PATTERN APPROACH TO CHEMISTRY EDUCATION

Abordagem padrão para a educação em química

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ABSTRACT

The literature has shown that secondary as well as college students face challenges with chemical topics such as mole, molar mass, stoichiometry and concentrations (MSC). However, to solve MSC problems the only math structure requirement is y = bx. Profound analysis of student's written solutions has revealed that although the numerical solutions are correct, they are not chemically plausible, showing lack of understanding about the chemical representations. The goal of this work is to present an approach based on patterns, employed by computer programming educators to recognize patterns, to enhance student's perceptions of chemical processes and representations as they deal with MSC questions. Only four patterns were identified and defined by the author: counting, converting, transforming and concentration. Those patterns interconnect daily life macroscopic problems, easily understood by the students, to MSC sub-microscopic ones and, consequently decrease the cognitive load in the learning process.

Keywords: chemistry education, problem solving, pattern

INTRODUCTION

Students usually face difficulties to solve numerical chemical problems because it is not only a matter of manipulating numbers and getting the correct answer at the end, but it also demands an intense cognitive process of representing the chemical abstract notation (CARDELLINI, 2014; RALPH and LEWIS, 2019; RAVIOLO, FARRÉ and SCHROH, 2021). Secondary as well as college students struggles to learn topics such as mol, molar mass, stoichiometry, and concentrations (MSC). Insufficient comprehension about MSC hinders the advance over more complex topics such as thermochemistry, chemical kinetics and equilibrium. Furthermore, the MSC forms the basis to understand and perform any laboratorial quantitative activity.

We often reason the students don't learn to solve chemical problems because they lack basic math. However, the only mathematical structure used to solve a variety of problems related to basic chemistry is simple and is described by Eq. 1. It seems students face difficulties to grasp the meaning of this three-term equation that represents a powerful tool applied extensively by any kind of worker on daily basis.

$$y = bx \qquad (1)$$

The y term is an unknown quantity, while the x term is a known quantity, and the b term is a proportional relationship between x and y quantities. Each term has unit, and it changes according to the context in which the equation is employed. The unit of b is a ratiobetween y and x units. A simple example of its application: what is the weight of 10 cows given the average weight of each cow is 450 kg? In this question we identify x as 10 cows and extract b from "the average weight of each cow is 450 kg", y is the unknown quantity, the weight of ten cows. The solution is given by Eq. 2.

$$y = \frac{450\ \text{kg}}{1\ \text{cow}}\ 10\ \text{cows} = 4500\ \text{Kg} \quad (2)$$

We can consider there is no distinction between the plural and singular forms of writing the units, so the words cows and cow cancel out. As one can see, the equation is short and simple as well as its interpretation. It is worth to further comment about the b term. As it is a ratio of y to x, so the information contained in the denominator is a one-unit value, which means that a unit change in x translates into a b change in y. For example, each cow that is brought to a farm will increase the weight of cow in that farm by 450 kg. We also can think of the b term as an operator. When it acts upon x quantity, it converts (or transforms) x into y quantity. In the previous example, it converted the information about the number of cows into the information about the mass of cow (10 cows to 4500 kg of cows).

The linear equation (eq. 1) is simple and easy to understand. If you ask an adult who never studied chemistry but was trained on basic math operations, "Given that 1 mol of water weights 18 g, what is the weight of 2 mols of water?", you will probably get the right answer because most of the adults have been using that equation for long time, often under the name "simple rule of three". Even if you make a strange question to someone else like "what is the amount of churupuro in 3 pororo of jutela, given that 10 siricu of churupuro contains 2 pororo of jutela? (Hint: the answer will be in siricu unit)", you might collect the correct answer: 15 siricu of churupuro. The linear equation is at the core of solving any MSC problem as pointed out in Figure 1. It is also a pattern encountered in daily life problems. But why is it so misused by students in the MSC context?

One of the answers might come from the former strange question along with the work of Ralph and Lewis (2019).The authors collected data of previous math scores and based on them classified undergraduate chemistry students as at risk and non-at-risk. Afterwards, they analyzed the student's written solutions for stoichiometric problems and identified a different group of students inside of the non-at-risk group (who have good math scores). They mentioned that this sub-group presented correct solutions for stoichiometric problems, however their solutions were not chemically plausible and lacked understanding of the chemical representations and notations. Although they had algebraical skills that enabled them to get the right answer, they did not show comprehension about the chemistry's concepts. They are the kinds that would read the stoichiometric questions as if they were the strange question and solve them correctly without grasping any chemical meaning.

