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# Teaching Methods for Balancing Chemical Equations: An Inspection versus an Algebraic Approach

**Nathan L. Charnock***

Hillsborough County Public Schools
*Corresponding author: nathan.charnock@sdhc.k12.fl.us

**Abstract** In secondary chemistry education, there are two predominate teaching methods which are typically employed to convey a systematic method of chemical reaction balancing: by inspection or with a linear algebraic approach. The objective of this study was to determine the most effective method to teach the skill set needed to perform the task of chemical reaction balancing in the secondary education setting as measured by performance on a teacher-made summative assessment. The results clearly indicated that the algebraic approach to balancing both simple and advance chemical reactions typically encountered in the secondary chemistry classroom is superior to that of the inspection method. The algebraic method is not a new approach to employ in the systematic resolution of stoichiometric coefficients and the novelty of application makes it an attractive, effective, and efficient teaching and learning method in practice.

***Keywords:*** *high school teachers, general chemistry, teaching methods, stoichiometry/balancing equations*

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## 1. Approach

The application of the law of conservation of matter is critical in chemistry education and is demonstrated in practice through balanced chemical equations [1,2]. Chemistry students have had persistent difficulty in topics related to reaction stoichiometry, particularly concerning its application with chemical reactions [1,3]. The understanding and application of this empirical law is the keystone to subsequent understanding in chemistry [1,2,3,4]. The *law of conservation of matter* states that an atom can neither be created nor destroyed in a chemical reaction; thus, in this context, the total mass of the reactant(s) must be conserved after the reaction proceeds forward and the resulting product(s) must be of equal mass. Thus, the law of conservation of matter determines the condition in which each mass quantity will be conserved, where a balanced chemical equation demonstrates the amenability of empirical conservation. For example, the chemical equation $wA + xB \rightarrow yC + zD$ depicts reactants A and B and the products C and D while $w$, $x$, $y$, and $z$ are the stoichiometric coefficients which represent the irreducible relative amount of each substance [5]. Previous studies have demonstrated that students' persistent inability to solve stoichiometric proportions largely stems from difficulty both in acquiring and systematically applying a skill set to this end [5]. The objective of this study was to determine the most effective method to teach the skill set needed to perform the task of chemical reaction balancing in the secondary education setting.

In secondary chemistry education, two predominant methods are typically employed to convey a systematic method of chemical reaction balancing: (a) by inspection or (b) with a linear algebraic method [6,7]. Balancing chemical equations by inspection is suitable in balancing situations with both simple and advanced reactions that are free from formal charges or those with several unknown factors [8,9]. The balance-by-inspection method is generally described using six steps with minor variations in preferential format from author to author and is depicted in Table 1 through 4 and represent in general by equation (1).

1. From the skeleton equation, the problem solver creates a list of each element participating in the reaction and separates the list into two columns, one for reactants and a second for products.
2. Balance metals (except hydrogen)
3. Balance the nonmetals (except oxygen)
4. Balance oxygen
5. Balance hydrogen
6. Recount all atoms (checking step)

In Example 1:

$$Zn + HCl \rightarrow ZnCl_2 + H_2 \tag{1}$$

Thus, from the unbalanced equation, the list would consist of (see Table 1):

**Table 1. Unbalanced Equation Atomic Inventory**

| Reactants | | Products | |
|---|---|---|---|
| Element | Quantity | Element | Quantity |
| Zn | 1 | Zn | 1 |
| Cl | 1 | Cl | 2 |
| H | 1 | H | 2 |

Now, to systematically apply the rules imposed by inspection methodology (see Table 2 – Table 4):

**Table 2. Rule 2 Balance the Metals (Except Hydrogen)**

| Reactants | | Products | |
|---|---|---|---|
| Element | Quantity | Element | Quantity |
| Zn | 1 √ | Zn | 1 √ |
| Cl | 1 | Cl | 2 |
| H | 1 | H | 2 |

**Table 3. Rule 3 Balance the Nonmetals (Except Oxygen)**

| Reactants | | Products | |
|---|---|---|---|
| Element | Quantity | Element | Quantity |
| Zn | 1 √ | Zn | 1 √ |
| Cl | ~~1~~ 2 √ | Cl | 2 √ |
| H | 1 | H | 2 |

