# A tabular approach to titration calculations

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**Titrations are common laboratory exercises in high school and university chemistry courses, because they are easy, relatively inexpensive, and they illustrate a number of fundamental chemical principles. While students have little difficulty with calculations involving a single titration step, there is a significant leap in conceptual difficulty when "scaling-up" to more involved titration calculations with two or more steps. Currently, there is no alternative approach for students who are unable to follow the standard textbook method for titration calculations. This paper presents a new method of setting out the titration calculations, which helps these weaker students to better organize the data. The connection between the new method and current models of learning is discussed to explain why the tabular approach is successful for students who have difficulty following the standard textbook method.**

## Introduction

Titrations are common laboratory exercises in high school and university chemistry courses. They are an excellent teaching aid because they are easy, the equipment is relatively inexpensive, and they illustrate a number of fundamental chemical principles, including stoichiometry, evidence of a reaction through a colour change (i.e., indicator colour change), and (usually) acid-base chemistry. Students with very little laboratory practise can achieve very high levels of precision and accuracy in the titration volumes (error < 1%). It is the simplicity of the equipment and procedure that makes titration a standard procedure in industry. For example, Rymills Winery, in the Coonawarra, showcases its analytical chemistry laboratory as part of its tourist and wine-tasting centre.

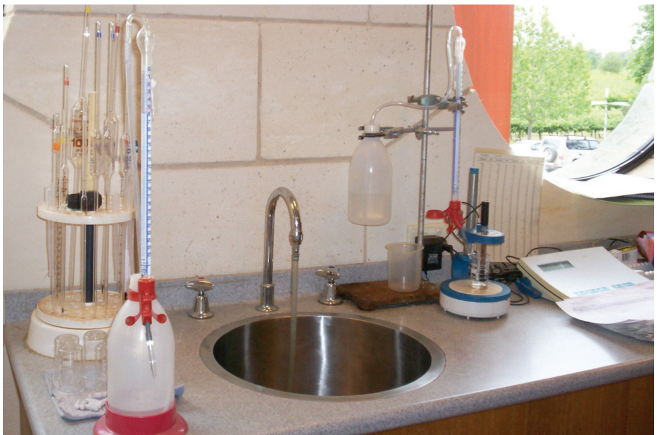

Figure 1: Titration apparati at Rymills Winery, Coonawarra, South Australia. The analytical chemistry laboratory is part of Rymills's tourist and wine-tasting centre.

High school and undergraduate general chemistry textbooks set out sample titration calculations in a linear step-by-step mathematical notation (eg Table I). See Billet and Thorpe (2001), Chang *et al* (2002), Hogendoorn (2007), James *et al* (1999), Jones and Atkins (1999), Masterton and Hurley (2001), Olmsted and Williams (2006), Oxtoby *et al* (1999), Robinson *et al* (1997), Sharwood *et al* (2007), Silberberg (2000), Slade (2005), Taylor *et al* (2007), Timberlake (2007), Whitten *et al* (2000), and Zumdahl and Zumdahl (2000) as representative textbooks. The various steps can include:

- determining the chemical amount (often imprecisely called "number of moles") from the concentration and volume;
- determining the concentration from the chemical amount and volume;
- determining the amount of one reactant from the amount of another reactant through a balanced chemical equation;
- occasionally determining the concentration for a dilution step from the volumes and previous concentration; and
- occasionally determining the concentration for a primary standard from the mass of solute and solution volume.

While students have little difficulty performing a one-step titration calculation, they often have difficulty scaling up the process to multiple-titration calculations such as the 3-step procedure:

1. first preparing a primary standard;
2. standardising a secondary standard by titration against a primary standard; and
3. finally determining the concentration of an "unknown" solution.