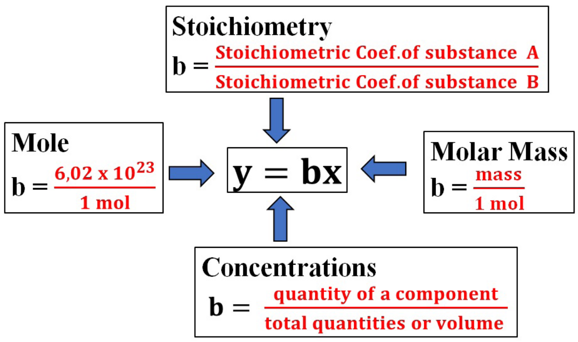

Figure 1. The MSC main ratios. Source: elaborated by the author (2024)

The work of Ralph and Lewis (2019) has certainly brought deeper understanding about the challenges faced by the students to learn MSC. It has shown us it is not only a matter of mathematical skills. Not only algebraic ability to manipulate numbers, but also the deep comprehension about the chemical representations, is required to interpret and solve chemistry numerical problems. The linear equation is the building block to solve any MSC problem. This equation relates all the variables or quantities in MSC. One can apply it blindly and yet gets the right answer at the end. Therefore, focusing only on the practice of that equation is not enough. We must devise instructions that takes in the chemical representations.

Mathematical skills are surely correlated to chemistry learning, however, as mentioned by Scott (2012): "If the underlying mathematics is not fully grasped and only understood through an algorithmic approach then one could expect to see students encountering difficulties with chemical calculations". Raviolo, Farré and Schroh (2021) evaluated undergraduate students' performance on a qualitative conceptual questionnaire about molarity. The questionnaire consisted of 6 questions which demanded only qualitative proportional reasoning without the need to perform calculations. The results showed that only 17% of the students answered all 6 questions correctly and most of the wrong answers were in questions that demanded inverse proportionality reasoning. Since they also interviewed some of the participants to examine their adopted strategies and misconceptions, it was revealed that some of them tried to reach the right answer through unnecessary numerical calculations. These students showed a blind numerical algorithmic approach without deep conceptual understanding about the relationships among the variables, n (amount of solute), V (volume of the solution) and M (molarity). These studies corroborate that only a mathematical algorithm approach is not enough to fully comprehend MSC. Meanings must be added to them. The pattern approach herein devised, as will be clear soon, tackles this issue once it adds extra meanings extracted from daily life context to MSC.

Cardellini (2014) in his work mentioned that the abstract nature of the chemical representations can mean to the student a significant increase of the mental load in the working memory. The capacity to differentiate atoms, molecules and chemical formulas is not rapidly acquired by the students. In MSC problems besides the need to sort out the chemical entities, there is the requirement to discern the concept of the quantities such as mass, volume, and amount of substance. Gulacar, Eilks and Bowman (2014) separated undergraduate chemistry students into two groups, lower and higher achieving, according to their stoichiometric scores on a pretest. Afterwards they evaluated them again through cognitive and stoichiometric tests. The results on the latter showed lower achieving students had more arithmetic and unit errors, besides showing lack of understanding about the mole concept. The analysis also revealed the higher achieving students can solve complex problems because they are able to link subproblems while the lower achieving ones are not. Therefore, it looks like some group of students need a more proximal approach with a differentiated instructional material.

The author of the present article usually uses analogies to make the students recognize the patterns that connects daily problems to chemical ones, since all of them at their core use the same math structure, the linear equation (Eq. 1). The daily life questions aim at paralleling the macroscopic representations to the sub-microscopic MSC representations so that the students figure out the meaning of the chemical notations. However, this way of teaching has not been applied under a structured frame. The daily questions have only been used as random examples during works on MSC problems. To improve students' learning, the author proposes an instructional material based on pattern recognition, an approach that has been used by the computer programming educators. No work that relates this way of teaching to chemistry education has been found. Therefore, this work might represent an alternative to chemistry education, specifically to MSC topics.