**Table 4. Rule 5 Balance Hydrogen**

| Reactants | | Products | |
|---|---|---|---|
| Element | Quantity | Element | Quantity |
| Zn | 1 √ | Zn | 1 √ |
| Cl | ~~1~~ 2 √ | Cl | 2 √ |
| H | ~~1~~ 2 √ | H | 2 √ |

Rewriting the chemical equation for the balanced condition imposed by the results of Table 2 – Table 4 gives the final solution for equation 1a:

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2 \tag{1a}$$

The second common teaching method involves applying linear algebra to solve for balanced chemical reactions with a system of equations [6]. Many students typically become frustrated with the inspection method, informally referred to as the *trial-and-error method*, when the student experiences a complication with applying it to more advanced problems that do not lend easily to an instantaneous or serendipitous solution [5]. Thus, the mathematical balancing method is more approachable than use of the novel inspection methodology [10]. The algebraic approach generally has six steps; the undetermined coefficient list, as discussed below, is depicted in Table 5 through 8.

1. Assign undetermined coefficients to each chemical species (e.g., *a*, *b*, . . . *y*, and *z*) of the unbalanced reaction.
2. Craft a list to track the solution of each undetermined coefficient.
3. Write a balanced condition for each element.
4. Set one of the undetermined coefficients to the value of 1.
5. Solve for each undetermined coefficient.
6. Simplify any factorial solutions through multiplication.

This method is grasped best through an example. As an example, balance the following chemical reaction illustrated with equation 2:

$$KMnO_4 + HCl \rightarrow Cl_2 + KCl_2 + MnCl_2 + H_2O \tag{2}$$

Applying Rule 1 to equation 2 gives rise to equation 2a:

$$aKMnO_4 + bHCl \rightarrow cCl_2 + dKCl_2 + eMnCl_2 + fH_2O \tag{2a}$$

Applying Rule 2 also gives rise to Table 5 for the undetermined coefficients:

**Table 5. Undetermined Coefficient List**

| Undetermined Coefficient | Solution Value |
|---|---|
| *a* | |
| *b* | |
| *c* | |
| *d* | |
| *e* | |
| *f* | |

Appling Rule 3 gives the following algebraic representation of the balanced condition for each element:

$$K: a = d \tag{2b}$$

$$Mn: a = e \tag{2c}$$

$$O: 4a = f \tag{2d}$$

$$H: b = 2f \tag{2e}$$

$$Cl: b = 2c + 2d + 2e \tag{2f}$$

Likewise, application of Rule 3 gives rise to the follow solution the undetermined coefficients depicted in Table 6:

**Table 6. Undetermined Coefficient List**

| Undetermined Coefficient | Solution Value |
|---|---|
| *a* | 1 |
| *b* | |
| *c* | |
| *d* | |
| *e* | |
| *f* | |

This instantaneously gives the solution set depicted in Table 7:

**Table 7. Undetermined Coefficient List**

| Undetermined Coefficient | Solution Value |
|---|---|
| *a* | 1 |
| *b* | |
| *c* | |
| *d* | 1 |
| *e* | 1 |
| *f* | |

Then, solving for the reaming undetermined coefficients gives the following conditions:

$$O: 4a = f \tag{2g}$$

$$H: b = 2f \tag{2h}$$

$$Cl: b = 2c + 2d + 2e \tag{2i}$$

$$O: 4(1) = f = 4 \tag{2j}$$

$$H: b = 2(4) = 8 \tag{2k}$$

$$Cl: 8 = 2c + 2(1) + 2(1) = 2 \tag{2l}$$

Completing the undetermined coefficient list yields the following solution set as depicted in Table 8:

**Table 8. Undetermined Coefficient List**

| Undetermined Coefficient | Solution Value |
|---|---|
| *a* | 1 |
| *b* | 8 |
| *c* | 2 |
| *d* | 1 |
| *e* | 1 |
| *f* | 4 |

Thus, plugging the resolved coefficients back into Equation 2a gives the following balanced chemical reaction illustrated in equation 2m:

$$KMnO_4 + 8HCl \rightarrow 2Cl_2 + KCl_2 + MnCl_2 + 4H_2O \quad (2m)$$

The goal of this study to was determine which methodological approach to balancing chemical reaction was most effective when measured with a teacher made summative assessment.

