Advanced Journal of STEM Education, Vol. 4 No. 1 (2026) https://doi.org/10.31098/ajosed.v4i1.3767

Research Paper

Matrix Calculator: An Innovative Approach to Balancing Chemical Equations

Zussette Candelario-Aplaon*, Dionisio E. Briñosa
Mindoro State University, Philippines

Received: September 9, 2025	Revised: November 22, 2025	Accepted: December 10, 2025	Online: May 29, 2026

Abstract

In the New Normal, higher education institutions are using Remote Emergency Teaching instead of face-to-face instruction. However, due to academic disruptions and abrupt shifts in learning modalities, teachers and students are encountering difficulties. Challenges are even greater in teaching and learning complex topics like balancing equations. Because of this, Chemistry teachers are devising plans and finding innovative ways to deliver effective instruction amidst pandemics. Using collaborative action research with mixed methods, this study aimed to improve the teaching and learning of balancing chemical equations in the New Normal. As an intervention strategy, the concept of the matrix in Linear Algebra is integrated. This study is the Phase II of the previously conducted expository research about balancing equations using Gauss-Jordan Elimination aided by Matrix Calculator. The mixed method design employed was the embedded approach. Fifty-two students enrolled in Organic Chemistry took part in the study. They were taught through team teaching, using traditional computation and the Matrix Calculator. They were given a test before and after the intervention, and their scores were treated using the mean and paired t-test. Ten students were selected and interviewed online. The responses during the interview were transcribed and analyzed through thematic coding. The results showed a significant difference between the pretest and post-test scores, indicating that Matrix Calculator is an effective tool for teaching and learning to balance chemical equations. Among the themes that emerged are accessibility, usability, and accuracy. Furthermore, the results indicated the need for a self-instructional module to support independent and flexible learning.

Keywords: *Chemistry Education, Matrix Calculator, Technology Integration, Balancing Chemical Equations; Innovative Pedagogy*

INTRODUCTION

The coronavirus pandemic that began in 2020 disrupted education worldwide, forcing over 1.38 billion learners to transition into distance learning, including 850 million who shifted to remote modalities (Affouneh et al., 2020). While this abrupt change created instructional disruptions, it also accelerated the adoption of innovative pedagogical approaches and technology-based solutions in Higher Education Institutions (HEIs). What was initially a temporary adjustment through Emergency Remote Teaching (ERT) (Hodges et al., 2020) has highlighted the long-term need for evidence-based curricular responses, effective technology integration, and discipline-based innovations to enhance teaching and learning (Toquero, 2020).

Among the most affected areas is the teaching of STEM subjects, particularly Chemistry, which is inherently challenging due to its abstract concepts, symbolic language, and mathematical requirements (Gafoor & Shilna, 2013; Moyo, 2018). Difficult topics such as the periodic table, chemical bonding, and chemical equations often hinder student comprehension (Özmen & Ayas, 2003; Wang, 2012). Specifically in balancing chemical equations, students struggle with the process's abstractness and the mathematical rigor it entails. This situation calls for alternative teaching strategies that merge mathematical tools with technology to foster both understanding and engagement.

Corresponding author's email: zca.minsubc@gmail.com

Linear algebra provides a systematic and logical approach to balancing chemical equations through methods such as Gauss-Jordan elimination. When aided by technology—such as the Matrix Calculator—this approach becomes more accessible to learners who may not be mathematically inclined or technologically advanced. Prior studies have shown that integrating mathematics into real-life applications not only strengthens comprehension but also promotes positive attitudes and motivation toward learning (Idris, 2003; Candelario-Aplaon & Izon, 2015; Malibiran et al., 2019; Magbanua & Aplaon, 2017). In particular, the use of matrix-based methods supported by user-friendly digital tools can reduce cognitive load, increase accuracy, and stimulate interest in both Chemistry and Linear Algebra (Candelario-Aplaon, 2019).

The study aims to provide a concrete interdisciplinary understanding of mathematics and chemistry education by enabling learners to build new knowledge on their existing knowledge actively and to see abstract mathematical models in real-world chemical systems. The study tests theories of cognitive learning, constructivism, experiential learning, and technology pedagogical content knowledge.

This study builds on previous expository research by moving beyond demonstration and examining the usability and effectiveness of applying the Matrix Calculator in actual teaching and learning contexts. The study shows how technology can make learning in STEM subjects more engaging and meaningful, especially during remote or flexible learning. By using a Matrix Calculator to teach students how to balance chemical equations through Gauss-Jordan elimination, the research highlights how digital tools can help connect mathematics and chemistry in practical ways. By leveraging technology to implement linear algebra, the study seeks to provide Chemistry teachers with a practical intervention that enhances instructional delivery and helps students confidently master balancing chemical equations.

Research Questions

This study aimed to determine the effectiveness of using the Matrix Calculator as an intervention tool in teaching and learning balancing chemical equations in the New Normal. Specifically, it sought answers to the following questions:

1. What are the difficulties encountered in learning to balance equations using traditional computation? (Planning)
2. What are the challenges encountered during the implementation of the intervention? (Implementation)
3. How did the intervention provide success in balancing the equation? (Evaluation)
4. What improvements should be made in teaching the lesson with the aid of a Matrix calculator in the future? (Reflection)

LITERATURE REVIEW

Pandemic-Driven Pedagogical Changes

The coronavirus hit the world at the beginning of 2020, affecting many lives, and the number of cases has grown exponentially. By March 2020, approximately 1.38 billion learners were affected, of whom 850 million had transitioned to distance learning worldwide (Affouneh et al., 2020). The pandemic forever changed people's lives. While facing the challenges and problems brought about by the pandemic, teachers and students should learn to accept and cope with the changes. The pandemic enables educators to practice evidence-based curricular response, establish a comprehensive online delivery system, and create a responsive curriculum (Toquero, 2020).

During the pandemic, everyone is advised to stay at home except those offering health services and other services related to basic needs and skeletal forces. At that time, most Higher Education Institutions (HEIs) were in the middle of their midterms, thus causing instructional disruption. The ECQ brought about a sudden shift of learning modality from face-to-face to "online learning". Since the curriculum is not intentionally designed to be delivered entirely online, it cannot be considered online education. Instead, instruction during those times uses fully remote teaching solutions, but will return to normal after the pandemic. This temporary shift of learning modality due to crisis circumstances was termed Emergency Remote Teaching (ERT) (Hodges et al., 2020).

