were able to construct mathematical equations from word problems and meaningfully interpret solutions compared to none (0%) from the comparison groups (n=71). These students identified the variables in the question, analyzed the problem, and represented them algebraically into two linear equations. The students then applied appropriate mathematical method(s) and formulas in a way that supported conceptual understanding of the problem and inferred the solution to real-life situations (see Figure 6).

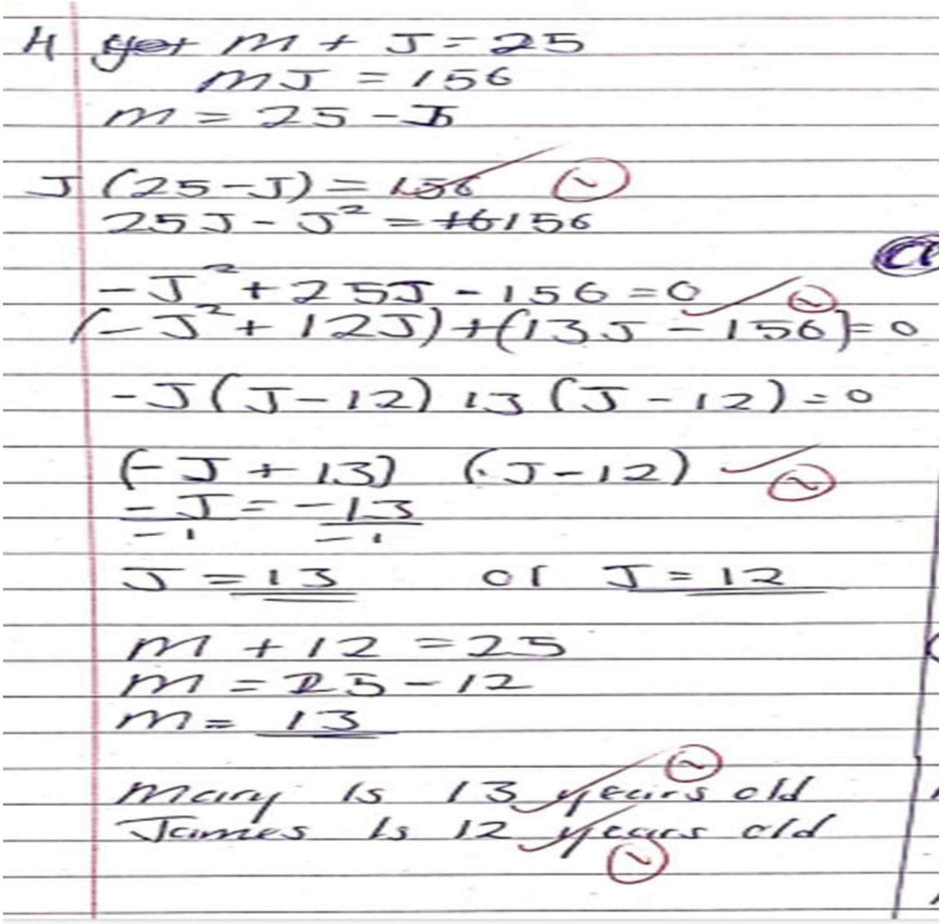

Figure 6. Students' ability to construct mathematical equations and meaningfully interpret solutions

In addition, Table 2 results also show that 73% and 94% of the students from the experimental groups (n=78) and the comparison groups (n=71), respectively, completely failed to construct mathematical equations from word problems, and in most cases, the question was omitted. These findings were rather shocking, given that students had learned quadratic equations in full and their application to real life. However, the proportion of students from experimental groups who demonstrated lower-order representation skills significantly reduced after the intervention compared to that of the students from the comparison group. The implications of these findings are discussed in the following sections.

DISCUSSION

Regardless of the level of performance before the intervention, a significant majority of the students who used the rubrics demonstrated higher-order thinking skills in the expected mathematical competence areas associated with solving quadratic equations than students who did not use the rubrics. These findings are significant contributions to understanding the impacts of rubrics on mathematics learning competencies in secondary schools, as the findings from previous studies are either contradictory (Tejeda & Gallardo, 2017; Willey & Gardner, 2009), or significantly biased toward higher education and older students (Andrade, 2019). The contradictory findings in the previous studies were attributed to how the rubrics were used. In some studies, the teachers did not share the rubrics with the students on time for formative assessment (Panadero & Jönsson, 2013), while in the other studies, rubrics were either provided to the students when the assessment was already in progress (Hubber et al., 2022), or during the summative assessments, which did not require additional feedback (Panadero & Jönsson, 2013). The significant feature of the intervention in the current study was the provision of rubrics and ensuring that the students used them not only to obtain constructive feedback and for self-assessment, but also to guide revisions and improve their own work. By considering the appropriateness of the pedagogical and instructional strategies, the use of the rubrics also improved the quality of mathematics lesson plans (Toalongo et al., 2022) through targeted and constructive feedback on students' weaknesses, such as correct use of the quadratic formula, accurate graphing and interpretation, and effective use of algebraic manipulations.

By highlighting the assessment criteria and emphasizing the standards of performance, the use of rubrics promoted conceptual understanding of mathematical concepts among the students and the development of procedural skills such as analyzing the problem, identifying patterns, logical reasoning, enhanced accuracy in calculations, and the ability to communicate solutions to teachers and peers clearly and effectively. As noted in the previous studies (Adeniji et al., 2022; Mukuka et al., 2020a), the significant differences in the number of students who demonstrated better higher-order thinking signify the different students' mathematical abilities and competencies in favor of the students who used the rubrics.