PATTERNS AND CHEMISTRY

Computer programming beginners face challenges to learn the skill of instructing electronic machines to perform a task. The programming educators often mention the reasons are the lack of abstraction, logical thinking, and mathematical skills (LEAL, 2014). To overcome the learning challenges, they have been adopting the pattern pedagogy. In this model the educator searches patterns present in computational problems. Then the educator names and describes them according to a criterion in order to make students understand their structure (CLANCY and LINN, 1999; MULLER, HABERMAN and AVERBUCH, 2004). Afterwards students are trained through problem-solving to recognize them. The approach helps the novice programmers to acquire repertoire to develop their own solutions and expertise.

As they face a new problem, experienced programmers can recognize its structure and figure out many possible strategies to solve it. However, the novice has not stored any tool yet to perform the implementation of a solution. Hence in order to acquire expertise they must be trained to recognize the structure of many problems and master small pieces of algorithm that are commonly used to solve them. These small pieces are building blocks, patterns, and their different combinations might represent a solution for a given problem. The programming educator classifies, describes and names the patterns to enhance student's comprehension. For example, in the work of Clancy and Linn (1999) it was mentioned two possibilities to stablish a set of patterns for the loop algorithm, one based on descriptive rules and other on constructive rules. The programming teacher presents the beginners to the patterns and elaborates a spectrum of examples and problems to increase their ability to recognize and apply them in a broad context.

The idea of pattern was lightly conveyed at the introduction when the author pondered about the linear equation (Eq. 1) as a recipe to solve a spectrum of daily and chemical problems. This equation is a mathematical pattern used to solve problems in many different fields of knowledge. However, as it was pointed out formerly, the ability to manipulate this equation is not enough to competently solve MSC problems. The barriers encountered by the secondary and undergraduate students are more complex. Besides mathematics, there is the lack of understanding about the chemical representations. This interpretation led the author to break MSC problems into representative patterns based on the relation between the variables used in MSC, in other words, based on the ratio that represents the b operator. Four patterns were identified, described and named as counting, converting, transforming and concentration. The patterns were set up in a way that it makes possible to link daily life to MSC problems. The study of them aims to improve the understanding of the chemical representations since they allow the MSC sub- microscopic representations to parallel to daily life macroscopic ones.

Leal (2014) also aimed at providing a more proximal approach when he promoted a lighter activity in which the students had to identify programming patterns (selection and repetition patterns) in concrete games created and played by them. The results showed the activity improved their ability to recognize the patterns in the computer programming context. The model proposed herein similarly provides an approach to MSC that is closer to students' initial knowledge. The description of the patterns was devised to allow the creation of specific daily life problems that catch MSC concept. Thus, working firstly on daily life context using the pattern reasoning might decrease the cognitive load demanded by MSC, allowing a more proximal approach to acquire competence in solving chemical problems.

In a not recent article Sweller and Cooper (1985) evaluated the effect of worked examples on secondary students' ability to solve algebra problems. The findings suggested emphasizing worked examples in the acquisition phase increase students' competency to deal with algebra operations. They reasoned about these findings based on expert-novice distinctions. What differentiates an expert from a novice chess player is not the short-memory term, instead, difference resides on the fact that the former got more memory of realistic chess positions. The authors said the expert can recognize, due to experience, a greater number of possible configurations and, by this way, can better evaluate the next move. Sweller and Cooper called them schemas. So, in order to turn novices into experts it is necessary to increase their schemas, and in algebra, according to the author, this is more rapidly and effectively achieved by worked examples. Cardellini (2014) initially collected frustrating undergraduate students' performance on stoichiometric tests and asked for Sweller's advice. Following his orientations on worked examples, Caderllini taught his students and they returned significant improvements. Their work was not about pattern pedagogy but is certainly related to it since Sweller and Cooper' schemas were defined as mental constructs that allow patterns or configurations to be recognized as associated to a previous learned category. Herein, the author devised four patterns that are applicable in two contexts represented by daily life (DL) and MSC, thus this model implies the creation of multiple connections that enrich students' schemas and, consequently, leads them from novice to expert level.