The abrupt change in modality from in-person to online delivery differs from planned online learning. During the transition to ERT, a comprehensive contingency plan is needed to provide support for students and faculty during online instruction. Even in times of crisis, delivering sustainable, high-quality education should be prioritized when developing long-term online learning strategies. Further, strategies implemented during an emergency can serve as a framework for developing institutional resilience (Johnson et al., 2020). When the pandemic is over, institutions should not just forget about ERT and return to pre-pandemic learning delivery.

ERT must become part of the institutional plan, including faculty and personnel professional development (Hodges et al, 2020). The education system should continually evolve toward the New Normal as a public health concern, and disasters that result in school closures will likely occur in the future. Further, teachers should devise teaching practices that enable students to become lifelong learners amid pandemics. Further studies should be conducted to provide valuable insights into students' responses to ERT and to shed more light on improving techno-pedagogical practices during a pandemic.

Aside from the many problems and challenges brought about by the abrupt change in learning modality, the challenges in teaching and learning STEM subjects are even greater. For subjects like Chemistry, students encountered difficulties (Moyo, 2018) because it involves many abstract concepts, uses micro- and symbolic language, and requires mathematical proficiency (Gafoor & Shilna, 2013; Moyo, 2018). Teachers should find innovative ways to deliver effective instructions amidst pandemics. Strategies found to be effective among others are the integration of other disciplines (Akinola et al., 2016; Candelario-Aplaon, 2019; Gabriel & Onwuka, 2015) and the integration of technology (Akinola et al, 2016; Candelario-Aplaon & Izon, 2015; Aydin, 2009; Candelario-Aplaon, 2019).

In Chemistry, among the most difficult topics are the periodic table, chemical bonding (Gafoor & Shilna, 2013), and chemical and ionic equations (Moyo, 2018; Özmen & Ayas, 2003; Wang, 2012). This study focused on balancing chemical equations and possible interventions to improve students' performance, as well as helping teachers teach the topic with confidence and efficacy.

Challenges in Chemistry Education

When the COVID-19 pandemic forced schools to shift abruptly to remote instruction, chemistry education faced unique challenges. Among the biggest challenges are inequality in access to technology (Aristovnik et al., 2023), teaching laboratory-based lessons (Díez-Pascual & Jurado-Sánchez, 2022), and student engagement and assessment (Broad et al., 2023). Both teachers and students experienced increased stress, isolation, and motivation problems, highlighting the emotional toll of the remote teaching environment.

Traditionally, balancing chemical equations is done using an inspection approach (Gabriel & Onwuka, 2015) or a trial-and-error approach (Tuckerman, 2011), which requires persistence in guessing (Gabriel & Onwuka, 2015) and can lead to difficulty and frustration (Croeau et al., 2007). Thus, to avoid such tedious, repetitive steps, an alternative step-by-step approach should be used (Hutchings et al., 2007).

Other methods that may be used in balancing chemical equations are the algebraic approach (Charnock, 2016; Tuckerman, 2011), systems of the linear equation (Schmidt, & Jignéus, 2003;

Wang, 2012), or application of matrix algebra (Akinola et al, 2016; Krishna et al., 2017; Padmaja et al., 2017; Risteski, 2009) but it requires basic skills in algebra (Zabadi, & Assaf, 2017). Balancing equations is not only about knowledge of Chemistry; it is more a matter of mathematical manipulation (Risteski, 2010; Risteski, 2012). That is why students should possess mathematical skills to succeed in Chemistry.

This study reflects the principles of Cognitive Load Theory (CLT), which explains that learning becomes more effective when instructional methods reduce unnecessary mental effort and help students focus on understanding core concepts (Sweller, 1988). In traditional chemistry classes, balancing equations through inspection or trial-and-error methods can overwhelm students because they must juggle multiple ideas—chemical formulas, coefficients, and conservation laws—all at once (Gabriel & Onwuka, 2015; Tuckerman, 2011). This heavy mental demand often leads to frustration and errors (Croeau et al., 2007).

By contrast, using structured approaches such as matrix algebra or Gauss–Jordan elimination can organize information into manageable steps, easing the cognitive burden and guiding students toward clearer, logical thinking (Akinola et al., 2016; Padmaja et al., 2017). This process supports CLT by lowering extraneous cognitive load and allowing students to focus on meaningful understanding rather than rote guessing. As Zabadi and Assaf (2017) noted, developing mathematical skills enhances students' success in chemistry, suggesting that integrating math-based tools not only simplifies complex tasks but also strengthens conceptual learning.

Mathematical Approaches to Balancing Equations

In this study, the mathematical concept of balancing equations was used because integrating mathematics with other disciplines and real-life applications has proven effective (Idris, 2003; Stewart & Thomas, 2003). Further, mathematics is easily learned when applied to real-life situations and concrete experiences (Candelario-Aplaon & Izon, 2015; Malibiran et al., 2019). It could foster positive attitudes toward the subject (Magbanua & Aplaon, 2017) and provide motivation, understanding, and conceptual understanding (Aydin, 2009).

Linear Algebra was used in this study because of its wide application to real-life problems and other disciplines (Candelario-Aplaon, 2019; Clugston & Flemming, 2002). Linear Algebra and Stoichiometric principles are interconnected (Gabriel & Onwuka, 2015), which is why chemical equations may be balanced using various concepts like Gauss Elimination (Akinola et al., 2016; Gabriel & Onwuka, 2015; Padmaja et al., 2017; Vishwambharrao et al., 2013), Gauss-Jordan elimination (Candelario-Aplaon, 2019; Padmaja et al., 2017), and algebraic approach (Risteski, 2012; Zabadi & Assaf, 2017). This study used Gauss-Jordan elimination because it is the least explored of the topics mentioned.

This study aligns strongly with the constructivist theory of learning, which holds that students learn best when they actively build their own understanding through meaningful, contextualized experiences (Piaget, 1973; Vygotsky, 1978). By using Linear Algebra, particularly Gauss-Jordan elimination, to balance chemical equations, learners do not just memorize steps; they explore how mathematical ideas apply to real chemical problems. This hands-on approach helps them see the connections between math and chemistry, making abstract concepts more concrete and easier to understand. In doing so, students become active participants in their learning, working together, thinking critically, and discovering knowledge for themselves, core ideas at the heart of constructivism.

Technology Integration in STEM Education

Aside from integrating other disciplines, integrating technology into teaching makes learning more interesting and motivating (Candelario-Aplaon & Izon, 2015). Technology creates opportunities for individualized learning (Diković, 2007), provides an environment for active exploration of concepts (Aydin, 2009; Trowbridge et al., 2008), and develops inquiry skills for understanding the nature of science (Trowbridge et al., 2008). In matrix operations, software can be used to avoid tedious trial and error (Idris, 2003).