Since there are multiple volumes, and solutions, students confuse what quantity needs to be determined at which step, using which formula. The traditional textbook approach (e.g., Table 1) gives no scaffolding to guide novice learners. In particular, the use of Equation 1 is problematic because it is only true for dilutions and does not apply to titrations other than 1:1 stoichiometry, such as that shown in Table 1.

Furthermore, the information is very dense. Students are expected to use a combination of written (i.e., textual) and mathematical reasoning to determine the required quantities; this an additional learning hurdle for students who are weak or lack confidence in mathematics.

| $c_1V_1 = c_2V_2$ | Equation 1 |
|---|---|

First, the amount of $Na_2B_4O_7.10H_2O$ is obtained using its molar mass:

amount of $Na_2B_4O_7.10H_2O$

$$= 4.3747\ \text{g}\ Na_2B_4O_7.10H_2O) \left(\frac{1\ \text{mol}\ Na_2B_4O_7.10H_2O}{381.37\ \text{g}\ Na_2B_4O_7.10H_2O}\right)$$

$= 0.0114710$ mol $Na_2B_4O_7.10H_2O$

Thus the $Na_2B_4O_7$ concentration is:

concentration of $Na_2B_4O_7$

$$= \left(\frac{0.0114710\ \text{mol}\ Na_2B_4O_7}{250.0\ \text{mL solution}}\right)\left(\frac{1000\ \text{mL}}{1\ \text{L}}\right)$$

$= 0.0458840$ mol $L^{-1}$ $Na_2B_4O_7$

We use the volume (20.00 mL) and concentration of $Na_2B_4O_7$ to calculate the amount of $Na_2B_4O_7$ used in the titration:

amount of $Na_2B_4O_7$

$$= \left(\frac{0.0458840\ \text{mol}\ Na_2B_4O_7}{1\ \text{L}}\right)(20.00\ \text{mL})\left(\frac{1\ \text{L}}{1000\ \text{mL}}\right)$$

$= 0.00091768$ mol $Na_2B_4O_7$

The balanced equation for this reaction is:

$2\ HCl\ (aq) + Na_2B_4O_7\ (aq) + 5\ H_2O\ (l) \rightarrow 4\ H_3BO_3\ (aq) + 2\ NaCl\ (aq)$

According to the balanced equation, 1 mol $Na_2B_4O_7$ reacts with 2 mol HCl. Therefore,

amount of HCl

$$= (0.00091768\ \text{mol}\ Na_2B_4O_7)\left(\frac{2\ \text{mol HCl}}{1\ \text{mol}\ Na_2B_4O_7}\right)$$

$= 0.0018354$ mol HCl

Thus the HCl concentration is:

concentration of HCl

$$= \left(\frac{0.0018354\ \text{mol HCl}}{19.53\ \text{mL solution}}\right)\left(\frac{1000\ \text{mL}}{1\ \text{L}}\right)$$

$= 0.093977$ mol $L^{-1}$ HCl

Table 1: Traditional textbook approach to calculations for an acid-base titration, corresponding to the first half of example 1.

## A New Tabular Approach to Titration Calculations

The tabular approach to titration calculations is illustrated by Table 2—Table 4. Table 2 shows a partly completed titration calculation, illustrating how the student would proceed to determine unknown quantities from known data, while Table 3 and Table 4 show fully completed calculations. The first column describes the experimental procedure, which corresponds to the calculation being performed in that row of the table. The independent quantities in the fundamental relationship, Equation 2, are the headings of the next three columns. Note that the final column (volume) contains space for unit conversions from mL to L.

| *(amount of substance) = (concentration) (Volume)* | Equation 2 |
|---|---|

Each row in the Table corresponds to one step in the experimental procedure. The student must consider what information (volume and either amount or concentration) has been collected or already known for each step (ie incomplete row of the Table), and then to use that information to determine what information will be obtained at the end of the experimental step corresponding with that row. Continuing in this manner, the student constructs the entire Table, row-by-row, during the course of setting out and performing the calculations. As an aid for the reader to understand Tables 2—4, the mathematical "implies" arrows (⇓, ⇒ and ⇐) have been included to show the logical sequence of calculations. The arrows are included here as an aid for the reader and are not given to the student. In practice, the student has to work out this logical progression of using known data to determine unknown quantities.

