fore, use the formula $s/\sqrt{n}$ to estimate the standard error (BLAND MARTIN, 2000), where s and n are the standard deviation and size of the sample. The estimate is referred to as the standard error of the mean.

The mean and standard error are often written as mean ± standard error. However, as pointed out by BLAND (BLAND MARTIN, 2000), the common expression would be rather misleading in that the true value may be up to two standard errors from the mean with reasonable probability. The standard error is often confused with the standard deviation (DAWSON *at all* 2000). The standard deviation is concerned with the variability of samples, but the standard error is used to measure the precision of estimates. Furthermore, the population mean is estimated to lie somewhere in the interval between these limits, which is called confidence interval in statistics. In the language of statistics mean ± 1.96 standard error, there is 95% confident that the mean lies between the ± 1.96 standard error limits.

CONCLUSIONS

From the above discussion, the expression of mean ± standard error is far from the definition of the measurement ± uncertainty (URONE 2001). The standard error of mean should not be treated as the uncertainty, even though they are frequently expressed in the same format. According to the definition of standard error of mean to rewrite Professor Schwartz's words, it should be read as "…later calculated the standard error of the mean as 0.012g. There is 95% confidence that the mean lies between the 2.47 ± 0.0235g limits".

The standard error of mean was treated as the gold standard to propagate significant figures of the mean value (SCHWART LOWELL 1985, PARRATT 1961). However, this article reviews the definition of the standard error of mean in statistics and finds that maybe the common expression causes the misunderstanding (BLAND MARTIN, 2000). Moreover, the newly published textbooks in physics and chemistry do not adopt the method of standard error of mean dealing with the significant figure of the mean value.

Any mathematical manipulation, such as calculating the mean value for a group of measurements, certainly could not increase accuracy of experimental values, but it can increase the confidence that the true answer is within a particular range. Therefore, propagating significant figures of the mean value by the standard error of mean is not recommended since it is difficult to apply appropriately.

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Hungarian secondary school students' strategies in solving stoichiometric problems

Estrategias de estudiantes húngaros de escuela secundaria para resolver problemas estequiométricos

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Abstract

A random sample of 750 out of 2954 Hungarian secondary school students (grade 7 to 11, aged 13-17) from 17 schools were participated in a paper-and-pencil test with free-response problem on the composition of binary compounds. In this study the following research questions were investigated: (1) whether Hungarian students – similar to the German high school students – also created their own strategy in solving simple stoichiometric problems, or they used the algorithmic methods learned at school, and (2) how the students' strategies changed during the education. We found that contrary to German high school students, Hungarian secondary school students applied the strategies learned at school (the mole method and the proportionality method) in stoichiometric calculations. The success and the ratio of the mole method to the proportionality method increased with the age of the students. Three possible interpretations of the contradiction results are discussed.

Key words*: stoichiometry, problem-solving strategies, composition of binary compounds*

Resumen

Una muestra aleatoria de 750 entre 2.954 estudiantes húngaros de la escuela (grado de 7 a 11, y edad 13-17) participaron en una prueba de papel y lápiz con un problema de respuesta libre sobre la composición de sustancias binarias. En este estudio se investigaron las preguntas siguientes: (1) si los estudiantes húngaros son similares a los estudiantes alemanes de escuela secundaria y pueden crear su propia estrategia para resolver problemas simples de estequiometría, o usan los métodos algorítmicos aprendidos en la escuela, y (2) cómo los estudiantes cambiaron las estrategias durante la educación. Se encontró que al contrario de los estudiantes alemanes, los estudiantes húngaros aplicaron las estrategias aprendidas en la escuela (los métodos de mol y de reglas de tres) en los cálculos estequiométricos. Los logros y la proporción del método de mol al método de reglas de tres aumentan con la edad de los estudiantes. Se discuten tres posibles interpretaciones de los resultados contradictorios.

Palabras clave*: estequiométria, estrategias para resolver problemas, composición de sustancias binarias*

INTRODUCTION

Research shows that the problem-solving strategy a student applies depends on different factors. SCHMIDT (1994, 1997) reported that the high school students in Germany successfully used their own strategy in solving simple stoichiometric problems, but tended to use algorithmic methods in case of difficult problems. In balancing chemical equations we found (TÓTH, 2004) that Hungarian high school students created their own balancing strategy (mainly the trial-and-error) before learning the oxidation number method at school, and they stuck to their own strategies of low efficiency even in case of complicated redox equations.