The findings of this study also show that the use of rubrics brings about transparency of learning expectations, improves the use of formative feedback, supports self-assessment, and revision. By engaging with the rubrics in these ways, secondary students can take an active role in their own learning, develop a deeper understanding of mathematics learning outcomes, and improve their own problem-solving skills through active learning and social interactions. These findings are supported by a body of literature (Fitriyani & Evendi, 2024; Hattori et al., 2025; Tashtoush et al., 2023). which conform to the social constructivism theory (Vygotsky, 1978). In a constructivism-grounded classroom, learning activities are characterized by ongoing constructive feedback to address students' needs and misconceptions (Powell & Kalina, 2009). The findings of this study further demonstrate that by providing clear expectations and criteria, the use of rubrics facilitates a shared understanding of mathematics learning outcomes between the teachers and the students, and improves student engagement in the learning process through interactive learning experiences of mathematical concepts (Krebs et al., 2022). Additionally, teachers and students may use the rubrics to define in advance the mathematics learning outcomes and specify what meeting these outcomes looks like so that the students, either as individuals or groups, can monitor their own level of understanding and where they are in the learning process (Hattori et al., 2025). The one-on-one discussions in small groups also help teachers to identify students' areas of strength and weakness daily while implementing the best practices of remediation for each student. Thus, the following conclusions are obtained from this study.

CONCLUSIONS

The use of rubrics has positive impacts on the students' algebraic competencies associated with solving quadratic equations, such as the graphing skills, the reasoning skills, and the representation skills. By highlighting the assessment criteria and emphasizing the standards of performance, the rubrics promote students' conceptual understanding of mathematical concepts and the development of procedural skills such as analyzing the problem, identifying patterns, logical reasoning, enhanced accuracy in calculations, and the ability to communicate solutions to teachers and peers clearly and effectively. These skills are part of the living conditions in the world that is becoming complex with scientific and technological advancements. Nevertheless, effective in-service continuing professional development (CPD) trainings in the use of rubrics remain equally crucial. The following implications for practice in mathematics education are provided.

Implications and recommendations for practice

This study's findings show that students may leverage the use of rubrics to obtain constructive feedback and use the opportunity to assess their own learning progress and determine what to learn next. This implies that giving the students the opportunities to engage in assessment as early as possible and discussing the assessment criteria well in advance may help them to develop study skills and build self-confidence. When the students understand the learning outcomes, they have ownership of their learning and feel more confident in their own abilities to tackle challenging questions, which may help them to improve their performance not only in school but also in life.

Limitations of the study

First, the inability to assign classes randomly to teachers and into groups precludes clear causal inference, as other confounding factors, such as students' motivation, levels of self-efficacy, and teacher bias, could also influence the results.

Second, the reliance on a moderate sample size (n=149) limits the extent to which the findings of this study may be generalized. Future studies may replicate this study with a larger sample.

Third, this study covered only six weeks, and it will be informative to determine the long-term effects of rubrics on the retention of mathematical concepts.

It should heed these limitations when interpreting the results of this study and use them as valuable insights for designing future studies that strive for more robust and widely applicable research outcomes. Within these methodological and contextual limitations, the findings of this study still provide significant implications for practitioners and researchers in mathematics education.

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Appendix 1: Task-generic rubrics for assessing graphing fluency, algebraic reasoning skills and representation skills

Desired Learning Outcome	Levels of performance					
	Extended Abstract level=4	**Relational level=3**	**Multi-structural level=2**	**Uni-Structural level=1**	**Pre-structural level=0**	**Score**
Graphing	✓Able to draw and interpret the $x-axis, y-axis, x-intercepts\ and\ y-intercepts$ to find solutions to quadratic equations correctly, including the use of interpolation.	✓Able to construct tables, draw and interpret graphs to find solutions to quadratic equations correctly.	✓Able to draw tables and graphs, but cannot interpret the graph to find solutions to quadratic equations.	✓Attempted to draw graphs, but work was characterized by the absence of a table of values, inappropriate scaling, and no clear labelling of the axes.	✓Not able to construct and draw tables and graphs. Works are incomplete, unorganized, and mathematically incorrect. ✓work left blank	
Reasoning skills	✓Able to apply and compare different quadratic concepts and procedures with logical reasons to find correct values of x in quadratic contexts and in real life situations.	✓Able to verify and justify correctly given solutions to quadratic equations using procedures that show clear understanding of quadratic equations.	✓Able to verify and justify correctly given solutions to quadratic equations using two methods, yet, procedures used are not consistent (are disjoint).	✓Able to verify and justify correctly given solutions using one method only. ✓Can manipulate simple procedures to partly justify the solutions to quadratic equations.	✓Procedures used are incorrect. ✓Wrong answers given. ✓Not able to find solutions to quadratic equations using any method. ✓Work left blank.	
Representation skills	✓Able to correctly interpret and construct symbolic and word problem representations using numerals and equations that showed conceptual understanding of quadratic equations and provided solutions in the context of the problem and in real life situations.	✓Able to correctly interpret and construct symbolic and word problem representations using numerals and equations that showed deep understanding of quadratic equations, yet cannot generalize solutions to real life situations.	✓Able to correctly interpret and construct symbolic and word problem representations using numerals and equations, yet cannot build a connection among different representations, leading to partly correct or incomplete solutions.	✓Able to partly interpret or construct word problem representations using numerals or equations, and used them to partly find solutions to quadratic equations ✓Can manipulate simple representations (equations) leading to incomplete solutions to quadratic equations.	✓Not able to correctly construct and interpret word problem representations using equations, symbols, numerals, or use representations incorrectly, leading to incorrect solutions to quadratic equations. ✓Work left blank.	