# 2. Methodology

## 2.1. Sample

The sample was purposefully drawn from the author's students enrolled in a chemistry courses at single suburban high school in the Southeast within a major U.S. metropolitan area. The sample was representative of the school district's distribution in terms of student algebra I ability and consisted of 196 students, 47% of which were female, enrolled in eight separate chemistry classes (whole-class cohorts). In total across all cohorts, high performing algebra I skills accounted for 28.9% of the sample, 37.5% of the sample accounted for average algebra I skill ability, and 33.6% of the sample accounted for below average algebra I skill ability (as determined by FCAT2.0® achievement levels). Similarly, the distribution of algebra I skill level abilities was analogous within the each of the eight whole-class cohorts.

## 2.2. Primary Instructional Practice

Four of the whole-class cohorts (49% of the sample) received two days of traditional direct instruction by the author and nine days of subsequent guided practice for balancing chemical reactions by inspection as previously described in Example 1. The direct instruction, facilitated by the author, occurred over the course of two 45-minute periods supplemented with guided practice for nine 45-minute periods over the course of nine school days. The nine days of guided practice were carried out with analogous practice problems similar to those in Table 9 (see equations A–E); this was done in order to focus on the conceptual skill development and sustainment at both the whole-group and individual learner levels. This pedagogy lends well to cooperative learning, which encourages problem solving and allows for a positive social support structure to enable learners to challenge misconceptions [11,12,13,14,15]. Specifically, each of the reactions in Equations A–E were modeled with direct instruction. Then, with instructor-facilitated, peer-supported guided practice, students completed 20 analogous problems over the course of four school days for one iteration of practice for each singular 45-minute period per day [16,17,18]. After four days of exercise with the sustainment problems, students were again exposed to the research problem set (Equations A–E) where solution resolution was supported by small peer groups and modeled by the instructor. The students then completed an additional 20 analogous problem sets over the course of four school days for one iteration of practice for each singular 45-minute period per day. At the end of the nine days of guided instruction, students were re-assessed with an instrument crafted specifically from Equations A–E.

Likewise, the remaining whole-class cohorts received traditional direct instruction, facilitated by the author, and sustained practice for algebraically balancing chemical reactions as previously described in Example 2 and conserved the teaching methodology previously discussed for the balance-by-inspection method. Again, the direct instruction method coupled with guided practice allowed for conceptual skill development and sustainment at both the whole-group and individual levels [11,12,13,14,15]. Moreover, this approach allowed for a cooperative learning environment that encouraged problem-solving and allowed for a positive social support structure to enable learners to challenge misconceptions [11,12,13,14,15]. Across all cohorts, all students were specifically exposed to the five research chemical reactions, as depicted in Table 9 (Equations A–E), during direct instruction, again after the fourth day of analogous practice, and once more on their summative assessment, which included the following (unbalanced) equations:

**Table 9. Balancing Chemical Reaction Assessment Items**

| Item | Type of Reaction | Unbalanced Chemical Equation |
|---|---|---|
| *A* | Synthesis | $N_2 + H_2 \rightarrow NH_3$ |
| *B* | Decomposition | $KClO_3 \rightarrow KCl + O_2$ |
| *C* | Single Replacement | $NaCl + F_2 \rightarrow NaF + Cl_2$ |
| *D* | Double Replacement | $Pb(NO_3)_2 + KI \rightarrow PbI_2 + KNO_3$ |
| *E* | Combustion | $C_5H_{11} + O_2 \rightarrow CO_2 + H_2O$ |

## 2.3. Summative Assessment Validity and Reliability

Table 9 depicts the five items used for summative assessment of all students for concept mastery. A table of specifications was employed to determine the validity of the test items as they pertain to Florida Sunshine State Standards SC.912.P.8.8 and SC.912.P.8.9 for chemical reactions and the *law of conservation of matter*, respectively. To this end, three on-site chemistry content teachers, with an average 15 years of experience, evaluated each of the five items and unanimously concurred with the summative assessment's item alignment with both of the content standards. Moreover, each content expert stated that the items were novel, representative, and appropriate for the secondary learner in a chemistry course of study.

The summative assessment, reported in Table 9, was initially pilot tested with a subset of representative students ($n$ = 24) whom proceeded the research cohorts by one academic year. Cronbach's alpha was calculated for the summative assessment from the pilot test data where: $\alpha$ = .813, demonstrating good internal test reliability, before fielding the assessment instrument with the research cohorts.