The most common are MATLAB/Octave's rref command (Akinola et al., 2016; Aydin, 2009), Maple (Dąbrowski et al., 2010), and Mathematica (Mathwright et al., 2009). However, this software is complex and command-driven (Dąbrowski et al., 2010) and cannot be used to balance equations with fractional oxidation numbers (Risteski, 2012). Thus, this study used the free software Matrix Calculator to balance equations because it is simpler and more user-friendly (Candelario-Aplaon, 2019).

However, integrating technology is challenging and requires commitment. To develop and sustain effective technology integration, teachers need ongoing support. It may be a good practice for the teachers to collaborate with other teachers to improve and support their teaching and learning (Norris et al., 2003). Thus, this study considered collaborative teaching as part of the intervention process. Further, collaborative action research was used to determine the effectiveness of the intervention program.

According to Sagor (2011), action research is "any investigation conducted by empowered people to take action concerning their actions to improve their future actions" (p. 5). Richards and Lockhart (1996) state that AR "typically involves small-scale investigative projects in the classroom and consists of several phases which often recur in cycles: planning, action, observation, and reflection" (p. 12). It helps practitioners improve their practice (Petre, 2020). Also, a deeper understanding of organizational change and community improvement could be achieved through collective action using participatory action research (Riel, 2019).

It has different types such as individual, collaborative, school-wide, and district-wide. This study used Collaborative Action Research (CAR), which involves an in-depth inquiry into one's professional interactions with others to move towards an envisioned future (McNiff, 2013; Fine, 2018; McNiff & Whitehead, 2010; Wood, 2017). According to Creswell (2012), it is the most widely used practical design among all research designs. It is mainly used to generate theories to improve practice (McNiff & Whitehead, 2006) and to develop solutions to practical problems (Clark & Creswell, 2015; Creswell, 2012; Thomas, 2017).

This study reflects the ideas of the Technological Pedagogical Content Knowledge (TPACK) framework, which holds that effective teaching occurs when teachers thoughtfully integrate what they know about the subject, how to teach it, and how to use technology to support learning (Mishra & Koehler, 2006). By using the Matrix Calculator to teach students to balance chemical equations, teachers integrate their knowledge of chemistry, teaching strategies such as collaboration and inquiry, and digital tools that make learning more engaging and meaningful. Through this integration, technology becomes more than just a tool; it becomes a way to connect ideas, motivate students, and make complex STEM concepts easier to understand.

With an interdisciplinary approach and the integration of technology, the study would help test whether the intervention significantly improves students' performance in balancing chemical equations by shifting from the traditional trial-and-error method to the Matrix calculator. Grounded in studies emphasizing the effectiveness of integrating mathematics and technology in enhancing learning (Candelario-Aplaon & Izon, 2015; Mishra & Koehler, 2006; Candelario-Aplaon, 2019), this hypothesis tests whether the combination of Linear Algebra concepts and digital tools like the Matrix Calculator can lead to meaningful learning gains compared to traditional trial-and-error methods. It aligns with constructivist and TPACK principles, suggesting that students learn better when they actively apply interdisciplinary knowledge through technology-supported, hands-on experiences.

RESEARCH METHOD

Research Design

Collaborative action research through mixed methods was used in the study. CAR is done by a group of people who are invested in the outcome. In this study, two researchers from different fields (mathematics and science) worked collaboratively to improve students' understanding and performance in balancing chemical equations. Single-cycle action research is used in the study, wherein the planning, implementation, evaluation, and reflection cycle is conducted only once.

Since it used an embedded mixed-methods design, quantitative and qualitative data were gathered before, during, and after the implementation. For quantitative data, participants' performance before and after the intervention was collected and analyzed. For qualitative data, documentary analysis (syllabus), field notes, in-depth interviews, and participants' reflective journals were transcribed and coded.

The embedded design is the mixed-methods design employed, wherein quantitative and qualitative data were collected and analyzed within a quantitative or qualitative research procedure. Data collection and analysis were done before, during, and/or after the primary methods (Riel, 2019). This design was the best fit for the study as it aims to examine the intervention process, in this case, the integration of Linear Algebra and the Matrix Calculator in balancing chemical equations. Presented in Figure 1 is the research paradigm following the Single Case Cycle action research.

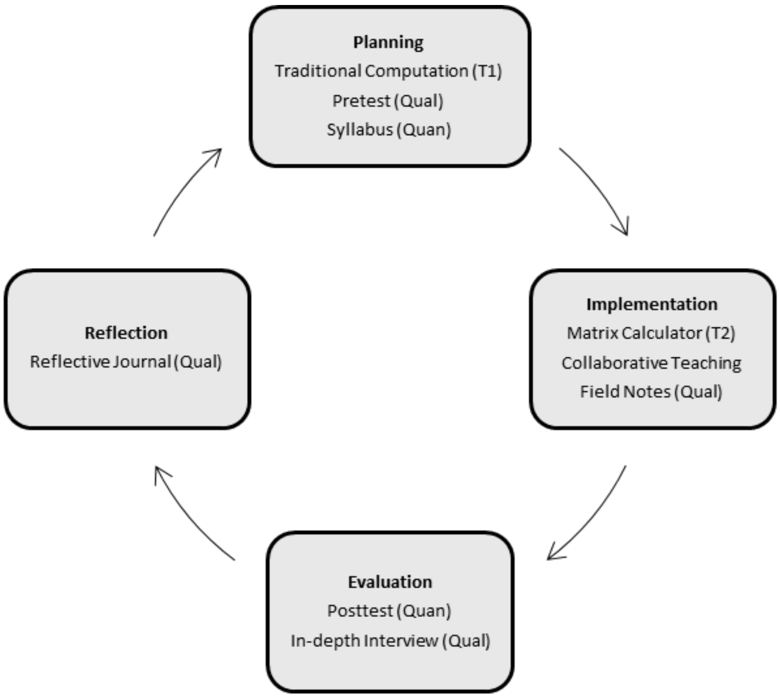

Figure 1. Research paradigm: Single Case Cycle using Embedded Design of Mixed Methods

The diagram shows the continuous cycle of collaborative action research that combines both numbers and stories to improve teaching and learning. It begins with planning, where students first learn to balance chemical equations using traditional methods, take a pretest, and follow a structured syllabus. In the implementation stage, teachers introduce the Matrix Calculator through team teaching and observe students' engagement with the new tool.

The evaluation phase follows, in which students take a posttest and share their experiences through interviews to assess how much they have learned and how they felt about the process. Finally, during reflection, teachers write in their reflective journals to consider what worked well and what could be improved. Altogether, these phases form a cycle that helps teachers and students continuously grow, making chemistry learning more effective and meaningful.

