Help students master chemical calculations using adaptive cases?

Joost van den Brink | Institute of Biology Leiden

Universiteit Leiden
The Netherlands

Joost van den Brink

- 2016: assistant-professor at IBL, Institute of Biology Leiden
- 30% scientist on fungal biotechnology and 70% lecturer on:

    - Basic practical training to Bachelor Biology students (year 1; semester 1)
    - Chemistry of life (year 1; semester 1)
    - Microbiology (year 1; semester 1)
    - Biochemistry (year 2; semester 2)
    - Molecular Microbiology (year 2; semester 2)

Bachelor Biology at Leiden University

- Bachelor Biology: ~180 Dutch first year students
- 4x Masters Biology: ~200 Dutch and International students

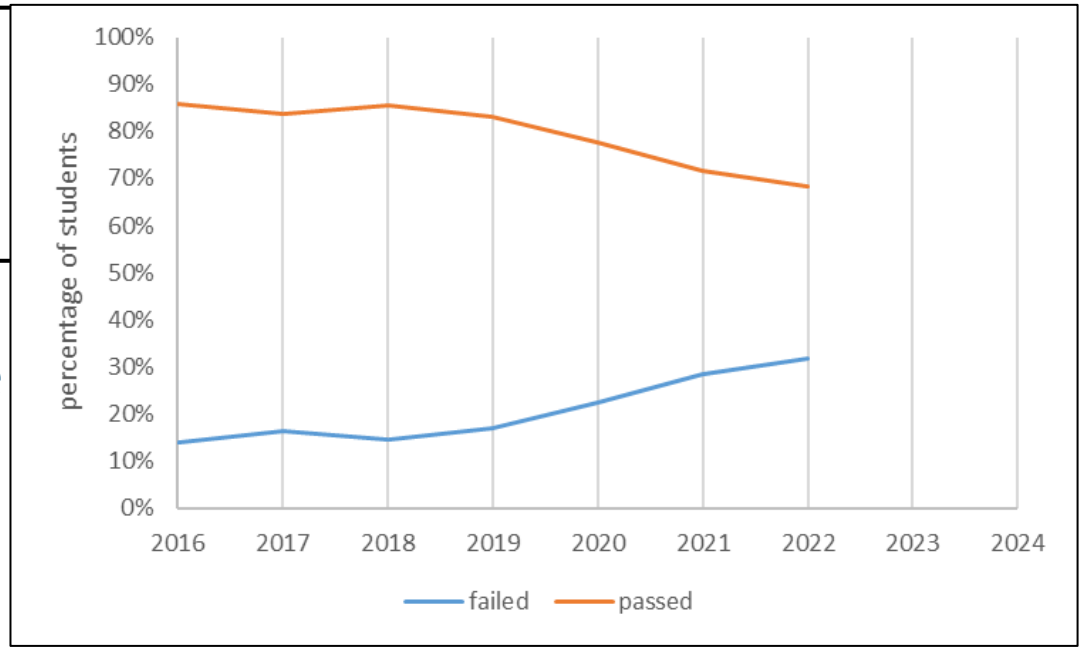
History of chemical calculation teaching at Bachelor Biology

