Students' strategies and errors in balancing chemical equations
Estrategias y errores de los estudiantes al balancear ecuaciones químicas

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Abstract

Hungarian secondary school (age of 14-18) students' strategies for balancing chemical equations and their typical errors were investigated in three studies. As a result of our studies one can conclude that Hungarian students seldom use methods based on the concept of oxidation numbers and they prefer balancing by inspection. The efficiency of the most widely used trial and error method fluctuates highly and two systematic errors can cause problems. Both of these originate from the habit not writing down the unitary coefficient (1) in the equation for the reaction during balancing process. At the same time, although students have not been taught this method in school, a significant portion of them applied a very effective balancing strategy, which appears similar to the chain rule or linked sets method algorithm. Exploring students' strategies in balancing chemical equations makes it possible to suggest teaching strategies to change their initial trial and error method of low efficiency into high performance strategies i.e. chain rule or change in oxidation number method by simply giving carefully chosen equations to be balanced by them.

Key words: *chemical equations; balancing; students' strategies; typical error*

Resumen

Estrategia de los estudiantes (edades de 14-18) para balancear ecuaciones químicas y sus errores típicos, se investigaron en tres estudios. Se puede concluir que los estudiantes raramente utilizan métodos con base en el concepto de número de oxidación y prefieren balancear por inspección. La eficiencia más ampliamente utilizada en el método de prueba y error fluctúa altamente y puede ocasionar dos errores sistemáticos. Ambos errores se originan desde el hábito de no anotar el coeficiente unitario (1) en la ecuación para la reacción durante el proceso de balanceo. A la vez, aunque a los estudiantes no les hayan enseñado este método en la escuela, una porción importante de ellos aplicó una estrategia equilibradora muy efectiva, parecida o vinculada al método de algoritmos. Explorando las estrategias de los estudiantes en balancear ecuaciones químicas se sugiere enseñar estrategias para cambiar su método inicial de prueba y error de baja eficiencia en estrategias de alto rendimiento, es decir, la regla de cadena o el cambio en el método de número de oxidación y proponerles ecuaciones cuidadosamente elegidas para ser balanceadas por ellos.

Palabras clave: *ecuaciones químicas; el balanceo; las estrategias de estudiantes; errores típicos*

INTRODUCCIÓN

Description of chemical reactions can be accomplished at three different levels:

(i) level of reality *i.e.* phenomenological, macroscopic description of the system; (ii) level of molecular events which is not available for our everyday sensing *i.e.* particulate level; and (iii) level of special notation of chemistry using chemical equations i.e. symbolic level (JOHNSTONE, 1991). When balanced equations for chemical reactions are used as symbolic models they express various aspects of chemical changes. The so called 'word equations' emphasise and signify only the identity of the reacting substances. Stoichiometric equations describe quantitative relations; relative masses (and volumes if gaseous) of the substances involved in chemical transformations. Students studying chemistry in the elementary or high school usually meet only these two types of chemical equations since mechanistic equations are met only at higher levels. Stoichiometric equations *i.e.* balanced chemical equations have very important role in chemical calculations, analytical chemistry and representation of inorganic chemical reactions. However, proper formulation of stoichiometric equations requires chemical knowledge and skills such as knowing the formula and properties of reacting substances as well as conservation laws. Although balancing a chemical equation is mainly a technical question it is still an important prerequisite of proper formulation of stoichiometric equations and hence for learning and application of chemical knowledge.

Several papers have dealt with the various methods of balancing chemical equations but comprehensive studies on the methods *really* used by students are very rare (HERNDON, 1997). Here we present our results to explore students' strategies for balancing chemical equations and highlight their systematic errors related to equation balancing.