Research Participants and Sampling

Fifty-two Bachelor of Secondary Education majors in science enrolled in Inorganic Chemistry took part in the study. They were taught using traditional computation in the first cycle and using the Matrix Calculator through team teaching in the second cycle. Of these 52 students, 10 were interviewed after the second cycle.

The primary informants were selected through purposive sampling, in which those who showed the highest percentage increase on the post-test were selected. The study involved 52 participants in the quantitative part, which is sufficient to detect meaningful differences with good statistical power, according to Cohen's (1988) guidelines. This size also fits the available population and resources (Cochran, 1977).

For the qualitative part, 10 interviewees were purposively chosen to provide deeper insights. Guest et al. (2006) found that key themes often appear within 10–12 interviews, making this number sufficient to reach data saturation. Two teachers were involved in this study: the main author, a mathematics teacher, was referred to as Teacher 2 (T2), and the co-author, a science teacher, as Teacher 1 (T1).

Instruments

Two sets of the test were used in the study, one for the pretest and the other for the post-test. Each test consists of 20 items, five for each reaction type: formation, single replacement, double replacement, and combustion. Both tests were posted and retrieved via Google Classroom. They are similar in terms of type and level of difficulty and were allotted a two-hour time frame.

To ensure that the instruments accurately measured what they were intended to measure, the pretest and post-test were reviewed by three experts in chemistry education. Their suggestions helped improve the clarity and alignment of the items with the learning objectives. A pilot test was then carried out with a small group of students who were not part of the study. The results showed a Cronbach's alpha of 0.87, indicating that the test was highly reliable and consistent (George & Mallery, 2019).

For the qualitative data, member checking and peer debriefing were done to strengthen the credibility of the findings. Participants reviewed their interview responses to confirm that their ideas were accurately represented, while peer debriefing with fellow researchers helped ensure that the analysis and interpretation were fair and unbiased (Lincoln & Guba, 1985). Through these steps, the study ensured that both the quantitative and qualitative data were trustworthy and truly reflected the students' learning experiences.

An interview guide was used to explore the participants' experiences before, during, and after the intervention, giving a deeper understanding of how they engaged with the learning process. The interviews were conducted online via Google Meet, making it easier for participants to share their thoughts comfortably and conveniently. To support and verify the interview data, documentary analysis was also carried out using the course syllabus, participants' reflective journals, and the researchers' field notes.

This process of triangulation strengthened the credibility of the findings by comparing different sources of information (Creswell & Poth, 2018; Denzin, 2012). The interview guide was used to capture participants' experiences before, during, and after the intervention for in-depth analysis. The interview was done online via Google Meet. For documentary analysis, the course syllabus, participants' reflective journals, and the researchers' field notes were used to triangulate findings from interviews and field notes.

Data Collection

This study utilized the single-cycle action research paradigm. The initial phase aimed to assess students' learning conditions prior to the intervention. The students were taught by T1 the traditional way of balancing the chemical equations - the trial-and-error method. The data were collected through the pretest, analysis of the syllabus (documentary analysis), and literature. In the final phase, the students were taught how to apply linear algebra in balancing chemical equations by T2.

The matrix calculator was introduced to them afterward. The data were gathered through the post-test, in-depth interview, participants' reflective journal (documentary analysis), and the researchers' field notes. After the cycle was complete, reflection and further analysis were conducted to develop a comprehensive instructional plan for teaching and learning on balancing chemical equations in the new normal.

Data Analysis

Statistical tools such as the mean, frequency count, percentage, standard deviation, and paired t-test were used to analyze the quantitative data. The paired t-test was selected to determine whether there is a significant difference between students' pretest and posttest scores after the intervention.

This test is appropriate for related or dependent samples, where the same participants are measured before and after an instructional treatment (Field, 2018). The paired t-test assumes that the differences between the two sets of scores are normally distributed and that the data are measured on an interval or ratio scale (Pallant, 2020).

For the qualitative data, analysis followed Merriam's (1998) model, which involved transcribing, coding, categorizing, and identifying themes from the interviews and documents. Through this process, patterns and insights were drawn to support and explain the quantitative findings.

FINDINGS AND DISCUSSION

This section presents the results of the data analysis, which were used to answer the previously stated research questions.

Planning Phase

In the initial phase, the goal was to assess students' performance after being taught using the traditional method of balancing equations. This served as an ex-ante of intervention to be employed. The data gathering includes identifying students' performance levels in balancing chemical equations using traditional computation, analyzing the syllabus, and examining the difficulties students encountered before the intervention to develop an intervention plan.

Pretest Scores

Table 1 presents the results of the test administered to participants after they were taught to use traditional computation. The results show that most students (63%) performed well, scoring within the Good range, while 37% performed at a Fair level. No students fell into the *Very Good* or *Poor* categories. This means that, overall, students showed a reasonable understanding of the lesson, but there is still room to improve their performance further.

These findings suggest that while most students were able to grasp the basic concepts of balancing chemical equations, their understanding did not yet reach a high level of mastery. Most scores in the Good range indicate that traditional instruction helped build foundational skills. However, some students still struggled to apply the method confidently, as reflected in the *Fair* category.

The absence of *Very Good* scores suggests a need for more engaging or innovative teaching approaches to deepen comprehension and accuracy. This highlights the importance of introducing interventions, such as integrating linear algebra and a matrix calculator, to enhance students' conceptual understanding and problem-solving skills in chemistry.

Table 1. Pretest Scores

Scores	Frequency	Percentage	Description
18 - 20	0	0	Very Good
14 - 17	33	63	Good
9 - 13	19	37	Fair
0 - 8	0	0	Poor
Total		**100**	

RQ1. What are the difficulties encountered in learning to balance equations using traditional computation? (Planning)

From students' reflective journal entries about the difficulties they encountered when balancing equations using the trial-and-error approach, the following themes emerged.

1. Time-Consuming

The traditional method of balancing equations uses trial-and-error (Tuckerman, 2011) or inspection-based approaches (Gabriel & Onwuka, 2015), which require successive intelligent guesses. Because of this, the student has to spend time and effort finding the appropriate coefficients to balance the equations. According to participant 2, "the time spent in balancing equations is too long, the longer time I consume, the more confusing it gets". Another student wrote, "The process is too long and needs extra effort to arrive at the correct answer. It is not easy *talaga (really)... basta wag sukuan (just do not give up)* until I arrived with the correct answer" (P8). "Using trial and error is extremely time-consuming," added participant 11.