Chemistry of Life: semester 1 of year 1

- 1.5 EC with focus on dilutions, molarity, pH and buffer calculations

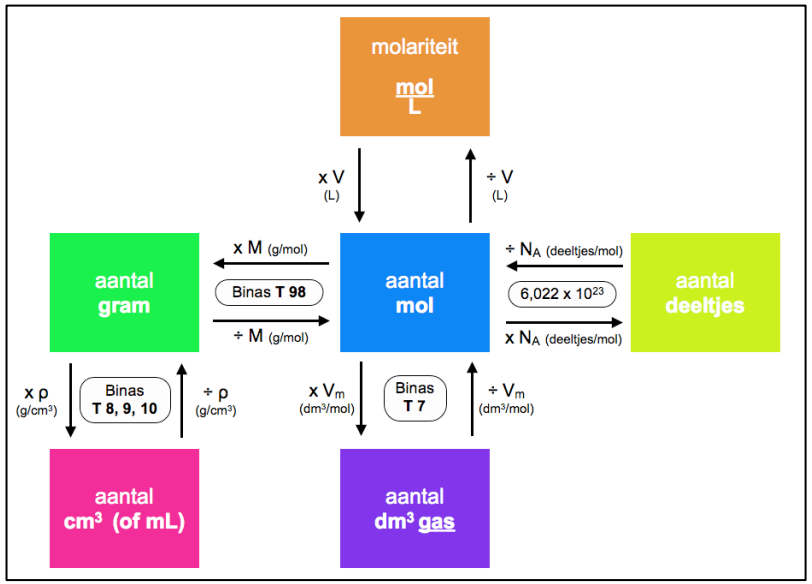
------ 2016 ---------- 2018
self-study using
19 questions

- feedback: not enough practice
- passing rates are going down



Chemical calculations: From high school to university

Starting point: all first-year students had chemical calculations at high school



Wikimedia: Tom Schoffelen

Challenges:

- differences between high schools
- declining knowledge on buffers
- differences in affinity for chemical calculations
- often only practiced in a conceptual way (theoretical exercises)
- > 6 months without any practice

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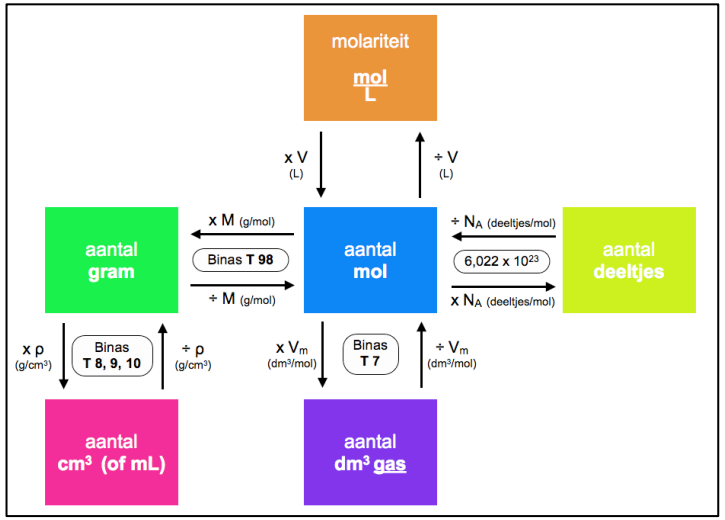

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End of three-year bachelor study: independent working within a laboratory environment

Strategy: use adaptive method

- personalized learning at scale (own pace and level)
- reduces copycat behavior
- enables teachers to identify bottlenecks in knowledge

2022: introduction of Online Laboratory calculus with automatic Feedback (OLaF)

- developed by teachers at Maastricht University
- >100 different questions on dilutions and molarity calculations
- divided in 4 different badges

Time	Top	Avg
18s	16s	09m10s

Badges

What is the concentration of a 99.7% (w/w) acetic acid solution with a density of 1.05 kg/L? _____ kg/L

What is the molarity of a 99.7% (w/w) acetic acid solution? _____ M

(Hint: the molecular weight of acetic acid is 60.052 g/mol.

In order to obtain 25 mL of this 0.16 M acetic acid solution, how much 99.7% acetic acid should you add to obtain the required dilution? (Fill in your answers with two decimals) _____ mL

Submit Answer | Reset | Edit question

Strategy: use adaptive method

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Still missing the most difficult part: calculations on pH and buffers

Strategy: use adaptive method

2024: adaptive method on pH and buffer calculations

- developed by LabBuddy in Dutch
- divided in 6 different badges:

1. pH calculations concerning **strong acids**
2. pH calculations concerning **strong bases**
3. pH calculations concerning **weak acids**
4. pH calculations concerning **weak bases**
5. **titration**-based calculations
6. **preparing buffers** or solutions with a desired pH

Dear student,

You are working in an Adaptive Case where you will learn how to perform various pH calculations. There are multiple learning objectives, which are represented by the "badges" you can earn.