In this study we investigated the questions:

1. whether Hungarian students - similar to the German high school students - also created their own strategy in solving simple stoichiometric problems, or they used the algorithmic methods learned at school, and
2. how the students' strategies changed during the education.

In this survey we used paper-and-pencil test with free-response problem on the composition of binary compounds similar to those developed by SCHMIDT (1992, 1994, 1997):

'How many grams of carbon are there in 96 g MgC_2? Write down your solution. $A_r(Mg) = 24$; $A_r(C) = 12$'

The data were collected at the end of the school year of 2002/2003. A random sample of 750 out of 2954 Hungarian secondary school students (grade 7 to 11, age 13 to 17) from 17 schools participated in the test. (The 7th to 10th graders have 2 lessons of chemistry per week, but only a few percentages of the students have chemistry lessons at 11th grade.) The female/male ratio was 1,58.

RESULTS AND DISCUSSION

As it is known from Schmidt's work (Schmidt, 1994, 1997), there are different strategies in solving stoichiometric problems like the above.

Strategy 1 (mole method):

1. Calculate the molar mass of the compound:
   $M(MgC_2)$ = 48 g/mol.
2. Calculate the amount of substance of the compound:
   $n(MgC_2)$ = 96 g / (48 g/mol) = 2 mol.
3. Calculate the amount of substance of the element whose mass is requested:
   $n(C) = 2\ n(MgC_2)$ = 4 mol
4. Calculate the mass of the element:
   m(C) = (4 mol) . (12 g/mol) = 48 g.

Strategy 2 (proportionality method):

1. Calculate the molar mass of the compound:
   $M(MgC_2)$ = 48 g/mol.
2. Formulate the ratio between masses and molar masses:
   $M(MgC_2)/2M(C) = m(MgC_2)/m(C)$
   (48 g/mol)/(2.12 g/mol) = 96 g/m(C)
3. Calculate the mass requested:
   m(C) = (96 g) . (2.12 g/mol) / (48 g/mol) = 48 g.

Strategy 3 (logical method):

1. Formulate the ratio of the molar masses:
   M(Mg): M(C) = 24: 12
2. Identify the mass ratio by comparing the molar mass ratio with the amount of substance ratio:
   M(Mg): M(C) = 2: 1 while n(Mg): n(C) = 1: 2,
   therefore m(Mg): m(C) = 1: 1
3. Split up the mass of the compound according to the ratio of masses:
   98 g MgC_2 = 48 g Mg + 48 g C.

Strategy 4 (factor-label method):

x g C = (96 g MgC_2) × [(1 mol MgC_2) / (48 g/mol)] × [(2 mol C) / (1 mol MgC_2)] × [(12 g C) / (1 mol C)] = 48 g C

(This is not a widely known method in Europe, however it is the most popular strategy in the US).

Table 1. **Results of the test on stoichiometric problem solving**

Students	N[a]	Success	Str 1[a]	Str 2[a]	Str 3[a]	Unknown[a]	No resp[a]
Grade 7	171	26%	23%[b] (41%)[c] 46%[d]	13%[b] (36%)[c] 73%[d]	2%[b] (7%)[c] 75%[d]	13%[b] (16%)[c] 32%[d]	49%
Grade 8	166	36%	23%[b] (45%)[c] 79%[d]	16%[b] (32%)[c] 73%[d]	2%[b] (7%)[c] 100%[d]	18%[b] (17%)[c] 33%[d]	44%
Grade 9	142	47%	35%[b] (66%)[c] 90%[d]	15%[b] (19%)[c] 62%[d]	3%[b] (7%)[c] 100%[d]	11%[b] (7%)[c] 31%[d]	36%
Grade 10	144	56%	42%[b] (62%)[c] 83%[d]	16%[b] (24%)[c] 83%[d]	4%[b] (6%)[c] 83%[d]	13%[b] (8%)[c] 33%[d]	26%
Grade 11	127	47%	39%[b] (63%)[c] 78%[d]	8%[b] (17%)[c] 100%[d]	5%[b] (10%)[c] 100%[d]	9%[b] (10%)[c] 50%[d]	39%
Total	750	41%	31%[o] (57%)[c] 77%[d]	14%[b] (25%)[c] 75%[d]	3%[b] (7%)[c] 92%[d]	13%[b] (11%)[c] 35%[d]	39%

a N: Number of students participated in the test.
a Str 1: Strategy 1 (mole method).
a Str 2: Strategy 2 (proportionality method).
a Str 3: Strategy 3 (logical method).
a Unknown: Unidentified or mixed method.
a No resp: No response.
b Number of students applied this strategy/Total number of students - in percentage.
c Number of students applied this strategy/Number of students who were successful in solving the problem – in percentage.
d Success of this strategy.