2. Tedious

The traditional method is tedious and requires persistence (Hutchings et al., 2007) to succeed in a trial-and-error approach. Because of this, some students get frustrated (Croeau et al, 2007) when they cannot arrive at the correct answer. Participant 3 entered in her journal that she could not find the right numbers to balance the equations, so she left some items unanswered. Another student wrote, "I get confused in balancing because I need to do it manually" (P4). "I find it frustrating to solve over and over again until I get the correct answer" (P6).

3. Number Anxiety

According to Croeau et al (2007), balancing more advanced problems is even more frustrating for students. Because it requires not only knowledge of chemistry but also mathematical competence (Risteski, 2012). "Aside from it being extremely time-consuming, it is frustrating when dealing with massive amounts of data," according to P 11. "It is difficult to balance an equation because one inaccurate number can affect the entire equation", said participant 10.

The intervention was formulated based on the test results and the difficulties the students encountered. Moreover, the syllabus used by T1 in his class was analyzed to ensure that the planned intervention would not conflict with the approved instructional strategies. In addition to the asynchronous and synchronous activities, the strategies include collaborative teaching and technology integration. Also, as part of the course requirements, the students are to submit reflective journals. All these elements were included in the intervention planning and in the plan for conducting the research.

Implementation Phase

In the implementation of the intervention, collaborative teaching was employed. T2 taught the students how to apply matrix concepts, specifically Gauss-Jordan elimination, to solve systems of equations. She later introduced the software Matrix Calculator as a tool for balancing equations. During implementation, the researchers observed students' performance and attitudes throughout.

RQ2. What are the challenges encountered during the implementation of the intervention?

1. Different discipline

Introducing a mathematical concept in a science class is not new. However, the participants find it challenging to learn another discipline aside from science. For participant 4, "integrating mathematics makes the lesson complicated because I have to understand the two concepts instead of learning only one". "I do not easily understand the process during the lecture. I must review some of the topics in Algebra to be able to grasp the idea" (P3). It is challenging to use math concepts because it requires an understanding of the solution and manipulation of the equation before I can make use of the software" (P6).

These experiences can be explained by Cognitive Load Theory (Sweller, 1988), which suggests that when learners are exposed to multiple new concepts simultaneously, their working memory can become overloaded, leading to difficulty in processing and understanding information. Likewise, the Interdisciplinary Learning Theory emphasizes that integrating different fields requires careful scaffolding so learners can see the connections between disciplines rather than viewing them as separate, competing subjects (Jacobs, 1989). This highlights the need for explicit connections between mathematical reasoning and chemical principles to help students build integrated knowledge structures.

2. New Technology

Introducing new technology to students is another challenging task for teachers and students alike. During the pandemic, when most classes were delivered online, teachers and students alike were constantly learning new technologies to meet the pressing demands of distance learning. It is therefore timely that the students were taught a tool they may use to balance equations. Participant 3 said that "using Matrix Calculator is a great help, but I need to follow the steps correctly or else I will not get the right answer". "When I first used the app, it was hard to understand how it works, but after some time, I mastered the procedures, and it is very useful" (P4).

These insights are supported by the Technology Acceptance Model (TAM) by Davis (1989), which posits that learners' acceptance of technology depends on their perception of its usefulness and ease of use. Initially, students may experience difficulty navigating new tools, but as familiarity increases, confidence and perceived value also rise. This is further supported by Vygotsky's (1978) Social Constructivist Theory, which highlights that learning is socially mediated; teachers and peers play a key role in guiding students through the learning process, especially when adopting new technology.

3. Guest Teacher

Establishing rapport between teachers and students helped make the teaching and learning process successful. Having a guest teacher is another challenge for students, who feel uncomfortable, especially if the guest teacher is not from their department. For participant 1, "I was shy to ask questions because I am afraid of being criticized. I am not familiar with the attitude of the guest teacher, so I just kept quiet". "I was timid to ask for some examples in solving long and complicated equations because I do not want the teacher to think I am *bida-bida*" (showing off) (P8).

This behavior can be understood through the Affective Filter Hypothesis (Krashen, 1982), which states that emotional factors such as anxiety, fear, or lack of confidence can block the input and hinder learning. When students feel uneasy or intimidated, their affective filter rises, reducing engagement and participation. Establishing rapport and a psychologically safe learning environment is therefore essential, as supported by Humanistic Learning Theory (Rogers, 1983), which emphasizes empathy, trust, and positive teacher-student relationships as foundations for effective learning.

Evaluation Phase

During the third stage, the student's performance was again determined using a similar test. The pretest and post-test scores were compared for significant differences attributable to the intervention. Furthermore, 10 students were invited to participate in an in-depth interview to examine the intervention process and to answer the qualitative questions posed in the earlier section.

Post-Test Scores

Table 2 shows students' performance on balancing equations after the introduction of the Matrix Calculator. As depicted, more than half of them showed very good performance, scoring 18 - 20, and the rest performed well, scoring 14 - 17. The results showed a significant increase in their test scores.

Table 2. Post-test Scores

Scores	Frequency	Percentage	Description
18 - 20	32	62	Very Good
14 - 17	20	38	Good
9 - 13	0	0	Fair
0 - 8	0	0	Poor
Total		100	

T-Test Result Between the Pretest and Posttest Scores

Before performing the paired t-test, the test's assumptions were checked to ensure the validity of the results. The normality of the difference scores between the pretest and posttest was examined visually using a histogram. The results showed that the data were approximately normal, confirming that the paired t-test was appropriate for use (Field, 2018).

Table 3 presents the t-test results comparing the pretest and posttest for the students. The analysis revealed a significant increase in students' scores from the pretest ($M = 13.79$, $SD = 1.33$) to the post-test ($M = 17.67$, $SD = 2.24$), $t(51) = 12.19$, $p < 0.01$. This result indicates that integrating linear algebra and using a matrix calculator significantly improved students' performance in balancing chemical equations.

The effect size, measured using Cohen's d, was 2.02, which is considered very large according to Cohen's (1988) benchmarks. This suggests that the intervention had a strong and meaningful impact on students' learning, not only showing statistical significance but also practical significance in improving their understanding and problem-solving skills.

The t-test results indicate a significant difference in participants' scores before and after the intervention. As the p-value is less than 0.01, the performance improvement could be attributed to the intervention implemented. Thus, implying the effectiveness of using the Matrix Calculator as a tool in balancing the chemical equations.