The badges are:

- Calculating the pH of a strong acid
- Calculating the pH of a strong base
- Calculating the pH of a weak acid
- Calculating the pH of a weak base
- Calculating concentration based on titration results
- Preparing a buffer or diluted solution with the desired pH

If you answer multiple questions correctly in a row, you will earn the badge. However, if you find the topic difficult and answer the questions incorrectly, you will receive a sub-objective to practice. This way, you practice at your own level. With each question, you are guided to the correct answer with feedback.

Good luck with answering the questions. Don't forget: making mistakes is okay! This is a practice tool.

Time	Top	Avg
06s	15s	01m24s

Badges

Calculate how to prepare a buffer with a **pH of 5.96** using $NaHCO_3$ (**molar mass = 84.007 mg/mol**).
Ensure a **total volume** of 100 mL and a **total concentration** of **0.1 mol/L** ([base] + [acid]).
The following **solutions** are available:

- 1.00 mol/L NaOH
- 1.00 mol/L HCl

Properties of the available **solid compound** (the provided pK_a values correspond to the acid):

Equilibrium	pK_{a1}
$H_2CO_3 \rightleftarrows HCO_3^- + H^+$	$pK_{a1} = 6.23$
$HCO_3^- \rightleftarrows CO_3^{2-} + H^+$	$pK_{a2} = 10.33$

Calculate how many mmol of each substance you need to prepare the buffer. Then, calculate how many g or mL this is.
Round your answers to two decimal places.

Substance	n to add (mmol)	Mass (g) / Volume (mL) to add
$NaHCO_3$		g
...		mL
MQ water		Fill up to 100 mL

Submit Answer Reset

You made a mistake in how much mmol $NaHCO_3$ should be added to this buffer.
You are asked to make a buffer from a weak acid and its conjugate base.

×

The total concentration of the buffer is equal to $[A^-] + [HA]$. The total concentration is therefore determined by the amount of $NaHCO_3$ you add.

You made a mistake in how much mmol $NaHCO_3$ should be added to this buffer.
You are asked to make a buffer from a weak acid and its conjugate base.

The total concentration of the buffer is equal to $[A^-] + [HA]$. The total concentration is therefore

× determined by the amount of $NaHCO_3$ you add.

This is given: 0.1 M. The total volume is also known and $n = c \cdot V$
$n = 0.1\ M \cdot 100\ mL = 10\ mmol$

You made a mistake in how much mmol HCl should be added to this buffer. Ensure your answer is rounded to two decimal places.

- Use the formula $pH = pK_a + \log [A^-]/[HA]$
- $pH = pK_a + \log [A^-]/[HA]$ and $[A^-] = c - x$ (where c = total concentration of the buffer) and $[HA] = x$
- $pH = pK_a + \log ((c-x) / x)$
- $10^{pH-pKa} = (c-x) / x$

×

- $10^{pH-pKa} x + x = c$
- $(10^{pH-pKa} + 1)\, x = c$
- $x = c / (10^{pH-pKa} + 1)$
- $x = 0.1 / (10^{0.59} + 1)$
- $[HA] = 0.02045$ M
- Now you know the final concentration [HA] needed in the solution. How much strong acid do you need to add to achieve this concentration? $n = c \cdot V$
- $n = 0.02045\ M \cdot 100\ mL = 2.04$ mmol

How was it integrated in the course Chemistry of life?