# 3. Results

Table 10 and Table 11 depict the percentage of correct responses to the summative assessment of the unbalanced chemical reactions for Equations A–E for both the balance-by-inspection and algebraic methods, respectively.

**Table 10. Correctly Balanced Chemical Equations, Inspection Method, by Item Number (n = 97)**

| | Equation by Item | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| *n* | 79 | 62 | 50 | 18 | 3 |
| % | 82.4 | 63.9 | 51.5 | 18.5 | 3.1 |

**Table 11 Correctly Balanced Chemical Equations, Algebraic Method, by Item Number (n = 99)**

| | Equation by Item | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| *n* | 95 | 88 | 91 | 87 | 93 |
| % | 95.9 | 88.9 | 91.9 | 87.9 | 93.9 |

A power analysis was performed with G*Power 3.1 to determine the minimal sample size required to perform an analysis for a mean difference between two independent groups with 95% confidence. To this end, an overall sample 176 was needed and achieved ($N$ = 196), where each cohort needed at least 88 participants. This requirement was surpassed, with subsamples of 97 and 99 for the inspection and algebraic class cohorts, respectively.

The sample mean for the summative assessment for the inspection method was lower than that of the algebraic group ($M$ = 62.0, $SD$ = 11.2; and $M$ = 88.0, $SD$ = 6.0). Welch's $t$ test revealed that there was a significant difference between the instructional methods, $t(143) = -20.48$, $p < .001$, where Cohen's $d$ was calculated ($d = 2.8$) demonstrating a large effect for students who received the algebraic-based instruction scored higher on the summative assessment for balancing chemical reactions compared to students who received instruction for inspection methodology when measured with the same instrument (Equations A–E).

## 4. Implications and Conclusion

The results clearly indicated that the algebraic approach to balancing both simple and advanced chemical reactions typically encountered in the secondary chemistry classroom is superior to that of the inspection method [18]. The algebraic method is not a new approach to employ in the systematic resolution of stoichiometric coefficients rather the approach was abandoned in favor of the inspection method in the early 1990's. To this end, researchers advocated for a shift from algorithmic approaches in favor of a more concrete conceptual understanding and approach to balancing chemical reactions, which may have resulted in a paradigm shift in favor of the inspection method [19]. This method has, however, been reported to be problematic and persistently troublesome for high school chemistry students, where the conceptual foundation is typically introduced with simple reactions (e.g., Equation A), but quickly progresses to more advanced reactions (e.g., Equations D and E) where the inspection method becomes difficult to apply in a logical fashion [3]. To this end, the linear algebra approach lends well to both simple and advanced reactions that can be reduced to a set of equations which then can be logically and systematically resolved [20,21]. The reported findings here are consistent with the literature concerning prior analysis of the algebraic method [20]; the generalizability of the findings reported here are limited, however, given the homogeneity of the sample in terms of affluence and race. Specifically, the sample was disproportionately skewed for affluence where only 18.0% of the sample was considered to be in a low socioeconomic status (SES), as measured by free or reduced priced lunch status. Moreover, the sample was not representative of the school district or of the national distribution for racial categories: 2% Asian or Pacific Islander; 10% Black, Non-Hispanic; 17% Hispanic; 7% Multiracial; and 65% White, Non-Hispanic. Therefore, this study should be replicated on a larger scale to increase the generalizability of the reported findings. Also, by reducing the cognitive burden borne from the task of resolving for balanced stoichiometric coefficients, future investigation could focus on investigating teaching methodology that catalyzes deeper understanding of the law of conservation of mass through macroscopic laboratory-based investigations.

## 5. Limitations and Future Research

This study's results represent a rather homogeneous sample from a single school site. The author is aware of the inherent limitations regarding sampling and future investigations should aim to draw a sample that more closely represents current national demographics. Future research should also investigate balanced reactions in connection with other stoichiometric concepts concerning theoretical yield, experimental yield, limiting, and excess reagents, in addition to investigating teaching methodology that fosters a deeper understanding of the law of conservation of mass through macroscopic laboratory-based investigations.