Table 1 shows the main results of our study.

We can establish that the percentage of the students giving correct answer ('Success') increases and the percentage of the students giving no answer ('No resp') decreases with the grade except of the grade 11. (The recession in success observed in case of the 11th graders can be explained by the lack of chemistry lessons.) Obviously, Hungarian students prefer the strategies taught at school, especially strategy 1 ('Str 1'), the mole method. Note that among 34 Hungarian chemistry textbooks and activity books 24 discusses the solution of stoichiometric problems: 11 show the mole method (strategy 1), 3 show the proportionality method (strategy 2), and 10 contain both of these strategies. The ratio of the students applying strategy 3 ('Str 3'), the so called logical method, is very low both as compared to the total number of the students and in comparison with the number of students giving correct answer. The ratio of the number of students applying strategy 1 to the number of students working with strategy 2 increases markedly with the grade indicating that students learning more and more chemistry prefer the mole method even in solving simple stoichiometric problems. These findings are totally contrasted with the Schmidt's results. He found (Schmidt, 1994) that high school students in Germany preferably used strategy 3 (50-60% of the students giving correct answer) in solving simple stoichiometric problems similar to the problem in our test, and only a few percentage (2-15%) of the students applied the mole method (strategy 1).

Unfortunately, in case of 9-18% students gave unidentified or mixed methods. The data in Table 1 also show that the success of the known strategies (especially the success of strategy 3) is much higher than that of the unidentified methods. We found some differences between the females and males in the applied strategy. Females applied strategy 2 more often than males. (The female/male ratio is 2,16.) Males have relatively higher portion in using strategy 1 and the unidentified strategies than females. (The female/male ratio is 1,24 and 1, resp.) According to the c2-test these differences between the females and males in the applied strategy are statistically correct (p = 0,05).

Finally, we do not let two findings pass. Some of the students (13%) explained this problem as the chemical reaction between magnesium and carbon. They wrote down the chemical equation and tried to calculate the mass of carbon needed to the formation of 96 g MgC_2. In our opinion this is a consequence of the fact that Hungarian chemistry teachers and the textbooks suggest writing chemical equation as the starting point of the solution of chemical problems. The other problem is that 14% of the students (23% of the students giving answer) used 'C_2' as a formula of carbon in MgC_2. These students regarded 'C_2' as an entity. They answered that 96 g MgC_2 contained '48 g of C_2' or - in a few case - '48 g of C_2, and 48:2 = 24 g of C'. Fortunately, the ratio of the students giving these types of solutions decreased to one half or one-third from 7th grade to 11th grade.

CONCLUSIONS

We found that contrary to German high school students, Hungarian secondary school students apply the strategies learned at school (the mole method and the proportionality method) in stoichiometric calculations. The success and the (strategy 1): (strategy 2) ratio increases with the age (and the education) of the students.

Our results raise the question: What is the reason that our findings are totally contrasted with earlier results obtained in Germany? The answering this question needs further research, but we point out three possible reasons:

The problem in our test differs to the original problem developed by Schmidt in the mass of MgC_2. Schmidt suggested 6 g. He writes: 'For the total mass of the compound a number was chosen that can easily be divided into two parts according to the ratio of the molar masses, the masses and the amounts of substance.' (Schmidt, 1994). However this total mass doesn't give simple number for the amount of substance (6/48 = 0,125) and this fact can make the mole method more difficult. Therefore we used 96 g, because it also can easily be divided into two parts, and the amount of substance can easily be calculated from this mass.

As we noted earlier, in Hungary the mole method is the suggested strategy contrary to the Germany, where the proportionality method is advised (Schmidt, 1994). It is noticeable that the proportionality method (strategy 2) is closer to the logical method (strategy 3) than the mole method (strategy 1).