## Example 1: Acid-Base Titration

First, a primary standard solution of sodium tetraborate decahydrate ($Na_2B_4O_7.10H_2O$; "borax") was prepared by measuring a 4.3747 g sample (weighing by difference) into a 250.0 mL volumetric flask, and making up to the mark with deionised water. Secondly, the borax primary standard is used to standardise an HCl solution. Three 20.00 mL aliquots of this standard solution were titrated with HCl solution using methyl red indicator. Measured titration volumes were 19.58, 19.50, and 19.50 mL. The HCl solution is a secondary standard solution. Finally, the HCl standard solution is used to determine the concentration of a sodium hydroxide solution. Three 20.00 mL aliquots of a sodium hydroxide solution (of unknown concentration) were titrated with the same HCl standard solution using phenolphthalein indicator. Measured titration volumes were 20.44, 20.36, and 20.34 mL. The textbook method applied to just the first two steps is shown in Table 1.

### The Tabular Approach to Titration Calculation (I)

The tabular approach to titration calculations is illustrated by the incomplete Table 2 and the completed Table 3. The third, incomplete row of Table 2 corresponds to the third step in the procedure: using a pipette (known volume) to transfer the borax standard solution into the titration vessel. The verbal (ie word-based) description of the procedural step is the entry in column 1. At this point, there is insufficient information to complete the entry for column 2. Column 3 is the borax concentration, determined from the previous step, has indicated by the down arrow (⇓). Column 4 is the known pipette volume. To complete the current (third) row, the student must determine the amount of borax placed in the titration vessel.

The next (fourth) row corresponds to the next step in the procedure: the titration, for which the student needs a balanced chemical equation (see Table 3). The fifth row, relating to the HCl solution in the burette is then constructed column by column. Again, Column 1 has the verbal description of the procedural step. Column 2 is the amount of HCl, which is known from the reaction stoichiometry (row 4) and the amount of borax (row 3). At *this* point, there would be insufficient information to complete the entry for column 3. Column 4 is the volume corresponding to this step in the procedure: the volume of HCl used. The entire Table is constructed *by the student*, column-by-column, and row-by-row, by determining unknown quantities from known data. Table 3 is the completed calculation.

| | AMOUNT OF SUBSTANCE (*n*) | CONCENTRATION (*c*) | VOLUME (*V*) |
|---|---|---|---|
| *Weighing of borax (Weighing is the only time to use: n = m / Mr)* | $n = \frac{4.3747\ \text{g}}{381.37\ \text{g mol}^{-1}}$ $= 0.011471$ mol ⇓ | Not applicable | Not applicable |
| *Preparation of borax (primary) standard* | 0.011471 mol ⇒ | $c = \frac{0.011471\ \text{mol}}{0.2500\ \text{L}}$ = 0.045884 mol $L^{-1}$ ⇓ | Volumetric flask 250.0 mL = 0.2500 L |
| *Borax in titration vessel for borax-HCl titration* | | ⇐ 0.045884 mol $L^{-1}$ | Pipette 20.00 mL = 0.02000 L |

Note: The mathematical "implies" arrows (⇓, ⇒ and ⇐) are only intended to show the sequence of calculations. They are included here as an aid for the reader. In practise, the student has to work out this logical progression of using known data to determine unknown quantities.