CHEMICAL QUANTITIES

Before the introduction of the pattern approach it is worth to briefly describe the main quantities used in MSC, since literature has pointed out even chemistry teacher might present misconceptions (FURIÓ et al., 2000) and herein the patterns has been described according to relations among them.

Mass, length and amount of substance are all fundamental physical quantities. Volume is obtained from the length. So, mass, volume and amount of substance are quantities often used in MSC problems. Their SI units are kilograms, cubic meter and mole (symbols: kg, m^3 and mol, respectively). As previously mentioned there might be misconceptions about them. For example, when the term mole (in Latin big mass) was initially introduced it had the meaning of mass and then evolved, due to the atomic-molecular theory (FURIÓ et. al., 2000), to the current definition: "The mole, symbol mol, is the SI unit of amount of substance. One mole contains exactly $6.022\ 140\ 76 \times 10^{23}$ elementary entities. This number is the fixed numerical value of the Avogadro constant, N_A, when expressed in mol^{-1}, and is called the Avogadro number" (MARQUARDT et al., 2018).

As seen in the definition mole is a unit of a quantity called amount of substance that serves to count particles, or chemical entities. Therefore, it does carry neither the meaning of mass nor the meaning of number of chemical entities. The same way the mass cannot be called number of kilograms, amount of substance cannot be called number of moles. It must be clear that mole (symbol mol) is a unit of the quantity amount of substance. The terms amount of substance (n), mass (m), volume (V) and number of elementary entities (N) are distinct. The quantity amount of substance is linearly related to the others by the molar mass (M), molar volume (V_m) and the Avogadro's constant (N_A), respectively. It's important to distinguish them so that the student will neither misunderstand nor misplace them as solving MSC problems. The reader is also invited to read Fang, Hart and Clarke's article (2014)which proposes a concept map to better understand the mole concept and the relationships involved in it.

THE PATTERN APPROACH IN MSC

According to the type of problems usually encountered in MSC, the author identified four patterns that links DL problems to MSC ones. As the linear equation (Eq. 1) is the unique math structure demanded to solve MSC problems, the patterns were differentiated based on the description of the b operator which is a ratio between two variables. The patterns were devised as a tool to facilitate students' ability to interconnect macroscopic to sub-microscopic representations, it was necessary to describe them in broader way, out of the chemistry specificities.

The mastering of the four patterns, applied firstly on DL context, is intended to increase the students' abstraction as they are presented to MSC concept and problems afterwards. Therefore, the pattern approach must be divided into two parts: mastering the patterns in daily life problems and applying them as MSC advances. These two parts could be taught one after another or in parallel.

Each pattern has a name, a description, a function, a representative problem, the key ratio of the representative problem and a similarity with MSC topic (or subtopic). The representative problem aims at making the first association between the pattern's description and the context in which it is applied. The representative problem solution involves only one step of calculation which means the linear equation (Eq. 1) is used only once. Here follows the complete characterization of each pattern.

Pattern's name: counting
Description: b operator is a ratio between two countable (discrete) quantities of different objects.
Function: it determines a countable information about an object from the knowledge of other.
Representative problem (RP1): You counted 80 cow's feet on a truck. How many cows are in the truck?
Key ratio: $\frac{1\ \text{cow}}{4\text{feet}}$
MSC topic: chemical formula and stoichiometric coefficients.

Pattern's name: converting
Description: b operator is a ratio between two different ways (unit) of expressing the same quantity of an object.
Function: it changes units.
Representative problem (RP2): How many eggs are there in 2.5 dozen?
Key ratio: $\frac{12\ \text{entity}}{1\ \text{dozen}}$
MSC topic: conversion of unities as dealing with quantities such as amount of substance.

Pattern's name: transforming
Description: b operator is a ratio between two different quantities of the same object, one of them must beuncountable (continuous).
Function: it transforms a quantity into another.
Representative problem (RP3): how many grains are in a 1000 g-package of beans given each grain weights 0.25 g?
Key ratio: $\frac{0.25\ \text{g}}{1\ \text{bean}}$
MSC topic: molar mass definition.