WEEK 1

Lecture 1: introduction on the course

+ 90 min to start with OLaF (dilutions and molarity)

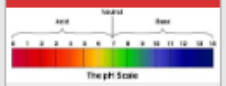
Lecture 2: pH and buffers

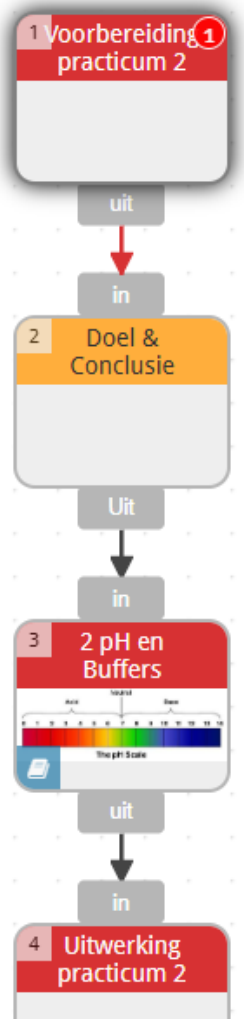
+ 90 min to start with adaptive case on pH and buffers

WEEK 2

Practical 1: make a NADH solution and dilution serie to determine NADH coefficient

Practical 2: make acetate solutions and perform a titration with HCl





1 Voorbereiding practicum 2

Introductie

pH-meter

Voorbereidingsvragen

Vraag 1

Tijdens het practicum ga je een natriumacetaat-oplossing titreren met 1.25 M HCl. Wat is de pH wanneer je 1 ml 1.25M HCl in 100 ml H_2O pipetteert? Geef het antwoord in één decimaal en gebruik een punt als decimaalscheidingsteken.

Submit Answer | Reset

Vraag 2

In de zuurkast staat een fles met 37% (w/w, dus gewichtsprocent) HCl. Het etiket vermeldt verder dat 1.0 liter = 1.19 kg en dat het molecuulgewicht van HCl 36.5 is.

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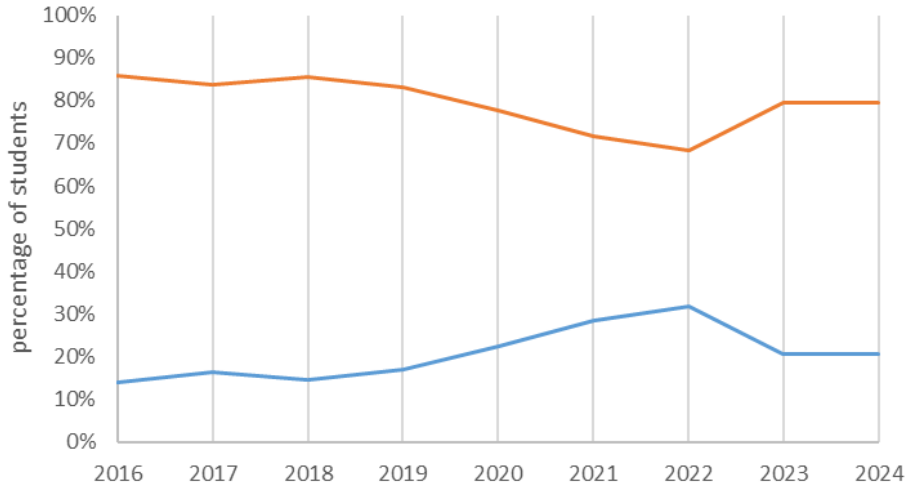
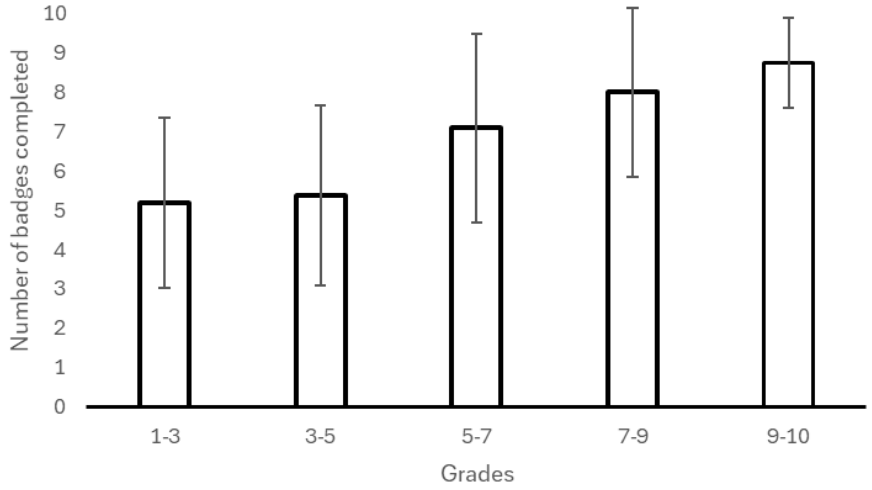
WEEK 4