Table 2: An incomplete calculation illustrating the tabular approach for acid-base titration, corresponding to example 1.

| | AMOUNT OF SUBSTANCE (*n*) | CONCENTRATION (*c*) | VOLUME (*V*) |
|---|---|---|---|
| Weighing of borax: only time we use *n = m / Mr* | $n = \frac{4.3747\ \text{g}}{381.37\ \text{g mol}^{-1}}$ $= 0.011471$ mol ⇓ | Not applicable | Not applicable |
| Preparation of borax (primary) standard | 0.011471 mol ⇒ | $c = \frac{0.011471\ \text{mol}}{0.2500\ \text{L}}$ = 0.045884 mol $L^{-1}$ ⇓ | Volumetric flask 250.0mL = 0.2500 L |
| Borax in titration vessel for borax-HCl titration | $n$ = 0.045884 mol $L^{-1}$ x 0.02000 L = 9.1768 x $10^{-4}$ mol ⇓ | ⇐ 0.045884 mol $L^{-1}$ | Pipette 20.00 mL = 0.02000 L |
| Borax-HCl titration | 2 HCl (aq) + $Na_2B_4O_7$ (aq) + 5 $H_2O$ (l) → 4 $H_3BO_3$ (aq) + 2 NaCl (aq) | | |
| HCl in burette for borax-HCl titration | $n_{HCl} = 2\ n_{borax}$ = 2 x 9.1768 x $10^{-4}$ mol = 1.8354 x $10^{-3}$ mol ⇒ | $c = \frac{1.8354 \times 10^{-3}\ \text{mol}}{0.01953\ \text{L}}$ = 0.093977 mol $L^{-1}$ ⇓ | Burette average volume 19.53 mL = 0.01953 L |
| **HCl (secondary) standard** | **0.0940 mol $L^{-1}$** ⇓ | | |
| HCl in burette for NaOH-HCl titration | $n$ = 0.093977 mol $L^{-1}$ x 0.02038 L = 1.9152 $10^{-3}$ mol ⇓ | ⇐ 0.093977 mol $L^{-1}$ | Burette average volume 20.38 mL = 0.02038 L |
| NaOH-HCl titration | HCl (aq) + NaOH (aq) → NaCl (aq) + $H_2O$ (l) | | |
| NaOH in titration vessel for NaOH-HCl titration | $n_{NaOH} = n_{HCl}$ = 1.9152 x $10^{-3}$ mol ⇒ | $c = \frac{1.9152 \times 10^{-3}\ \text{mol}}{0.02000\ \text{L}}$ = 0.095762 mol $L^{-1}$ ⇓ | Pipette 20.00 mL = 0.02000 L |
| **NaOH solution** | **0.0958 mol $L^{-1}$** | | |

Note: The mathematical "implies" arrows (⇓, ⇒ and ⇐) are only intended to show the sequence of calculations. They are included here as an aid for the reader. In practise, the student has to work out this logical progression of using known data to determine unknown quantities.

Table 3: A completed calculation illustrating the tabular approach for acid-base titration, corresponding to example 1.

## EXAMPLE 2: MOHR (PRECIPITATION) TITRATION

The Mohr titration involves the precipitation of $Cl^-$ ions by $Ag^+$ solution. There is no colour change at the equivalence point, when all the $Cl^-$ ions have just been precipitated. Use of a small amount of $CrO_4^{2-}$ produces a distinct colour when excess $Ag^+$ ions form $Ag_2CrO_4$ precipitate. This end point, the first visible colour for $Ag_2CrO_4$ precipitate, is typically 1–3 drops past the equivalence point and will vary from one person to another, depending on individual perception of colour.

A student tested her colour perception by the use of a blank titration. Mixtures of ca. 150 mg calcium carbonate (to simulate the white precipitate of silver chloride), indicator solution (containing $CrO_4^{2-}$) in deionised water were titrated with $AgNO_3$ solution. Measured titration volumes were 0.10, 0.10, and 0.16 mL. These blank values must be used later in the procedure to correct the end point to determine the true equivalence point.