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## References

[1] Dalaklioğlu, S.; Demirci, N.; & Şekercioğlu, A. Eleventh Grade Students' Difficulties and Misconceptions About Energy and Momentum Concepts. *International Journal of New Trends in Education and Their Implications*, 2015, *6*; 13-21. 2015

[2] Fach, M.; de Boer, T.; & Parchmann, I. Results of an Interview Study as Basis for the Development of Stepped Supporting Tools for Stoichiometric Problems. *Chemistry Education Research and Practice*, 2006, *8*; 13-31.

[3] Özmen, H.; & Ayas, A. Students' difficulties in understanding of the conservation of matter in open and closed-system chemical reactions. *Chemistry Education: Research and Practice*, 2003, *4(3)*; 279-290.

[4] Abraham, M.; Williamson, V.; & Westbrook, S. A cross age study of the understanding of five chemistry concepts. Journal of Research in Science Teaching. 1994, *31*, 147-165.

[5] Croeau, J.; Fox, W.; & Varazo, K. 2007. Mathematical Modeling of Chemical Stoichiometry. *Problems and Issues in Mathematics Undergraduate Studies*, 2007, *17*; 301-315.

[6] Herndon, W. On Balancing Chemical Equations: Past and Present. *Journal of Chemical Education*, *1997*, *74*; 1359-1365.

[7] Porter, Spencer. How Should Equation Balancing Be Taught? *Journal of Chemical Education*, *1985*, *62*(6); 507-509.

[8] Guo, C. A New and General Method for Balancing Chemical Equations by Inspections. *Journal of Chemical Education*, 1997, *74*; 1365-1380.

[9] Zoltán, T. Balancing Chemical Equations by Inspection. *Journal of Chemical Education, 1997, 74*(9): 1363.

[10] Schmidt, H.; & Jignéus, C. Students' Strategies in Solving Algorithmic Stoichiometry Problems. *Chemistry Education: Research and Practice, 2003, 4*(9); 305-317.

[11] Artzt, A.; Armour-Thomas, E.; Curcio F; & Gurl, T. *Becoming a Reflective Mathematics Teacher*. New York: Lawrence Earlbaum Associates, 2008.

[12] Bransford, J.; Brown, A.; & Cocking, R. eds. *How People Learn: Brain, Mind, Experience, and School*. (Eds.). Washington, DC: National Academy Press, 1999.

[13] Davidson, N. *Cooperative Learning in Mathematics: A Handbook for Teachers.* Eds. Menlo Park: Addison-Wesley, 1990.

[14] Johnson, D.; & Johnson, R. *Learning Together and Alone: Cooperation, Competition, and Individualization.* Englewood Cliffs: Prentice Hall, 1975.

[15] Shellard, E.; & Moyer, P. *What Principals Need to Know About Teaching Math.* Alexandria: National Association of Elementary School Principals and Education Research Service, 2002.

[16] Baker, S.; Gersten, R; & Dae-Sik, L. A Synthesis of Empirical Research on Teaching Mathematics to Low-Achieving Students. *The Elementary School Journal,* 2002*, 103*, 51-73.

[17] Baker, S.; Gersten, R.; Dimino, J.; & Griffiths, R. The Sustained Use of Research-Based Instructional Practice: A Case Study of Peer-Assisted Learning Strategies in Mathematics. *Remedial and Special Education*, 2004*, 25,* 5-24.

[18] VanDerHeyden, A.; & Burns, M. Using Curriculum-Based Assessment and Curriculum-Based Measurement to Guide Elementary Mathematics Instruction: Effect on Individual and Group Accountability. *Assessment for Effective Intervention, 2005, 30*;15-31.

[19] Niaz, M.; & Robinson, W. 1991. Teaching Algorithmic Problem Solving or Conceptual Understanding: Role of Developmental Level, Mental Capacity, and Cognitive Style, 1991, *Annual Meeting of the National Association for Research in Science Teaching*, Lake Geneva. http://files.eric.ed.gov/fulltext/ED331717.pdf.

[20] Olson, J. An Analysis of the Algebraic Method for Balancing Chemical Reactions. *Journal of Chemical Education*, 1997*, 74*; 538-542.

[21] Risteski, I. A New Approach to Balancing Chemical Equations, 2012; retrieved from: http://www.siam.org/journals/problems/downloadfiles/71-025s.pdf.