**Teaching Notes**

**Topic: Calibration (Science)**

This enhancement asset is a stand-alone lesson on calibration, why it is important and the skills required to calibrate a balance, a pH meter, a mechanical (variable volume) pipette and a conductivity meter. It is designed to be slotted into existing teaching schemes and the suggested sequencing of concepts and activities can be adapted as appropriate for your students and circumstances. Unless otherwise stated, definitions of key terms have been developed by the authoring team and reviewed in the context of the activities. Teachers may choose to revise definitions as necessary.

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| **Route** | **Health & Science** |
| **Qualification** | T Level Technical Qualification in Science (Level 3): [www.ncfe.org.uk/qualification-search/qualification-detail/t-level-technical-qualification-in-science-level-3-delivered-by-ncfe-883](http://www.ncfe.org.uk/qualification-search/qualification-detail/t-level-technical-qualification-in-science-level-3-delivered-by-ncfe-883) |
| **Topic** | Calibration |
| **Specification coverage** | **Performance outcome 2:**  K2.4, K3.2, K3.4  **Scientific skills:**  S1.76, S1.86, S3.7, S3.9, S3.10, S3.11 |

Version information

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| **Version** | **Description of change** | **Date of Issue** |
| Version 1 | Original version | March 2025 |
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# Industry importance

Calibration is a common skill needed in many workplaces and is often performed daily in laboratories. It can help prolong equipment life, it is essential for compliance with standards and it helps to ensure that equipment provides accurate, reliable and trusted results that meet legal requirements.

*“Calibration of laboratory equipment is a critical process in ensuring the reliability of test results.”****Tahmina Hussain, Biomedical Scientist  
Institute of Biomedical Science and University of Salford***

# Industry links

* Information on calibrating pH electrodes – Thermo Fisher Scientific: <https://assets.thermofisher.com/TFS-Assets/CMD/Product-Bulletins/TN-ph-calibration-procedure-for-optimal-measurement-precision-T-PHCAL-EN.pdf>
* Information about how a pH meter works and how to care for one – BiteSizeBio: [bitesizebio.com/8750/how-to-care-for-your-ph-meter/](https://bitesizebio.com/8750/how-to-care-for-your-ph-meter/)
* A video showing different types of pH meter and a step-by-step guide on how to calibrate one, including making adjustments and some general information on pH – CLEAPSS: [science.cleapss.org.uk/resource/ph-meter-calibration.vid](https://science.cleapss.org.uk/resource/ph-meter-calibration.vid)
* Information on why calibrating a pH meter is important, how often they need to be calibrated, how to choose the correct buffers and how to perform a calibration – Metrohm: [www.metrohm.com/en\_gb/discover/blog/2024/calibrate-pH-meter.html](http://www.metrohm.com/en_gb/discover/blog/2024/calibrate-pH-meter.html)
* A free online simulation of calibrating a pH meter – NC Community Colleges: [www.ncbionetwork.org/educational-resources/elearning/ph-meter-calibration](http://www.ncbionetwork.org/educational-resources/elearning/ph-meter-calibration)
* Information on an arterial blood gas machine, one application of a pH meter in real life – Anaestheasier: [anaestheasier.co.uk/arterial-blood-gas-measurement/](https://anaestheasier.co.uk/arterial-blood-gas-measurement/)
* Examples of the use of conductivity meters in industry – The Laboratory Store: [www.thelabstore.co.uk/water-quality-products/conductivity-meters/](http://www.thelabstore.co.uk/water-quality-products/conductivity-meters/)
* Information on calibrating thermometers, how to calibrate them, different types of thermometers and why calibration is important – RS: [uk.rs-online.com/web/content/discovery/ideas-and-advice/thermometer-calibration-guide](https://uk.rs-online.com/web/content/discovery/ideas-and-advice/thermometer-calibration-guide)
* Information on calibrating balances/scales, why it is necessary and some examples of industries that use balances/scales – Solent Scales: [www.solentscales.co.uk/blog/why-is-calibration-so-important-for-industrial-scales/](http://www.solentscales.co.uk/blog/why-is-calibration-so-important-for-industrial-scales/)
* Examples of types of industrial weighing scales and where they are used – RS: <https://uk.rs-online.com/web/content/discovery/ideas-and-advice/weighing-scales-guide>
* An online PDF giving detailed and extensive information on calibrating mechanical variable volume pipettes, techniques to use and how and when to calibrate pipettes – National Physical Laboratory: <https://eprintspublications.npl.co.uk/3026/>
* Information on calibrating mechanical variable-volume pipettes, step-by-step instructions on how to calibrate pipettes, when to calibrate them and a small number of consequences of not calibrating – BiteSizeBio: [bitesizebio.com/40766/performing-pipette-calibration-yourself](https://bitesizebio.com/40766/performing-pipette-calibration-yourself/)
* A four-minute video on pipette calibration and the equipment, procedures and environment needed for success, and a video guide on how to perform a pipette calibration – Sartorius: [www.youtube.com/watch?app=desktop&v=fyOV9iyZMNY](http://www.youtube.com/watch?app=desktop&v=fyOV9iyZMNY)
* A website giving information on calibration and checking the accuracy of a pipette, including other tests that can be performed (e.g. gravimetric analysis) and further calculations that could be performed to get a more accurate report of the calibration of the pipette – Integra: [www.integra-biosciences.com/united-kingdom/en/calibration-check-how-calculate-accuracy-and-precision-pipette](http://www.integra-biosciences.com/united-kingdom/en/calibration-check-how-calculate-accuracy-and-precision-pipette)
* Materials for topics to support Health and Science T-levels are also available on the NCFE YouTube Channel at: <https://www.youtube.com/playlist?list=PL05CIlRfHw9iJ-Ga_OSWeRXU_ZDyaKJ5v>