Three 20.00 mL aliquots of 0.062834 mol $L^{-1}$ NaCl (primary standard) solution were titrated with $AgNO_3$ solution using chromate indicator. Measured titration volumes were 24.28, 24.26, and 24.22 mL. A 20.00 mL sample of brackish (salt) water was diluted in a 250.00 mL volumetric flask. Three 20.00 mL aliquots of the (diluted) sample were titrated with the same $AgNO_3$ solution using chromate indicator. It is assumed that the only halide ion present is $Cl^-$. Measured titration volumes were 19.80, 19.90, and 19.86 mL.

### The Tabular Approach to Titration Calculation (II)

The tabular approach is illustrated by the completed Table 4. The organization imposed by the tabular approach is particularly helpful to the students in working *backwards* through the dilution step to recover the concentration of the original brackish water. Note that the final column (volume) contains space for the blank corrections to the titration volumes.

| | AMOUNT OF SUBSTANCE ($n$) | CONCENTRATION ($c$) | VOLUME ($V$) |
|---|---|---|---|
| NaCl in titration vessel for NaCl-$AgNO_3$ (standardization) titration | $n$ = 0.062834 mol $L^{-1}$ x 0.02000 L = 1.2567 x $10^{-3}$ mol $\Downarrow$ | $\Leftarrow$ 0.062834 mol $L^{-1}$ | Pipette 20.00 mL = 0.02000 L |
| NaCl-$AgNO_3$ titration | $\Downarrow$ | $AgNO_3$ (aq) + NaCl (aq) $\rightarrow$ $NaNO_3$ (aq) + AgCl (s) | |
| $AgNO_3$ in burette for NaCl-$AgNO_3$ (standardization) titration | 1.2567 × $10^{-3}$ mol $\Rightarrow$ | $c = \frac{1.2567 \times 10^{-3}\text{ mol}}{0.02413\text{ L}}$ = 0.05208 mol $L^{-1}$ $\Downarrow$ | Burette average volume 24.25 - 0.12 mL = 24.13 mL = 0.02413 L |
| **$AgNO_3$ solution** | | **0.0521 mol $L^{-1}$** $\Downarrow$ | |
| $AgNO_3$ in burette for (dilute brackish water) $Cl^-$-$AgNO_3$ titration | $n$ = 0.05208 mol $L^{-1}$ x 0.01973 L = 1.027 x $10^{-3}$ mol $\Downarrow$ | $\Leftarrow$ 0.05208 mol $L^{-1}$ | Burette average volume 19.85 - 0.12 mL = 19.73 mL = 0.01973 L |
| (dilute brackish water) $Cl^-$-$AgNO_3$ titration | $\Downarrow$ | $AgNO_3$ (aq) + $Cl^-$ (aq) $\rightarrow$ $NO_3^-$ (aq) + AgCl (s) | |
| $Cl^-$ in titration vessel for (dilute brackish water) $Cl^-$-$AgNO_3$ titration | $n_{Cl^-} = n_{AgNO_3}$ = 1.027 x $10^{-3}$ mol $\Rightarrow$ | $c = \frac{1.027 \times 10^{-3}\text{ mol}}{0.0200\text{ L}}$ = 0.05138 mol $L^{-1}$ $\Downarrow$ | Pipette 20.00 mL = 0.02000 L |
| **$Cl^-$ solution (dilute brackish water)** | | **0.0514 mol $L^{-1}$** $\Downarrow$ | |
| $Cl^-$ solution (dilute brackish water) after dilution | $n$ = 0.05138 mol $L^{-1}$ x 0.2500 L = 0.01284 mol $\Downarrow$ | $\Leftarrow$ 0.05138 mol L-1 | Volumetric flask volume 250.0 mL = 0.2500 L |
| $Cl^-$ solution (dilute brackish water) before dilution | 0.01284 mol $\Rightarrow$ | $c = \frac{0.01284\text{ mol}}{0.0200\text{ L}}$ = 0.6422 mol $L^{-1}$ $\Downarrow$ | Pipette 20.00 mL = 0.02000 L |
| **$Cl^-$ solution (brackish water sample)** | | **0.642 mol $L^{-1}$** | |

Note: The mathematical "implies" arrows ($\Downarrow$, $\Rightarrow$ and $\Leftarrow$) are only intended to show the sequence of calculations. They are included here as an aid for the reader. In practise, the student has to work out this logical progression of using known data to determine unknown quantities.