BACKGROUND

Some examples of chemical equations should be known by students

In Hungary students study chemistry for 2 years (in 7th and 8th grades) in primary, and for 3 or 4 years (in 9th, 10th, and 11th or 12th grades) in secondary high schools. Although the first equation balancing method, the oxidation number method, is presented only at the end of the 9th grade (in their 3rd year study in chemistry), they have to know a lot of complicated reaction equations like these:

In 7th and 8th grades:

$$3\ CaSO_4 + 2\ Na_3PO_4 = Ca_3(PO_4)_2 + 3\ Na_3PO_4$$

$$Fe_2O_3 + 3\ CO = 2\ Fe + 3\ CO_2$$

$$2\ Al + 6\ H_2O = 2\ Al(OH)_3 + 3\ H_2$$

$$6\ CO_2 + 6\ H_2O = C_6H_{12}O_6 + 6\ O_2$$

$$Cu + 4\ HNO_3 = Cu(NO_3)_2 + 2\ NO_2 + 2\ H_2O$$

In 9th-12th grades:

$$4\ NH_3 + 5\ O_2 = 4\ NO + 6\ H_2O$$
$$SO_2 + I_2 + 2\ H_2O = 2\ HI + H_2SO_4$$
$$Al_2O_3 + 2\ NaOH + 3\ H_2O = 2\ Na[Al(OH)_4]$$
$$C_6H_{12}O_6 = 2\ C_2H_5OH + 2\ CO_2$$
$$MnO_4^- + 8\ H^+ + 5\ Fe^{2+} = Mn^{2+} + 4\ H_2O + 5\ Fe^{3+}$$

Students in this situation either try to memorise these equations by rote learning, or develop their own right or wrong balancing strategies.

Balancing strategies

There are several techniques available for balancing chemical equations. The simplest variant is the so-called balancing by inspection, which is a trial and error method. It is not widely known, that two logical algorithms can be deduced for balancing chemical equations by inspection *i.e.* the chain rule (Tóth, 1997a) and the so called linked sets method (Guo, 1997). Other balancing methods use the concept of oxidation numbers. Among these one can mention the method of changes in oxidation numbers and the ion-electron half reaction method and they are the most widely known balancing methods for chemical equations used by chemical text books, too. The third group contains purely mathematical methods *i.e.* algebraic method, matrix method and computerised equation balancing programs.

The two logical algorithms of balancing by inspection are not widely known or taught in schools but because of their simplicity one can expect that they may show up among students' balancing strategies so it is advisable to review their theoretical background and evaluate their efficiency as a strategy for balancing chemical equations.

Balancing chemical equations by inspection algorithms

The rules of the *chain method* is that

(i) balancing should be started using a symbol which is present in only one formula on each side of the equation; and

(ii) it should be continued with a symbol which is present only in one formula whose coefficient is not yet known (Tóth, 1997a).

For example balancing the equation

$$HI + HIO_3 \rightarrow I_2 + H_2O$$

can be started only with O

$$HI + 1\ HIO_3 \rightarrow I_2 + 3\ H_2O$$

and it should be continued using H

$$5\ HI + 1\ HIO_3 \rightarrow I_2 + 3\ H_2O$$

and finally it should be finished with I

$$5\ HI + 1\ HIO_3 = 3\ I_2 + 3\ H_2O$$

The balancing chain is: $O \rightarrow H \rightarrow I$.

The rules of the *linked sets method* could be described as

(i) first balance the equation in any symbols that appear only once on each side of the equation; then

(ii) separate two different linked sets involving formulae balanced with respect to each other in one or more symbols; and finally

(iii) by using the symbols that occur in both linked sets one should balance the two sets with respect to each other (Guo, 1997).

For example the equation of

$$NH_3 + O_2 \rightarrow H_2O + N_2$$

first should be balanced for both N and O

$$2\ NH_3 + 1\ O_2 \rightarrow 2\ H_2O + 1\ N_2$$

Then we write two linked sets, one for the N-containing formulas

$$2\ NH_3 \rightarrow 1\ N_2$$

and one for the O-containing formulas

$$1\ O_2 \rightarrow 2\ H_2O$$

Finally the two linked sets can be coupled using the common H. As number of H decreases by six in the first linked set and increases by four in the second one the first equation should be multiplied by two and the second one should be multiplied by three and then we should add them to have the reaction equation balanced for H, too.

$$4\ NH_3 + 3\ O_2 = 6\ H_2O + 2\ N_2$$

(We can sign this balancing strategy in a short form as follows: N-H-O, where the balanced symbols in the linked sets stand on the right and left sides, while the common symbol stands between them.)