Pattern's name: concentration
Description: b operator is a ratio between two quantities, one must convey the information about a component and the other the information about the whole or space. The components do not interact to a form a separated entity.
Function: it determines information of the component from the whole and vice-versa.
Representative problem (RP4): a school are going to open a branch in other city and 400 newcomers are expected to enroll in. If the principals plan to get 20 students per classroom, how many classrooms will the branch school have?
Key ratio: $\frac{1\ \text{class room}}{20\ \text{students}}$
MSC Topic: concentrations such as molar concentration, mass percent and molar fraction.

PATTERN'S GOALS

The four patterns were conceived in a general way to encompass DL context therefore they surely do not capture all the details involved in MSC calculation, but they certainly support it. To improve the reader's understanding about this approach, the author presents four MSC problems (MSCP) that are similar to the representative problems (RP) presented in the charts, respectively.

MSCP1: In a cylinder there are $3x10^{21}$ carbon atoms, what is the amount of butane molecules? Molecular formula of butane: C_4H_{10}.
Ratio: $\frac{1C_4H_{10}}{4C}$

MSCP2: What is the number of molecules in 0.2 mol of ethanol?
Ratio: $\frac{6.02\ x\ 10^{23}\ \text{molecules}}{1\ \text{mol of ethanol}}$

MSCP3: What is the amount of water in 3.6 g of this substance, given the molar mass of water is 18 g / mol?
Ratio: $\frac{1\ \text{mol of water}}{18\ \text{g of water}}$

MSCP4: What volume of a 0.20 M NaOH aqueous solution contains 2 mols of solute?
Ratio: $\frac{1\ \text{L of solution}}{0.2\ \text{mols NaOH}}$

Bellow each MSCP there is the characterizing ratio which is used in the calculation and is the part associated to the pattern description. Table 1 parallels RPs, which are related to DL context, to MSCPs. In each line, through a careful comparison between the problems associated to the first and the third columns and having in mind each pattern description, it is possible to note the resemblance. The patterns conceptually link DL to MSC problems. Furthermore, it is clear the patterns take a great fraction of MSC concept into DL context. So, mastering the patterns in DL context before introduction to MSC, might increase the students' cognitive capacity to recognize the chemical representations involved in MSC.

Table 1. Representative and MSC problems.

Representative Problem	Pattern	MSC problem
RP1	counting	MSCP1
RP2	converting	MSCP2
RP3	transforming	MSCP3
RP4	concentration	MSCP4

Source: elaborated by the author (2024).

The patterns are building blocks present in a variety of DL and MSC problems. It is possible to create DL problems that carries features of MSC by taking into consideration the patterns. The connection between MSC and DL context is made through the patterns and is intended to improve students' conception in MSC. Thus, the main objective of the associated DL problems is to decrease the cognitive load related to MSC alone and redistribute it in two parts: DL and MSC context.

Each problem might carry more than one pattern and by this way requires more than one calculation step. The following DL problems were created by jointly taking the patterns and MSC problems into consideration:

DLP1: How many dozens of tires are required to assemble 600 four-tire cars?
Ratios: $\frac{4\text{tires}}{1\text{car}}$ **and** $\frac{1\text{dozen}}{12\text{cars}}$

DLP2: How many rods are there in 3 kg of welding rods? Each 2 rods weight 50 g.
Ratios: $\frac{1000\text{ g}}{1\text{ kg}}$ **and** $\frac{2\text{ rods}}{50\text{ g}}$

DLP3: How many chickens are necessary to kill to fill up a bag with 1000 g of drumsticks? Weight of a drumstick on average is 100 g.
Ratios: $\frac{1\text{ drumstick}}{100\text{ g}}$ **and** $\frac{1\text{ chicken}}{2\text{ drumstick}}$

DLP4: A farm has 5 hog pens. In each of them there are 10 hogs. If the farmer decides to kill 3 pens, how much ham will he get? Suppose the average weight of a ham is 12 kg.
Ratios: $\frac{10\text{ hogs}}{1\text{ pen}}$, $\frac{2\text{ hams}}{1\text{ hog}}$ **and** $\frac{12\text{ kg}}{1\text{ ham}}$

The following MSC problems pair up with the previous DL problems. As shown in table 2 each DLP-MSCP pair shares the same set of patterns.