Table 3. t-test Results

Variables	Mean	SD	$t_{computed}$	$t_{tabular}$	Result
Pretest	13.79	1.33	12.1902**	2.0076	Significant
Posttest	17.67	2.24			

$p<0.05$* $p<0.01$**

To shed light on the results, the qualitative data gathered from in-depth interviews and reflective journals were analyzed. The themes are presented as follows:

RQ3. How did the intervention provide success in balancing the equation?

1. Accuracy

Balancing chemical equations may be done using the algebraic approach (Charnock, 2016; Tuckerman, 2011) to avoid the tedious trial-and-error method (Hutchings et al, 2007). "Matrix Calculator makes the process easier and more convenient. I do not need to rely on trial and error. I can arrive at the exact answer in just a few algebraic manipulations and a few clicks on my computer," according to participant 8. Participant 4 added that the Matrix Calculator computes the equation, and you can check the answer by substitution.

These experiences align with Cognitive Load Theory (Sweller, 1988), which suggests that reducing unnecessary mental effort allows learners to focus on understanding essential concepts rather than on repetitive or inefficient procedures. By automating the computational part, the Matrix Calculator minimizes extraneous cognitive load and enables students to engage more deeply in conceptual reasoning. This also reflects Vygotsky's (1978) Social Constructivist Theory, as technology acts as a mediating tool that supports learners in moving from procedural to conceptual understanding through guided exploration.

2. Accessibility

Matrix Calculator is a simple, user-friendly, free software tool for solving matrix-related problems (Candelario-Aplaon, 2019). The students enjoyed using it because of its accessibility. "Anybody with an internet connection can easily access the software. No need to download and register. I like it" (P10).

This reflects the Technology Acceptance Model (TAM) by Davis (1989), which explains that the perceived ease of use and usefulness of technology greatly influence users' acceptance and willingness to integrate it into learning. Because the Matrix Calculator is readily available online and requires no complicated installation or registration, students found it convenient and motivating to use. This sense of accessibility aligns with the principles of Universal Design for Learning (UDL), which emphasize providing multiple means of engagement and removing barriers to learning (Meyer et al., 2014).

3. Usability

The use of technology enables students to perform mathematical analyses without time-consuming calculations (Idris, 2003). "Matrix Calculator is a helpful tool, and it makes balancing easier and faster" (P1). "It saves time and is not as complicated as the traditional method" (P9). "It is very easy to use. Once you have formulated the algebraic expressions, you just encode them into the software, and the answer will automatically appear" (P4). "The process is automated, so it helps the student to solve complicated problems in a short period" (P6). "It is a good application for extremely difficult problems" (P10).

These experiences reflect the Technology Acceptance Model (TAM) by Davis (1989), which highlights perceived usefulness and ease of use as key factors influencing users' acceptance of technology. When learners recognize that a tool reduces cognitive effort and streamlines problem-solving, they are more motivated to adopt it. Similarly, the Cognitive Theory of Multimedia Learning (Mayer, 2001) supports this finding, suggesting that well-designed digital tools reduce unnecessary cognitive load, allowing students to focus on understanding concepts rather than on computations.

4. Stimulation

Technology helps students become actively engaged in acquiring scientific knowledge and in developing their understanding of the nature of science and inquiry (Trowbridge et al., 2008). Participant 7 said that "Matrix Calculator helps me develop a positive attitude for continued successful learning, which was hard in manual calculation". For participant 8, it is more convenient and makes solving exciting because of the utilization of the new technology. "Since it can be used to solve multiple complex and challenging equations, it gives me confidence in solving," added participant 5.

For participant 10, Matrix Calculator makes the boring topic like balancing equations fun and interesting". This aligns with Constructivist Learning Theory (Bruner, 1961) and Self-Determination Theory (Deci & Ryan, 1985), both of which emphasize that when learners actively engage with interactive tools, their intrinsic motivation and confidence grow. Moreover, as Trowbridge et al. (2008) noted, technology can foster curiosity and deeper scientific inquiry by allowing students to explore concepts in dynamic ways. In this case, the Matrix Calculator transformed balancing equations from a tedious task into an enjoyable and confidence-building experience.

Reflection Phase

The final stage of the action research cycle is the reflection on the experiences and the intervention process. The results were drawn from the participants' reflective journals and other previously used data-gathering instruments. Based on the study's results, the intervention was successful in improving students' performance in balancing equations.

Collaborative teaching facilitates a better understanding of the two disciplines because both instructors possess mastery of their respective topics. The case may be different if the science instructor teaches matrix manipulation, which would be challenging for him. Technology integration elicits students' interest and motivates them by providing an easy, reliable solution.

RQ4. What improvements should be made in teaching the lesson with the aid of a Matrix calculator in the future?

1. Self-Instructional Module

Since introducing new technology and another discipline may be confusing for students, it is necessary to provide a step-by-step approach that teachers and students can use (Hutchings et al., 2007). "A detailed module with the step-by-step procedures should be provided by the teacher. It should contain worksheets for practice and evaluation," suggested participant 6.

2. Accessible video tutorial

Participant 3 suggested that "a tutorial video on how to use the Matrix Calculator should be made accessible to the students. Since internet connection is always a problem, it would be good if it could be downloaded and be watched offline".

3. Opportunities for Collaborative Learning

For the learning experience to be more enjoyable, it should be active and collaborative. Participant 1 recommends including activities that provide opportunities for collaboration and socialization in the teaching balancing equation using the Matrix Calculator.

CONCLUSIONS

The use of collaborative action research provided the researchers with clear insights into the difficulties students encountered in balancing equations using the traditional method. The traditional method of trial-and-error is found to be time-consuming, tedious, and unsuccessful, leading to anxiety and frustration. An embedded mixed-methods design employed various data types to formulate and evaluate intervention plans to improve students' performance.

The integration of other disciplines, such as linear algebra, collaborative teaching, and technology, was found to be effective in improving not only students' knowledge and skills but also their values and attitudes toward the topic. Despite the challenges students encountered during the intervention, they actively participated and had an engaging learning experience. The Matrix Calculator provides students with confidence, as it has proven to be accurate, accessible, and stimulating.

Theoretically, this study advances STEM education by demonstrating that integrating mathematical reasoning and digital tools in chemistry promotes deeper conceptual understanding and more efficient problem-solving. It supports Cognitive Load Theory (Sweller, 1988) by demonstrating that technology, such as the Matrix Calculator, can reduce unnecessary mental effort. It aligns with Constructivist and TPACK frameworks (Mishra & Koehler, 2006) by illustrating how interdisciplinary, technology-enhanced instruction fosters active, meaningful learning. Overall, the study highlights the potential of interdisciplinary approaches to strengthen students' STEM literacy and promote innovative, technology-supported pedagogy in the sciences.