Evaluation of efficiency of most important balancing methods

We have investigated the efficiency of the three most important methods for balancing chemical equation *i.e.* (i) chain rule, (ii) linked sets method and (iii) usage of changes of oxidation numbers in balancing chemical equations abundant in Hungarian elementary and high school chemistry textbooks as well as in another text book published for English speaking students (Ebbing: General Chemistry).

It was concluded that using both chain rule and linked sets method it should be possible to balance any chemical equation. In the case of the chain rule one should introduce one or two unknown coefficient in 8% or 10% of the cases of the balanced equations (Tóth, 1997a). This means that 90-92% of textbook reaction equations can be easily balanced using the chain rule alone. In case of the linked sets method this ratio is much lower *i.e.* 27-37%. There is a certain 'trick', the so-called formula doubling, which makes the strategy applicable in most cases (Guo, 1997). The change of oxidation number can be applied only in case of simple redox equations *i.e* when only one oxidation and one reduction process can be separated which meant 71-74% of the studied cases. The strategy fails in case of non-redox reactions and can be applied using a special aid for balancing so called double redox reactions, like for example $CaC_2 + 3\ CO = 4\ C + CaCO_3$ (Cardinali et al., 1994; Giomini et al., 1995; Ludwig, 1996; Tóth, 1997b).

THE AIMS OF THE STUDY

In this study we have tried to answer the following questions:

1. Do Hungarian students develop their own balancing strategy before learning oxidation number method?
2. If they do, what is this strategy like, and
3. what types of systematic error occur in balancing.
4. How often and how effectively do Hungarian students use the oxidation number method in balancing redox equations?

RESEARCH METHODOLOGY

Hungarian high school students' equation balancing strategies and their errors (including so called 'random' errors and 'systematic' errors as defined by Kousathana *et al*., 2002) were studied in written tests and oral interviews. Students were asked to balance redox equations, which contained formulas for all starting materials and that of all products, and only stoichiometric coefficients were missing. As they were not discussed in the textbooks used in primary and secondary levels, these skeletal equations were probably unfamiliar for the students. Four parallel written tests were used. Each of them contained the same items in different random distribution. Teachers volunteered for the investigation were asked to supervise the work of the students during the written tests. The written tests were evaluated by pinpointing the balancing strategy used, it's efficiency, and the most typical wrong answers were collected. Only wrong answers, which produced at least 10% of all wrong answers, were considered to be typical and suitable for further evaluation. Three consecutive studies were performed.

Written test N° 1

Hungarian students in grade 9, age of 14-15 years were evaluated how they balance chemical equations after two years of chemistry learning. These students were taught how to write chemical equations and their meaning explained but no balancing methods were provided for them. Altogether 968 students from different types of schools participated in the survey, which 424 studied in secondary grammar schools, 366 in secondary vocational schools and 178 in trade schools after finishing their elementary school studies. Students were asked to balance 3 redox equations within 15 minutes in this written test.

Written test N° 2

Balancing strategies of secondary grammar school students were studied at the beginning of grade 10-12, age of 15-18. These students had already studied chemistry for 3-5 years and all of them had been taught the concept of oxidation numbers and its usage in balancing redox equations. Altogether 242 students of a good middle level secondary grammar school in Debrecen, Hungary participated. 59 students were from grade 10, 86 from grade 11 and 97 from grade 12. Students had to solve two written tests within 45 minutes each. One of the test contained 12 redox equations of different complexity while the other 18.