Note: (Equivalence point) = (End point) – (Blank titration volume)
(Average blank titration volume) = (amount needed to see colour) = 0.*120 mL*

Table 4: A completed calculation illustrating the tabular approach for Mohr (preciptation) titration, corresponding to example 2.

## Discussion

Calculations involving a single titration step are a simple problem, as the objective (to find an unknown concentration), the method and the available data (given) are all well defined. This is a routine problem.

There is a leap in conceptual difficulty when "scaling-up" to more involved titration calculations with two or more steps. Although each step in solving the problem consists of a familiar method, the *combination* of the steps is seen to be an ill-defined or unfamiliar method (Johnstone, 1998): which step comes first, and which one next? Although the standard textbook method (eg Table I) is a successful approach for many students, there is a significant number who have difficulty in applying the textbook method to more involved titration calculations. An educational psychology model, which explains the difficulty experienced by students in solving these problems, is the computer analogy for information processing (Bee, 1997; McInerney & McInerney, 1998). Johnstone (1997) has found that novice learners are overwhelmed by about 8 or more items of data. When two or more steps are involved in an extended titration problem, the amount of data has increased – there are 6 titration volumes, 2 average titration volumes, the volume of the volumetric flask and pipette volumes – "overloading" the students' capacity to manipulate data. Consequently, students make one or more of the following procedural mistakes:

- confuse the different volumes in each of the examples and also blank titration volumes in example 2; or
- confuse the solutions, eg confuse the primary standard (eg borax or NaCl) with the secondary standard (eg HCl or $AgNO_3$) concentrations; or
- omit one or more steps in the procedure.

The traditional (or textbook) method requires the student to be able to switch between verbal (word-based) and mathematical (algebraic and numerical) descriptions of the problem (see Table 1 and previously-cited references): this difficulty has been discussed in the context of learning physical chemistry (Lim *et al.*, 2002a, 2002b; Nicoll & Francisco, 2001). The problem is further compounded by difficulties in the recall and transfer of mathematics skills from one context to another (Britton *et al.*, 2007; New *et al.*, 2001; Roberts, 2004). Even though the mathematical skills required are only multiplication and division, the need to set out and perform mathematical operations is a barrier to learning. Furthermore, the calculations in the current textbook method are grounded in the tradition of dimensional analysis, which receives only cursory treatment in some curricula. Bunce (2004) has noted that:

> *"The real problem is not the mathematical manipulations, but rather knowing which numbers to add, subtract, multiply, and divide … Weaker students … can really benefit from seeing and using an explicit approach to problem solving."*

The tabular method proposed in this paper, is such an explicit approach, giving a *structure for organizing the data*, and delineating the steps required for the calculation. The fundamental relationship, Equation 2, between amount of substance, solution volume and concentration is reflected in the columns of the tabular approach, while the use of known information from one step in the procedure to determine unknown information in each step is reflected in the rows of the table.

Note that the IUPAC- recommended "amount" (Mills *et al.*, 1993) has been used in Equation 2 and elsewhere in this paper, in preference to the common textbook terminology "number of moles". For example: mass is a quantity, which is measured in kilograms; the quantity is not "number of kilograms". Likewise the correct quantity is amount, which is measured in moles; the quantity is not "number of moles".