Based on the findings, it is recommended that teachers incorporate interdisciplinary and technology-assisted approaches in teaching complex scientific concepts. Integrating mathematical tools, such as the Matrix Calculator, into chemistry lessons can help students visualize relationships among concepts and reduce learning anxiety. Curriculum developers should design learning modules that promote STEM integration, emphasizing the connections between mathematics, technology, and science to build a deeper understanding.

Furthermore, professional development programs may focus on TPACK-based training to equip educators with the skills to merge content, pedagogy, and technology effectively. Future researchers are encouraged to replicate this study across different contexts and STEM disciplines further to validate the effectiveness of interdisciplinary, technology-enhanced learning strategies.

LIMITATION & FURTHER RESEARCH

Based on the results and conclusion presented, it is recommended that a Self-Instructed Module (SIM) on using the Matrix Calculator to balance equations be developed. The said SIM should contain individualized and collaborative activities. Furthermore, a video tutorial should be prepared so that students can access and watch it at any time. Training on the use of the Matrix Calculator should be conducted for chemistry teachers in public and private secondary schools through the university's extension program to equip them with current approaches to teaching the topic. Further, testing the Matrix Calculator in other STEM contexts, using more diverse samples, is highly recommended for future studies.

REFERENCES

Affouneh, S., Salha, S., & Khlaif, Z. N. (2020). Designing quality e-learning environments for emergency remote teaching in coronavirus crisis. *Interdisciplinary Journal of Virtual Learning in Medical Sciences, 11*(2), 135–137. https://doi.org/10.30476/ijvlms.2020.86120.1033

Akinola, R. O., Kutchin, S. Y., Nyam, I. A., & Adeyanju, O. (2016). Using row reduced echelon form in balancing a chemical equation. *Advances in Linear Algebra & Matrix Theory, 6*(4), 146–157. https://doi.org/10.4236/alamt.2016.64014

Aristovnik, A., Karampelas, K., Umek, L., & Ravšelj, D. (2023). Impact of the COVID-19 pandemic on online learning in higher education: A bibliometric analysis. *Frontiers in Education, 8*, Article 1225834. https://doi.org/10.3389/feduc.2023.1225834

Aydin, S. (2009). The factors affecting teaching linear algebra. *Procedia - Social and Behavioral Sciences, 1*(1), 1549–1553. https://doi.org/10.1016/j.sbspro.2009.01.274

Broad, H., Carey, N., Williams, D. P., & Blackburn, R. A. R. (2023). Impact of the COVID-19 pandemic on chemistry student and staff perceptions of their learning/teaching experience. *Journal of Chemical Education, 100*(2), 664–671. https://doi.org/10.1021/acs.jchemed.2c00856

Bruner, J. S. (1961). The act of discovery. *Harvard Educational Review, 31*(1), 21–32.

Candelario-Aplaon, Z. C., & Izon, M. (2015). The teaching practices in Mathematics IV, students' competence and mastery level in Bongabong Districts. In *Proceedings of the 2nd International Research Presentation and Seminar* (pp. 18–24). MinSCAT, TUCST, & EDS Business School International Research Journal.

Candelario-Aplaon, Z. (2019). Balancing chemical equations using Gauss-Jordan elimination aided by Matrix Calculator. *Innovative Technology and Management Journal, 2*, 34–46.

Charnock, N. (2016). Teaching methods for balancing chemical equations: An inspection versus an algebraic approach. *American Journal of Educational Research, 4*(7), 507–511. https://doi.org/10.12691/education-4-7-2

Clark, V. L. P., & Creswell, J. W. (2015). *Understanding research: A consumer's guide* (2nd ed.). Pearson.

Clugston, M., & Flemming, R. (2002). *Advanced chemistry*. Oxford University Press.

Cochran, W. G. (1977). *Sampling techniques* (3rd ed.). Wiley.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Pearson.

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). Sage Publications.

Croeau, J., Fox, W., & Varazo, K. (2007). Mathematical modeling of chemical stoichiometry. *PRIMUS, 17*(4), 301–315.

Dąbrowski, A. M., Mitkowski, S. A., Porebska, A., & Kurgan, E. (2010, September 14–17). Formulating structural matrices of equations of electrical circuits containing dependent sources, with the use of the Maple program. In *Proceedings of the 1st World Conference on Technology*. Krakow, Poland.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340. https://doi.org/10.2307/249008

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. Springer.

Denzin, N. K. (2012). Triangulation 2.0. *Journal of Mixed Methods Research, 6*(2), 80–88. https://doi.org/10.1177/1558689812437186

Díez-Pascual, A. M., & Jurado-Sánchez, B. (2022). Remote teaching of chemistry laboratory courses during COVID-19. *Journal of Chemical Education, 99*(5), 1913–1922. https://doi.org/10.1021/acs.jchemed.2c00022

Diković, L. (2007). Interactive learning and teaching of linear algebra by web technologies: Some examples. *The Teaching of Mathematics, 10*(2), 109–116.

Field, A. (2018). *Discovering statistics using IBM SPSS statistics* (5th ed.). Sage Publications.

Fine, M. (2018). *Just research in contentious times: Widening the methodological imagination*. Teachers College Press.

Gabriel, C. I., & Onwuka, G. I. (2015). Balancing of chemical equations using matrix algebra. *Journal of Natural Sciences Research, 5*(5), 29–36.

Gafoor, K. A., & Shilna, V. (2013, April 10–11). *Perceived difficulty of chemistry units in Std IX for students in Kerala stream calls for further innovations*. Paper presented at the conference *Innovations in Pedagogy and Curriculum: From Theory to Practice*, GCTE Thalassery, Kerala, India. https://files.eric.ed.gov/fulltext/ED545397.pdf

George, D., & Mallery, P. (2019). *IBM SPSS statistics 26 step by step: A simple guide and reference* (16th ed.). Routledge.

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field Methods, 18*(1), 59–82. https://doi.org/10.1177/1525822X05279903

Hodges, C., Moore, S., Lockee, B., Trust, T., & Bond, A. (2020). The difference between emergency remote teaching and online learning. *EDUCAUSE Review*. https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning

Hutchings, L., Peterson, L., & Almasude, A. (2007). Collaborative explorations in college algebra: Balancing chemical equations and matrix algebra. *The Journal of Mathematics and Science: Collaborative Explorations, 9*, 119–133.

Idris, I. M. (2003). *Toward a right way to teach linear algebra*. Mathematics Department, Faculty of Science, Ain Shams University. http://www.cimt.org.uk/journal/idris.pdf

Jacobs, H. H. (1989). *Interdisciplinary curriculum: Design and implementation*. ASCD.