MSCP5: What is the amount of nitrogen atoms in 3.6 x 10^{23} hydroxychloroquine ($C_{18}H_{26}ClN_3O$)?
Ratio: $\frac{3\text{ N}}{1\ C_{18}H_{26}ClN_3O}$ **and** $\frac{1\text{ mol}}{6.02 \times 10^{23}}$

MSCP6: What is the amount of water in 4,8 kg of water? Water molar mass is 18 g / mol.
Ratio: $\frac{1000\text{ g}}{1\text{ kg}}$ **and** $\frac{1\text{ mol } H_2O}{18\text{ g}}$

MSCP7: In a sample of glucose ($C_6H_{12}O_6$) there are 4.8 g of carbon. What is the amount of glucose in the sample?
Carbon molar mass is 12 g / mol.
Ratio: $\frac{1\text{ mol C}}{12\text{ g C}}$ **and** $\frac{1\text{ mol } C_6H_{12}O_6}{6\text{ mol C}}$

MSCP8: What is the mass of sodium atoms in 0.2 L of a 2 M NaCl aqueous solution? Na molar mass = 23 g / mol.
Ratio: $\frac{2\text{ molNaCl}}{1\text{Lsolution}}$, $\frac{1\text{molNa}}{1\text{molNaCl}}$ **and** $\frac{23\text{gNa}}{1\text{molNa}}$

Table 2. Daily life and MSC problems.

DL problem	Patterns	MSC problem
DLP1	counting and converting	MSCP5
DLP2	converting and transforming	MSCP6
DLP3	transforming and counting	MSCP7
DLP4	concentration, counting and transforming	MSCP8

Source: elaborated by the author (2024).

In general, when teaching worked examples that involves numerical calculations, it is important to justify and rationalize each step so that the students get the meaning of the whole process. The patterns are a brief way for it since they provide a concise description of each step. For example, the DLP3 is solved in two steps:

$$N_d = \frac{1\text{ drumstick}}{100\text{ g}} \times 1000\text{ g} = 10\text{ drumsticks (transforming)} \quad (3)$$

$$N_{ch} = \frac{1\text{ chicken}}{2\text{ drumstick}} \times 10\text{ drumstick} = 10\text{ chickens (counting)} \quad (4)$$

The pattern in the first step is transforming and, in the second step, counting. Surely the words transforming and counting are too formal for high school students. Therefore expressions 3 and 4 should be presented as "the bean grain problem" and "the cow problem", respectively. It is hoped that as the students master attributing each step to the corresponding pattern, it will increase their perception about the nature of the variables and the relationships between them and, consequently, their cognitive ability to abstract strategies to solve MSC problems. For example, the MSCP7 problem, that lies to the right in the third column is also solved by sequentially using "the bean grain" and "the cow" patterns:

$$N_C = \frac{1\text{ mol C}}{12\text{ g}} \times 4.8\text{ g} = 0.4\text{ mol C (transforming)} \quad (5)$$

$$N_{glu} = \frac{1\text{ mol } C_6H_{12}O_6}{6\text{ mol C}} \times 0.4\text{ mol C} = 0.067\text{ mol } C_6H_{12}O_6\text{ (counting)} \quad (6)$$

The patterns highlighted the resemblance between DL and MSC concept present in each calculation step. As cited in the work of Gulgacar, Eilks and Bowman (2014), lower achieving students faces difficulties to deal with complex stoichiometric problems because they cannot link the underlying subproblems. They are able only to solve simple exercises which involves only one calculation step. So, to help lower achieving students it is important to look for alternative approaches and the model proposed herein might be one of them. The DL context makes it easier for students to learn about the patterns. Herein each pattern might be seen as a subproblem. Thus, working on problems with increasing levels of complexity first on DL context will probably smooth their way into the task of linking MSC subproblems. Furthermore, as they become experienced, they might present a one-shot solution for two-pattern problems (or for more-than-one pattern problems), for example DLP3 and MSCP7 could be solved by this way:

$$N_{chicken} = \frac{1 \text{ chicken}}{2 \text{ drumstick}} \text{ x } \frac{1 \text{ drumstick}}{100 \text{ g}} \text{ x } 1000 \text{ g} = 5 \text{ chickens}$$

$$n_{glucose} = \frac{1 \text{ mol } C_6H_{12}O_6}{6 \text{ mol } C} \text{ x } \frac{1 \text{ mol } C}{12 \text{ g } C} \text{ x } 4.8 \text{ g } C = 0.067 \text{ mol } C_6H_{12}O_6$$