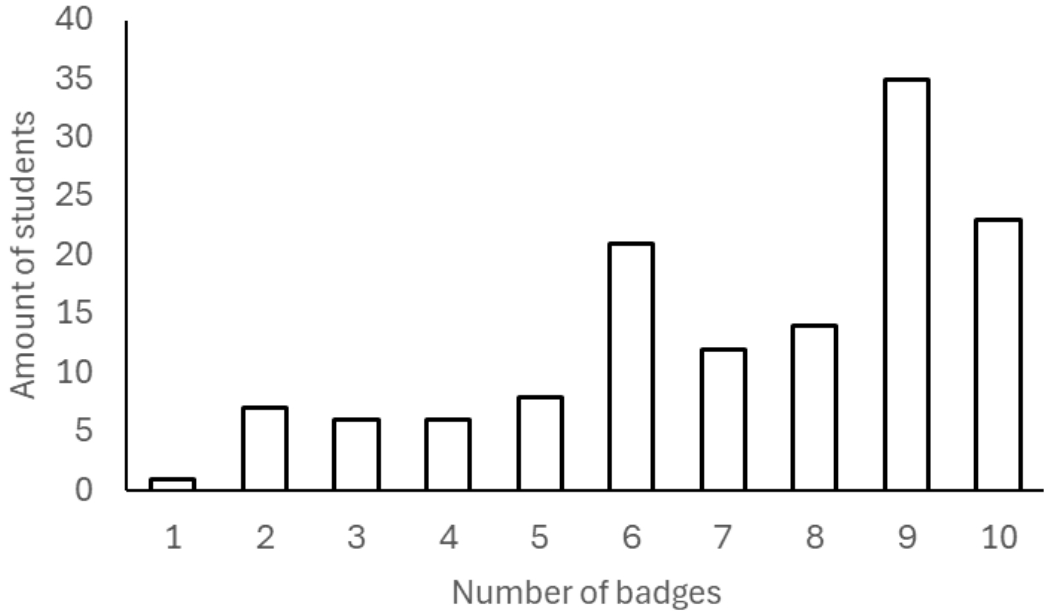
Q&A and exam

Experience first trial





Feedback from 133 of 175 students



General feedback:

- positive; '*wish I had practiced more*'
- frustrating to get stuck at badge 4
- more help during the questions

Universi Leiden The Netherlands

2025-2026: integration in the course Chemistry of life?

WEEK 1

Lecture 1: introduction on the course

+ 60 min to start with OLaF (dilutions and molarity)

Practical 1: make a NADH solution and dilution series to determine NADH coefficient

WEEK 2

Lecture 2 part 1: pH and buffers

+ 60 min to start with adaptive case on pH and buffers

Practical 2: make acetate solutions and perform a titration with HCl

WEEK 4

Lecture 2 part 2: explaining pH and buffers questions

Exam

Summary

- Using adaptive cases can help students to be better at chemical calculations
- You need to think it through to integrate the cases in a course

- Repeat these skills in more courses (second year Biochemistry course and third year internship)

- Working together between universities (with help of LabBuddy) in developing common basic skills works!

Development of the adaptive case on pH and buffer calculations

Other adaptive case topics:

- Cell culture calculations

QUESTIONS?

j.van.den.brink@biology.leidenuniv.nl