The columns of Table 2—Table 4 enable the students to separate the verbal and mathematical descriptions of the problem. de Bono (1992) has explained that the role of structures is

> *"… to help thinking. The structures lay out a series of steps. We take each step in turn. The steps help to direct our attention and help us to focus on one thing at a time."*

This organization is particularly helpful to the students in working *backwards* through the dilution step to recover the concentration of the original brackish water. In the Mohr titration, it is the dilute solution that has "known" concentration, with the objective of finding the unknown concentration of the concentrated solution. This is a reversal of the common textbook situation, where the concentrated solution always has known concentration. While the organization helps students, they still need to think: Table 2—Table 4 make it clear that the tabular approach is not "plug-and-chug" method as students must decide whether any step is a weighing by difference, preparation of a primary standard, titration, or dilution.

Many textbooks use Equation 1 for dilutions, and advocate it for titrations, without the caveat that is only true for 1:1 stoichiometry. The tabular approach naturally avoids the use of Equation 1, eliminating another potential source of student error.

Each row in the table corresponds with one step in the experimental procedure. The newly determined information on each row carries over into the next step (row) of the procedure. The flow of information shown by the arrows in Table 2—Table 4 follows a logical pattern. Spencer (1861) wrote that "science is organised knowledge": the acquisition of scientific knowledge lies in recognizing trends, similarities, patterns and principles that describe and consolidate disparate data. The use of the tabular format in setting out and performing the titration calculation makes it easier for a student to recognize the logical pattern that underlies any titration procedure, since this logical pattern is represented by a spatial pattern in the flow of information in the table. The recognition of the thought pattern is more difficult for many students when using the traditional method of setting out the calculation (eg., Table I), since there is no equivalent pattern.

The development of what is now the standard textbook method of doing calculations (eg., Benson, 1971; Hamilton & Simpson, 1947) may have been appropriate in the early- to mid-20th century, when the small (ie, elite) group of chemistry students were self-selected to be strong in mathematics. However, one of the aims of a 21st century science education is to developed science-literate citizens, (ACARA, 2011; Goodrum *et al.*, 2001; MCEETYA, 2006) and this means that introductory chemistry must accessible to all students, including those who are weak or not confident in mathematics. Perusal of old chemistry texts, indicates that the only significant advancement in the teaching and learning of titration calculations over the last 100 years has been the change from "gram-molecules" (Simon & Base, 1916), a form of chemical equivalents, to calculations using concentrations and amount of substance. There has been no other advancements since the 1940s calculations (eg, Benson, 1971; Hamilton & Simpson, 1947), or even earlier. Given the variety of students' learning preferences and "intelligences", there is a need for alternatives to the standard textbook method: this paper proposes such an alternative.

As students gain experience with these titration calculations, they will further recognize that the tabular method partitions data into groups related to the first (standardization) titration, the second titration, etc. This is known as *clustering*, which is a successful strategy in student learning (Bee, 1997; McInerney & McInerney, 1998). At this stage, having mastered titration calculations, the students will not require the structure imposed by the tabular approach. Again, to quote de Bono (1992):

> *"There is no magic about these structures and they do not have to be used. They are presented as a matter of convenience. They help to reduce confusion in thinking. They also help with the discipline of thinking."*

The tabular approach helps students master titration calculations, by a spatial organization of data and calculations that corresponds to an organized flow of logic from one step of the titration procedure to the next. Once mastery of the calculations has been achieved, students no longer need to continue using the tabular approach. This tabular approach is not an end in itself, but is a useful aid for many (weaker) students to achieve a learning objective.

## Conclusions

Most students have little or no difficulty with calculations involving a single titration step. However, when they first encounter calculations involving multiple titration steps, a significant number of students are overwhelmed by the apparent complexity of the task, and the seemingly large amount of data to be analysed. A new method, in which students construct a table during the course of setting out and performing the titration calculations, has been presented here. The tabular approach is intended for students who find the textbook method unsuitable. This approach is a structure, which helps the students to organize and analyse the data. The spatial arrangement, of the data and calculations, aids students to recognize the logical pattern inherent in titration calculations.

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