The goal of the counting pattern is to increase students' awareness of the numerical relationships between counting variables, such as the ratios between the quantities that represents amount of substance or number of chemical entities. The author expects the students to ponder the same way a cow is constituted of 4 legs, 2 feet, 1 tail, 2 ears or 2 horns, an ethanol molecule is constituted of 2 carbon, 6 hydrogen and 1 oxygen atoms. At the end, they must acknowledge the counting pattern in MSC is as easy as determining the number of cows given the number of their feet or vice-versa. The counting pattern is intended to tackle another frequent student mistake. Although stoichiometric coefficients in a chemical equation represent molar ratios (Figure 1), it is not rare students incorrectly relates them to mass data (SCOTT, 2012), so the counting pattern might also help them realize molar ratios are associated with amount of substance or number of chemical species, not mass.

The same quantity of an object may be expressed in different ways and the conversion of one way into another does not change its meaning. For example, instead of expressing an information as 0.001 g it is sometimes convenientto write 1 mg. The converting pattern aims mainly at making the students understand that mol is the unity of amount of substance that serves to count particles (FURIÓ et al., 2000) and they must notice all the calculations with mole definition is as simple as converting the counts of eggs to dozen.

Transforming pattern was mainly designed because of the molar mass concept. The goal of the transforming pattern is to highlight the relationship between a countable (discrete) and an uncountable (continuous) variable. The students must notice we are not usually able to directly determine the amount of chemical specie, but we can indirectly count them in the laboratory as we weight, because the ratio (or operator) called molar mass allow us to do that. That's similar to determine the number of grains in a package of beans: we can weight some small number of grains, determine the ratio between mass and number of grains, and finally estimate the number of grains in a whole package that informs the mass of beans it contains. Students usually confuses density and common concentration in MSC, because both have the same unit. However, the transforming pattern may help set them apart, because density is a ratio between two different quantities, mass and volume, of the same object, and in the concentration pattern the ratio is between two quantities of different objects, a component and the whole.

As mentioned, the concentration pattern also describes the ratio between two different quantities, but they must highlight the idea of something contained by something broader. It differs from the counting patterns as the components must not interact to form a separated entity as in the case of cow's feet / cow and carbon atom / ethanol molecule. Its goal is to increase students' awareness about the relationship between a quantity that represents the solute and a quantity that represents the solution. As pointed out by Raviolo, Farré and Schroh (2021) it is necessary to understand the relationships among the variables when it comes to concentration concept. According to them it is important to create problems that emphasize qualitative reasoning so that students get the concept of it rather than only the solving algorithm. So, variations of the representative problem should be worked on by the students. After the students have solved RP4, then it could be added the following examples: 1) what would be the effect on the ratio amount of students / number of classrooms, if the number of newcomers increase to 600? 2) what would be the effect on this ratio if the number of students is kept to 400 and the school expanded the number of classrooms? 3) Three schools have equal number of students, and each classroom in the schools are the same size, so the school with the lower number of classrooms has? A) student-to-classroom ratio equals to 15, B) student-to-classroom ratio equals to 30 or C) student-to-classroom ratio equals to 20. The last question might represent a cognitive load. Similar questions could be employed as teaching about concentrations in MSC.

After the presentation of the patterns to the students, initially they may not be able to recognize them in a set of DL problems. It is worth to mention the implementation of patterns for secondary students should not be too formal. Instead of the detailed description of the patterns, the introduction could be performed through worked examples and be named after the representative problems. So, counting, converting, transforming and concentration could be translated to cow, eggs, beans and classroom, respectively, so that they would not need to search for each pattern description to recognize a problem. They would rather associate them with the type of representative problem. Hence equations 3 and 4 (or 5 and 6) would be instead attributed to beans and cow patterns, respectively.