Interview

Students of grade 11-12 who prepare for their entrance examination and intended to continue their studies at universities were asked to balance a few redox equations in an oral interview and they were asked to explain their balancing strategy in a few words, too. Altogether 10 students participated in this survey from secondary grammar schools of Debrecen and neighbouring towns. None of them were participated in written tests. Students were interviewed individually at the University of Debrecen.

RESULTS AND DISCUSSION

Results of written test N° 1

Tables 1 and 2 show the most interesting results of written test No. 1. One can conclude that the main reaction balancing strategy in case of students finishing elementary schools is the trial and error method which results in good or wrong solutions depending on the complexity of formulas in the reaction equation and values of stoichiometric coefficients. (Question mark means that in some cases equation balancing method could not be identified unambiguously because students wrote down only the good coefficients but there were no signs how this correct solution was achieved. These attempts, which could not be identified, were categorised in all cases as trial and error method.) It was clear from the written answers that a significant portion of students *i.e.* 19% and 16% balanced the equations using the logic similar to the chain rule. In these cases the success rate is rather good, for example in the case of Equation 2, when the chain rule gave immediately the smallest integer coefficients it is 84%, while in case of Equation 1 the moderate success rate *i.e.* 51% is the consequence that the chain rule gave fractional number (3/2) as coefficient of O_2. We've found examples of application of linked sets method for Equation 1, although in small portion (6%) and with very low success rate (16%). Equation 2 belongs to that group of problems which can be solved only by using the technique of formula doubling trick so it is clear why no students had used this strategy.

The tables contain the most frequent erroneous solutions, too. (In this case the frequency means to the total number of erroneous solutions). In case of equation 1 only one faulty solution type could be identified which is connected to the application of the chain rule. In this case students made a mistake in the final step when the question is determination of coefficient of O_2. They were disturbed by the result that the coefficient is a fractional number and so they simply changed it an integer. Erroneous solutions for equation 2 were also connected to the application of the chain rule as students started the balancing correctly with O but later they had forgotten that coefficient of HIO_3 was considered to be 1, since they did not write it down explicitly. Then in the second step they calculated the 6 H with the wrong combination of the two formulae on the left side.

Results of written test N° 2

In this survey we have studied equation balancing strategies of students of secondary grammar schools who had been taught the concept of oxidation numbers in case of redox equations.

Tables 3 and 4 show the results for equations which can be balanced using any of the three mentioned algorithms. One can see that only 1 or 2 students had tried to use the method based on the concept of oxidation numbers. The most fruitful strategy turned out to be the trial and error method. The majority of students used this strategy for Equation 4. It is worth pointing out the efficiency of chain rule and its relatively high usage. The significant difference in the frequency for equations 3 and 4, 45% and 16%, respectively, is a consequence of the fact that balancing equation 3 can be started using any of the symbols. However, Equation 4 can be balanced only by starting the balancing with N. In case of equation 3 the same typical error was observed which was mentioned in case of equation 1, *i.e.* several students had difficulty in finding the correct coefficient for O_2 when it is a fractional number. It was observed for both equations, that students tried to apply strategies similar to the linked sets method and could reach only the first step. They balanced the equation for every symbol which appears only in one formula at both sides of the equation. This type of error was responsible for 37% and 46% of the wrong solutions in case of Equations 3 and 4, respectively. Several students have the faulty idea that balancing of chemical equation has been finished when there are coefficients for all formulae.

Equations in tables 5 and 6 can not be balanced easily using the linked sets method. This explains why none of the students had chosen this method. The number of students trying to use the concept of oxidation numbers is still negligible. In the case of equation 5 the most frequently and most efficiently applied strategy is the chain rule. There seem to be two reasons for this. The equation can be balanced by starting with either C or S while balancing Equation 6 can be started only with C. On the other hand in these cases the chain rule results the smallest integer coefficients directly. It is a very common mistake, that number of symbols appearing in both formulae on the right side of the equation *i.e.* O in equation 5 and Cl or H in equation 6, is added as if their coefficient would be 1 and coefficient for formulae at the left side, O_2 and Cl_2, respectively, is determined accordingly. The final result is a typical faulty solution with abundance of 21% in which students added number of O at the right side as if coefficient for both CO_2 and SO_2 would be 1 which results a wrong coefficient of 2 for O_2. Finally they changed the fixed but not written coefficient for SO_2 to balance the equation for S.