The grade 11, 12 and 13 German high school students having 3 or 5 lessons of chemistry per week probably are much more familiar with solving chemistry problems than our grade 7, 8, 9, 10 and 11 students learning chemistry in 2 lessons per week. Probable experts can develop their logical methods easier than novices, who usually are looking for algorithms to solve a problem. If this is so, we can suggest an implication for classroom practice: it would be worth trying the method suggested by Schmidt (1997) for introducing stoichiometric problem solving and improving students' problem-solving thinking.

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Football: effect of increasing goal size on the number of goals
Fútbol: efecto del incremento de tamaño de las porterías en el número de goles

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Abstract

Here is an example of elastic collision to be presented in a contextual manner to a physics class. Namely, the effect of increasing goal mouth size on the number of goals scored in a football match is discussed, considering elastic collisions of the ball with the posts. The results are compared with data taken from the Spanish Professional League, that show a high number of shots-to-post. Surprisingly, there is a direct correlation of the increase in goal mouth area with the increase of goals.

Key words*: physics, elastic collision, soccer, goal size.*

Resumen

Se presenta un ejemplo de colisión elástica para ser mostrado de un modo informal en una clase de física. En particular se discute el efecto que tendría un incremento del tamaño de las porterías en el número de goles de los partidos de fútbol, tras considerar que las colisiones del balón con los postes son elásticas. Los resultados se comparan con datos obtenidos de la Liga de Fútbol Profesional de España, que muestran un número muy alto de balones al poste. Sorprendentemente, hay una correlación directa entre el incremento de área de la portería y el incremento de goles.

Palabras clave: física, colisión elástica, fútbol, tamaño de portería.

The popularity of some sports is a good resource to attract students' interest. In this way, the creation of scientific attitudes in the analysis of any aspect of daily life, or the introduction of specific concepts of any particular subject, are more effective if they are incorporated in non-conventional or even surprising examples. Here is presented one such example, involving football, in which the concept of elastic collision as well as the quantification of curious facts, are made.

Football is the most popular sport in Europe, and a major area of economic activity: in Spain, for example, figures from the Professional Football League suggest that the football industry accounts for 1% of Gross National Product. In the rest of the world, football's influence is increasing apace. Given such significant repercussions, it is interesting to consider whether it might be possible to improve the game's entertainment value on the basis of analyses of play situations (Oudejans *et al*., 2000), or even by introducing changes in the rules. Clearly, goals are the crowning moments of a match. Typically however, the number of goals scored is small, and not surprisingly many matches end as 0-0 draws. One proposal for increasing the number of goals has been to increase the size of the goal mouth. In an attempt to quantify the likely consequences of such a measure, summary statistics for First Division matches in the Spanish Professional League, 2000-2001 season (Guía Marca, 2002), have been analysed. The total number of shots-at-goal hitting the post (and not going in) was 231. Given that the total number of goals in this period was 1095, in 380 matches (2.88 goals per match), expressing shots-to-post as a percentage of goals scored gives 21.1%, a higher proportion than expected given the small frontal area of the posts (which are at most 12 cm thick). The effect of varying goal size on number of goals can be estimated as follows (under the simplifying assumptions that all shots are perpendicular to the goal line and that the ball's collisions with the cylindrical posts are perfectly elastic): if the goal mouth were expanded laterally and vertically by one ball-diameter (rules require ball diameter to be between 21.6 and 22.3 cm) plus 7 cm, then all current shots-to-post would be goals (whether without hitting the new posts or after hitting them). The 7-cm increase is necessary to ensure that the ball changes direction by at least 90 degrees after the collision, even in the least favourable case. Of course, further refinements of the model might be considered (relating to shot angles, shot probabilities across the goal area, and new play situations created after rebounds from the posts of the enlarged goal mouth); however, the simple model is probably sufficient. Increasing goal size in such way means an increase from 2.44 m x 7.32 m (17.86 m^2) to 2.73 m x 7.90 m (21.57 m^2). This percentage increase in area, 20.8%, is almost equal to the above-noted increase in goals (21.1%), which is rather surprising. Taking into account that the increase in goals would occur at the edges of the goal, less accessible to the goalkeeper, in principle the probability of goal in the "new" area should be higher than in the central areas where the keeper spends more of his time.

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