The implementation of the proposed approach requires teacher's creativity and expertise. It is possible to create a great spectrum of DL problems associated to MSC, but the teacher must create them restricted by the four selected patterns and sometimes only experienced teacher can abstract the similarity between DL and MSC problems. Nonetheless, it is important to highlight there is the possibility of devising a different set of patterns based on different criteria, other than the b operator of Eq. 1 as herein adopted. Maybe the teacher finds other set of patterns and stablish a different connection to MSC content. It is open for teacher's own perceptions and creativity. Even the students should be open-minded to find their own set of patterns and reflect on them.

POSSIBLE DRAWBACKS AND ADVANTAGES

The model proposed herein might be more time consuming. The chemistry educator might come cross difficulties even at the first phase of working on DL problems, since literature has shown students can lack general proportionality reasoning (RAVIOLO, FARRÉ and SCHROH, 2021). Thus, the chemistry educators might find themselves spending more time with mathematics than with chemistry. A novice teacher might find it difficult to abstract the patterns and does not notice the similarities between the DL and MSC problems, so for them the pattern approach might make them feel unable to apply it. The strict following of the proposed model requires the creation of DL examples and problems restricted to the four defined patterns and using quantities commonly present in quantitative chemistry. These problems must be close to students' actual knowledge. So, the creation process isn't easy and might heavily burden the novice chemistry educator.

The MSC topics when directly taught represents a heavy cognitive load. The students have to discern atoms, molecules, mole, molar mass, mass (the m words are usually mistaken one for the other), substances, chemical formula, volume, Avogadro's number, units of those quantities, stoichiometric coefficients and a bunch of relationships among them like molarity, common concentration, mass proportion, density and so on. It takes long time and practice to discern all information and put it in the form of mathematical equations. As the reader observed in tables 1 and 2, MSC concept is present in DL problems. The patterns made DL and MSC problems paired up. They are entangled in each other, sharing parts. Furthermore, they require the same math structure to solve related problems. Thus, the insertion of the practice on DL problems, through pattern recognition, might carries away a fraction of cognitive load associated with MSC alone. Once the students have mastered solving properly created DL problems, they will be in better position to abstract strategies to solve MSC ones. As MSC comes, the major difficulty will be the change of language and symbols because the concept has already been grasped. Figure 2 shows the intended weight withdrawing effect of working firstly with patterns in DL context.

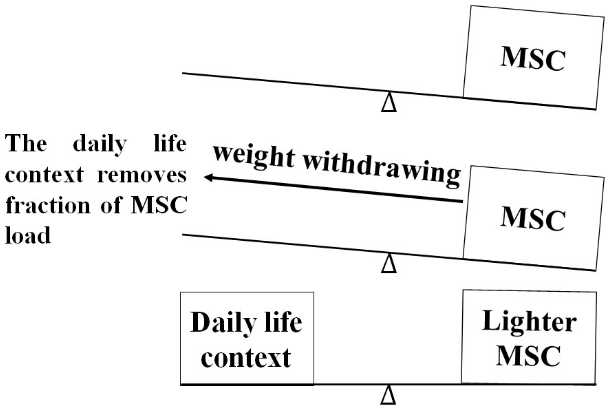

Figure 2. Weight withdrawing effect. Source: elaborated by the author (2024).

CONCLUSIONS

Helping the students recognize the patterns firstly in DL problems might increase their ability to understand and solve MSC problems. However, the mastering of the patterns will lead them to acquire a broader competence, since it will enhance their ability to manipulate the linear equation (Eq. 1) in a vast spectrum of numerical problems. Furthermore, each pattern's definition is not based on specific chemistry terms so that through the patterns the students can match real life problems (macroscopic representations) to MSC problems (chemical sub-microscopic representations), by this way, they can get a better cognitive condition to get into MSC problem solving, not only by employing carelessly the linear equation, but also by recognizing the chemical meaning of each step. Whether the pattern approach will take longer, or whether it is more effective than other conventional models, it is yet unknown, but it is worth a try because MSC topics are chemistry's essentials, and it suggests a sound additional way to meaningfully acquire the problem-solving competence in MSC context. Furthermore, for lower achieving or at-risk students (GULACAR, EILKS and BOWMAN, 2014; RALPH and LEWIS, 2019) the patterns provide a bridge to go from simple-exercise solver to MSC expert.

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