It was especially interesting to study balancing strategies for equations which can not be easily balanced using either the chain rule or the linked sets method. In such cases the most powerful method of balancing is based on the changes of oxidation numbers. However, as it can be seen from tables 7-9 only a few students had tried to apply this method with very limited success rate. The number of students who gave up and did not try any strategy had increased dramatically in case of these difficult problems. The others had tried the trial and error method almost exclusively with moderate success in case of equation 7 and with surprisingly high efficiency in case of equation 8. The high success rate of 61% for equation 8 is a result of the typical wrong strategy discussed earlier in case of equations 5 and 6: the coefficients for KI, $NaNO_2$ and H_2SO_4 were calculated from the coefficients of KNO_3 and Na_2SO_4 by supposing if the later were 1. Only 4 students could balance the Equation 9. The problem with Equation 9 was that the four unknown coefficients are different and relatively high numbers, which gave difficulties in trial and error strategies. The same wrong balancing strategy had occurred in case of equation 7, too, and students incorrectly believed that coefficient for all formulae on the left side is 1. Finally coefficients of formulae on the right side was determined in 17% by adding number of H and in 40% by adding the number of N. The reason of the quite frequent *i.e.* 36% of wrong solution in case of equation 9 that students first balanced the reaction equation for H and then for N, too, by changing coefficients of NO_2 and N_2O. They got four coefficients but they did not realise that the balance for O was wrong.

These results clearly show that students in this school prefer the inspection methods (mainly as trial and error) to applying oxidation numbers. However, we can assume that this is characteristic of all Hungarian students, because in another study we observed similar results in case of 12th grade students from a top quality Hungarian high school. Among 102 12th graders only 1 student used the oxidation number method for balancing redox equations like Equation 1 and 2, most of them (~80%) used trial and error with excellent success rate (>90%).

Results of the interview

During the interviews we tried to support our finding based on the written answers for the background of the wrong balancing strategy, *i.e.* students often think that there is coefficient 1 in front of the formulae in the skeletal equations. Table 10 shows some equations balanced by this typical wrong strategy. When students were asked to explain their balancing method in a few words, they answered: '… as altogether there are 2 sulphur atoms / 2 nitrogen atoms / 4 chlorine atoms / 3 nitrogen atoms / 3 iodine atoms at the right side of the equation so at the left side we should have 2 molecules of sulphuric acid / 2 molecules of nitric acid / 2 molecules of chlorine / 3 molecules of nitric acid / 3 iodine ions …' Note, that this wrong strategy sometimes works and gives correct solution (see the first three equations in table 10).

CONCLUSIONS AND IMPLICATIONS

We can conclude the results of our studies among Hungarian high school students as follows:

1. Most redox equation can be balanced without using the oxidation numbers by applying the balancing strategies based on simple inspection.
2. Efficiency of different balancing methods highly depends on the equation in question. There are equations which can be easily balanced using the chain rule while for other equations linked sets method or changes of oxidation numbers gave the simplest solution.
3. Hungarian students definitely prefer balancing strategy by inspection rather than applying oxidation numbers.
4. Trial and error method is the first choice of students' balancing strategies but there are examples for application of chain rule and linked sets method.
5. There are special balancing errors connected to certain equation balancing strategies. In case of the chain rule the biggest problem is the fractional number as coefficient. The main problem with the linked sets method is that students do not know the final step *i.e.* coupling the two linked sets using the common symbol should be performed. In these cases a serious error occurs, too, *i.e.* when we have coefficients for all compounds then the equation has already been balanced. For all strate-

gies, but especially in case of the trial and error method, systematic errors can occur because coefficient 1 is not written down explicitly. Students often consider that there are coefficient 1's for formulae in the unbalanced equation. This leads to a wrong balancing strategy that was often observed in writing and verified during the interview. Another source of systematic errors is that coefficient 1 is not written down during balancing either and later students had changed this fixed but not marked coefficient.