Johnson, N., Vletsianos, G., & Seaman, J. (2020). U.S. faculty and administrators' experiences and approaches in the early weeks of the COVID-19 pandemic. *Online Learning, 24*(2), 6–21. https://doi.org/10.24059/olj.v24i2.2285

Krashen, S. D. (1982). *Principles and practice in second language acquisition*. Pergamon Press.

Krishna, Y. H., Ramana Reddy, V., & Praveen, J. P. (2017). Balancing chemical equations by using matrix algebra. *World Journal of Pharmacy and Pharmaceutical Sciences, 6*(2), 994–999. https://doi.org/10.20959/wjpps20172-8569

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publications.

Magbanua, M., & Aplaon, Z. C. (2017, January 26–27). Sex-role in mathematical dichotomy among grade 7 students in Bongabong South. In *Proceedings of the 2017 Cebu International Conference in Business, Management, Education and Law (SBMEL-17)*. Cebu, Philippines. http://fze.uconferencealerts.com/siteadmin/upload/DIR0117526.pdf

Malibiran, H., Candelario-Aplaon, Z., & Izon, M. (2019). Determinants of problem solving performance in Mathematics 7: A regression model. *International Forum Journal, 22*(1), 65–86. https://journals.aiias.edu/iforum/article/view/431

Mathwright, J., Porter, T., & Simon, M. (2009). Enhancing linear algebra instruction using Mathematica. *International Journal of Mathematical Education in Science and Technology, 40*(6), 763–778. https://doi.org/10.1080/00207390902914121

Mayer, R. E. (2001). *Multimedia learning*. Cambridge University Press.

Merriam, S. B. (1988). *Case study research in education: A qualitative approach*. Jossey-Bass.

Meyer, A., Rose, D. H., & Gordon, D. (2014). *Universal design for learning: Theory and practice*. CAST Professional Publishing.

McNiff, J. (2013). *Action research: Principles and practice* (3rd ed.). Routledge.

McNiff, J., & Whitehead, J. (2006). *All you need to know about action research*. Sage Publications.

McNiff, J., & Whitehead, J. (2010). *You and your action research project* (3rd ed.). Routledge.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Moyo, C. (2018). Investigating the areas of student difficulty in chemistry curriculum: A case study in Qatar. *Texila International Journal of Academic Research, 5*(2), 1–8. https://doi.org/10.21522/TIJAR.2014.05.02.Art003

Norris, C., Soloway, E., & Sullivan, T. (2003). Examining 1:1 computing in the classroom: Pedagogical implications and teacher collaboration. *Journal of Technology and Teacher Education, 11*(2), 231–248.

Özmen, H., & Ayas, A. (2003). Students' difficulties in understanding the conservation of matter in open and closed-system chemical reactions. *Chemistry Education Research and Practice, 4*(3), 279–290. https://doi.org/10.1039/B3RP90011D

Padmaja, Y., Harikrishna, Y., & Ramana Reddy, G. V. (2017). An innovative approach of matrix algebra to balancing chemical-reaction equations. *World Journal of Pharmacy and Pharmaceutical Sciences, 6*(3), 260–266. https://doi.org/10.20959/wjpps20173-8656

Pallant, J. (2020). *SPSS survival manual: A step by step guide to data analysis using IBM SPSS* (7th ed.). McGraw-Hill Education.

Petre, G. (2020). Using flipped classroom to facilitate cooperative learning implementation: An action research case study with photovoice. *Journal of Education Studies, 1*(2), 5–35. https://doi.org/10.2139/ssrn.3786157

Piaget, J. (1973). *To understand is to invent: The future of education*. Grossman Publishers.

Richards, J. C., & Lockhart, C. (1996). *Reflective teaching in second language classrooms*. Cambridge University Press.

Riel, M. (2019). *Understanding collaborative action research*. Center for Collaborative Action Research, Pepperdine University. http://cadres.pepperdine.edu/ccar/define.html

Risteski, I. B. (2009). A new singular matrix method for balancing chemical equations and their stability. *Journal of the Chinese Chemical Society, 56*(1), 65–79. https://doi.org/10.1002/jccs.200900010

Risteski, I. B. (2010). A new complex vector method for balancing chemical equations. *Materials and Technology, 44*(4), 193–203.

Risteski, I. B. (2012). New very hard problems of balancing chemical reactions. *Chemistry: Bulgarian Journal of Science Education, 21*(4), 574–580.

Rogers, C. R. (1983). *Freedom to learn for the 80s*. Charles E. Merrill Publishing Company.

Sagor, R. (2011). *The action research guidebook: A four-stage process for educators and school teams* (2nd ed.). Corwin.

Schmidt, H., & Jignéus, C. (2003). Students' strategies in solving algorithmic stoichiometry problems. *Chemistry Education Research and Practice, 4*(3), 305–317. https://doi.org/10.1039/B3RP90013J

Stewart, S., & Thomas, M. (2003). Difficulties in the acquisition of linear algebra concepts. *New Zealand Journal of Mathematics, 32*(Supplementary Issue), 207–215.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

Thomas, G. (2017). *How to do your research project: A guide for students* (2nd ed.). Sage Publications.

Toquero, C. M. D. (2020). Emergency remote teaching amid COVID-19: The turning point. *Asian Journal of Distance Education, 15*(1), 185–188. https://doi.org/10.5281/zenodo.3881748

Trowbridge, L. W., Bybee, R. W., & Powell, J. C. (2008). *Teaching secondary school science: Strategies for developing scientific literacy* (10th ed.). Pearson.

Tuckerman, M. E. (2011). *Advanced chemistry lecture notes*. New York University. http://www.nyu.edu/classes/tuckerman/adv.chem/lectures/lecture_2/node3.html

Vishwambharrao, K., Raju, N. I., & Shivarudrappa, H. (2013). Balancing chemical equations by using mathematical model. *International Journal of Mathematical Research & Science, 1*(4).

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wang, Y. (2012). In search of denotational mathematics: Novel mathematical means for contemporary intelligence, brain and knowledge sciences. *Journal of Advanced Mathematics and Applications, 1*(1), 4–25. https://doi.org/10.11648/j.jama.20120101.12

Wood, L. (2017). Community development in higher education: How do academics ensure their community-based research makes a difference? *Community Development Journal, 52*(4), 685–701. https://doi.org/10.1093/cdj/bsv068

Zabadi, A., & Assaf, R. (2017). From chemistry to linear algebra: Balancing a chemical reaction equation using algebraic approach. *International Journal of Advanced Biotechnology and Research, 8*(1), 24–33.