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HEALTH AND SAFETY

This topic has been safety checked but not trialled by CLEAPSS.

It is assumed that activities outlined in these Teaching Notes will be undertaken in suitable facilities or work areas and that good practices, appropriate use policies and procedures will be observed. Teachers should consult their employers’ risk assessments before use and consider whether any modification is necessary for the particular circumstances of their own class/institution.

For practical activities, the Technical Education Networks programme has tried to ensure that experiments are healthy and safe to use in colleges and schools, and that any recognised hazards have been indicated together with appropriate control measures (safety precautions). It is assumed that experiments and activities will be undertaken in suitable laboratories or work areas and that good laboratory practices will be observed. To access the CLEAPSS materials in this suite, institutions will need to be a member of CLEAPSS. Further details are available at www.cleapss.org.uk If necessary, CLEAPSS members can obtain further advice by contacting the Helpline by email at science@cleapss.org.uk or on 01895 251496.

Acknowledgements

We are grateful to the following individuals and organisations for their input and support: Alyssa Charles (author); Alison Ackroyd (teacher advisor); Rosalind Eccles (teacher advisor); Alex Wright (advisor); CLEAPSS; NCFE; Alex Wright, University of Kent; Tahmina Hussain, Institute of Biomedical Science and University of Salford; Jorge Alvarez, South East Laboratories Ltd; Griff Crouch, GPC Clear Solutions; Nabil Mugharbel, Mid Kent College.

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**Learning outcomes and specification coverage**

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| **Learning outcomes** | **Specification coverage** | **Skills and general competencies** | **Links to other specification content** |
| Students will be able to:   * explain why it is important to calibrate and test equipment; * perform a calibration of a pH meter, balance and mechanical pipette; * write Standard Operating Procedures (SOPs) for the calibration of a pH meter, balance, mechanical pipette and conductivity meter; * use a conductivity meter to measure the conductivity of a solution; * describe the difference between precision and accuracy. | **K2.4** The principles of laboratory equipment validation when planning scientific tasks.  **K3.2** The importance of recognising equipment faults/technical issues in laboratory equipment used to undertake scientific techniques commonly found in a laboratory environment.  **K3.4** How to minimise errors in scientific tasks. | Skills  **S1.76** Use the following practical scientific techniques to measure a range of physical properties.  **S1.86** Calibrate scientific equipment and check it is fit for use.  **S3.7** Resolve issues with a range of scientific equipment.  **S3.9** Recognise when a piece of equipment is producing inaccurate data.  **S3.10** Recognise when equipment is likely to be damaged or cause injury due to malfunction.  **S3.11** Report faults and source expert help when required.  General competencies  English:  **GEC1** Convey technical information to different audiences  **GEC2** Present information and ideas  **GEC3** Create texts for different purposes and audiences  **GEC4** Summarise information/ideas  **GEC5** Synthesise information  **GEC6** Take part in/lead discussions  Digital:  **GDC3** Communicate and collaborate  Maths:  **GMC1** Measuring with precision  **GMC2** Estimating, calculating and error spotting  **GMC3** Working with proportion | **A6.5** The difference between systematic and random data errors.  **A6.6** How to minimise errors occurring in a scientific setting.  **A8.1** The principles of good practice in scientific and clinical settings.  **A8.6** The potential impacts of not maintaining, cleaning and servicing equipment.  **A8.7** Why it is important to calibrate and test equipment to ensure it is fit for use.  **A8.8** How to escalate concerns if equipment is not correctly calibrated/unsuitable for intended use.  **A10.1** Common causes of equipment and technical faults that may have an impact on scientific results.  Links within Metrology:   * K2.1 – K2.5; * K1.26; * K1.30; * K1.66.   Links within Food Science:   * K1.2; * K1.15; * S1.81. |