Based on our studies the following suggestions can be concluded for the everyday teaching practice:

1. Teachers should be well aware of the various possible strategies of balancing chemical equations as well as students' expected strategies and their common errors.
2. Students should be trained to write down coefficient 1, too, and in this way a very important source of systematic errors could be eliminated.
3. As students develop and apply their own balancing methods teachers must be aware of that and adapt their teaching to build on the natural tendency for students to use trial and error.
4. It is also important to realise that these balancing techniques are parallel methods all of which have their own limitations and advantages.

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Table 1.
Frequency, success rate and typical incorrect answer of grade 9 students' strategies in balancing equation 1

$4\ \mathbf{NH_3} + 3\ \mathbf{O_2} = 6\ \mathbf{H_2O} + 2\ \mathbf{N_2}$

Balancing method	Frequency	(Success rate)
Oxidation number	-	(-)
Chain method	19%	(51%)
Linked sets	6%	(16%)
Trial-and-error (?)	71%	(53%)
No answer	4%	
Total		(48%)
Typical incorrect answer	*Frequency*	
$2\ NH_3 + x\ O_2$ (=) $3\ H_2O + 1\ N_2$ *(where x = 1 or 2)*	*17%*	

Table 2.
Frequency, success rate and typical incorrect answer of grade 9 students' strategies in balancing equation 2

$5\ \mathbf{HI} + \mathbf{HIO_3} = 3\ \mathbf{I_2} + 3\ \mathbf{H_2O}$

Balancing method	Frequency	(Success rate)
Oxidation number	-	(-)
Chain method	16%	(84%)
Linked sets	-	(-)
Trial-and-error (?)	72%	(27%)
No answer	12%	
Total		(33%)
Typical incorrect answer	Frequency	
$x\ HI + (6-x)\ HIO_3$ (=) $3\ I_2 + 3\ H_2O$ *(where x = 1, 2, 3 or 4)*	*10%*	

Table 3.
Frequency, success rate and typical incorrect answer of grade 10-12 students' strategies in balancing equation 3

$4\ \mathbf{NH_3} + 3\ \mathbf{O_2} = 6\ \mathbf{H_2O} + 2\ \mathbf{N_2}$

Balancing method	Frequency	(Success rate)
Oxidation number	1%	(0%)
Chain method	45%	(79%)
Linked sets	9%	(14%)
Trial-and-error (?)	39%	(88%)
No answer	6%	
Total		(71%)
Typical incorrect answer	Frequency	
$2\ NH_3 + x\ O_2$ (=) $3\ H_2O + 1\ N_2$ (where x = 1 or 2)	*37%*	
$2\ NH_3 + 1\ O_2$ (=) $2\ H_2O + 1\ N_2$	*26%*	

Table 4.
Frequency, success rate and typical incorrect answer of grade 10-12 students' strategies in balancing equation 4

$2\ \mathbf{HN_3} + 5\ \mathbf{H_2S} = 5\ \mathbf{S} + 3\ \mathbf{N_2H_4}$

Balancing method	Frequency	(Success rate)
Oxidation number	1%	(50%)
Chain method	16%	(59%)
Linked sets	19%	(20%)
Trial-and-error (?)	56%	(82%)
No answer	8%	
Total		(60%)
Typical incorrect answer	Frequency	
$2\ HN_3 + x\ H_2S$ (=) $x\ S + 3\ N_2H_4$ (where x = 1, 2 or 3)	*46%*	

Table 5.
Frequency, success rate and typical incorrect answer of grade 10-12 students' strategies in balancing equation 5

$\mathbf{CS_2} + 3\ \mathbf{O_2} = \mathbf{CO_2} + 2\ \mathbf{SO_2}$

Balancing method	Frequency	(Success rate)
Oxidation number	1%	(100%)
Chain method	71%	(81%)
Linked sets	-	(-)
Trial-and-error (?)	26%	(48%)
No answer	2%	
Total		(70%)
Typical incorrect answer	Frequency	
$1\ CS_2 + 2\ O_2$ (=) $1\ CO_2 + 1\ SO_2$	*15%*	
$1\ CS_2 + 2\ O_2$ (=) $1\ CO_2 + 2\ SO_2$	*21%*	

Table 6.
Frequency, success rate and typical incorrect answer of grade 10-12 students' strategies in balancing equation 6

$\mathbf{CH_4} + 3\ \mathbf{Cl_2} = \mathbf{CHCl_3} + 3\ \mathbf{HCl}$

Balancing method	Frequency	(Success rate)
Oxidation number	1%	(50%)
Chain method	31%	(83%)
Linked sets	-	(-)
Trial-and-error (?)	55%	(38%)
No answer	13%	
Total		(48%)
Typical incorrect answer	Frequency	
$1\ CH_4 + 2\ Cl_2$ (=) $1\ CHCl_3 + 1\ HCl$	*20%*	
$1\ CH_4 + 4\ Cl_2$ (=) $2\ CHCl_3 + 2\ HCl$	*10%*	

Table 7.
Frequency, success rate and typical incorrect answer of grade 10-12 students' strategies in balancing equation 7

$\mathbf{HN_3} + 5\ \mathbf{NH_3} = 4\ \mathbf{N_2H_4}$

Balancing method	Frequency	(Success rate)
Oxidation number	2%	(0%)
Chain method	-	(-)
Linked sets	-	(-)
Trial-and-error	66%	(30%)
No answer	32%	
Total		(20%)
Typical incorrect answer	Frequency	
$1\ HN_3 + 1\ NH_3$ (=) $1\ N_2H_4$	*17%*	
$1\ HN_3 + 1\ NH_3$ (=) $2\ N_2H_4$	*40%*	

Table 8.
Frequency and success rate of grade 10-12 students' strategies in balancing equation 8

$$2\ KI + 2\ NaNO_2 + 2\ H_2SO_4 = K_2SO_4 + Na_2SO_4 + I_2 + 2\ NO + 2\ H_2O$$

Balancing method	Frequency	(Success rate)
Oxidation number	1%	(33%)
Chain method	-	(-)
Linked sets	-	(-)
Trial-and-error	78%	(61%)
No answer	21%	
Total		(48%)

Table 9.
Frequency, success rate and typical incorrect answer of grade 10-12 students' strategies in balancing equation 9

$$6\ \mathbf{NH_3} + 8\ \mathbf{NO_2} = 7\ \mathbf{N_2O} + 9\ \mathbf{H_2O}$$

Balancing method	Frequency	(Success rate)
Oxidation number	2%	(0%)
Chain method	-	(-)
Linked sets	-	(-)
Trial-and-error	69%	(2%)
No answer	29%	
Total		(2%)

Typical incorrect answer	Frequency
$2\ NH_3 + 2\ NO_2\ (=)\ 2\ N_2O + 3\ H_2O$	*36%*

Table 10.
Some answers as results of the typical wrong balancing strategy of grade 11-12 students observed during the interviews

$$Cu + 2\ H_2SO_4 = CuSO_4 + SO_2 + 2\ H_2O$$
$$Ag + 2\ HNO_3 = AgNO_3 + NO_2 + H_2O$$
$$2\ NO_2 + H_2O = HNO_3 + HNO_2$$
$$CH_4 + 2\ Cl_2\ (=)\ CHCl_3 + HCl$$
$$Cu + 3\ HNO_3\ (=)\ Cu(NO_3)_2 + NO_2 + H_2O$$
$$Cu^{2+} + 3\ I^-\ (=)\ CuI + I_2$$

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