**Lesson guidance**

## Preparation

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| **Resources provided** | * Slide deck * Activity 1 Worksheet * Activity 2 Worksheet * Activity 2 Student support sheet * Activity 2 Worksheet answers * Activity 3 Worksheet * Activity 3 Teacher and technician notes * Plenary Answer sheet * Consolidation Worksheet |
| **Equipment needed** | **Activity 1**  Equipment per group:   * 4 x mechanical (variable-volume) pipettes * 2 x 50 cm3 beakers * Mass balance to 4 d.p. * Distilled water * Thermometer   **Activity 3**  Station 1 – Calibrating a balance Equipment per student:   * A mass balance, minimum of 2 d.p but 4 d.p is preferred * A set of masses that can be used as calibration masses   You may have to add into the worksheet (or demonstrate to students) how to calibrate the pieces of equipment used.  Station 2 – Calibrating a pH meter Equipment:   * pH meter * pH meter calibration buffer solutions (pH 4.0, pH 7.0, pH 10.0) in small beakers * Distilled or deionised water * Lint-free tissue * Beakers for rinsing   Station 3 – Calibrating a pipette Equipment per student:   * Mechanical (variable volume) pipette * Calibrated high-sensitivity balance (or at least 0.0001 g) * Weighing boats or small containers * Distilled or deionised water in clean flasks/beakers * Thermometer   Station 4 – Calibrating a conductivity meter Equipment per student:   * Conductivity meter * Standard conductivity calibration solution(s) (150 µS/cm conductivity standard, 1413 µS/cm conductivity standard and 2880 µS/cm conductivity standard) * Distilled or deionised water * Clean beaker(s) for the standard solution(s) * Lint-free tissue |
| **Safety factors** | It is assumed that all activities will be undertaken in suitable facilities or work areas and that good practices, appropriate use policies and procedures will be observed. Teachers should consult their employers’ risk assessments before use and consider whether any modification is necessary for the particular circumstances of their own class/institution.  Teachers and students are required to carry out their own risk assessments.  Safety goggles should be worn when working with solutions in the practicals.  If using solutions made from tablets or commercial buffer solutions, refer to any hazard warning labels on the containers.  For commercial calibration solutions, refer to the manufacturer’s safety instructions. |
| **CLEAPSS references** | If buffer solutions need to be prepared, instructions (and hazards) can be found on CLEAPSS recipe card 18: [science.cleapss.org.uk/Resource/RB018-Buffer-solutions.pdf](https://science.cleapss.org.uk/Resource/RB018-Buffer-solutions.pdf) |
| **Prior learning** | * Completing the calibration practicals will be easier and probably quicker if students are familiar with the names of different glassware, have followed Standard Operating Procedures (SOPs)/methods previously and have had experience using pH meters, mechanical pipettes, balances and conductivity meters. * Students should already be familiar with how to calculate uncertainties, as this is not explained or covered in detail. * If possible, ask students to read Worksheet 3 covering the Calibration practical details before attending this class. This is not essential but will maximise their time carrying out the practicals if they have familiarity with the instructions beforehand. |
| **Common misconceptions** | * Students may struggle with the difference between precision, accuracy, reliability and validity and what human versus mechanical and instrumental versus random error are (**A6.5/A10.1**) and how they arise. * Students sometimes believe that calibration only needs to happen once, or as a one-off when things have been recognised to have gone wrong or not met Quality Assurance. Students need to understand that once an instrument is calibrated, it still needs to be validated/calibrated again later, and that calibration (or the ability to calibrate correctly) can be affected by environmental conditions (e.g. pH changes with temperature, and volumetric glassware is calibrated to specific air pressure and room temperature). * Students sometimes believe that all calibration is done in-house. Students need to be reminded that professional services are often required to ensure equipment and instruments meet United Kingdom Accreditation Service (UKAS) standards, or for complicated company audits. * Students often believe that calibration always involves adjusting an instrument to bring it within tolerance, when in reality, its primary purpose is often to monitor and validate performance rather than make adjustments. |
| **Accessibility** | * Seek to ensure wide representation for any visiting speakers and case studies used (where appropriate). * The use of glassware and chemicals can be worrying for some students. Care needs to be taken when performing the practicals. * Access to laboratories may be limited for various reasons, so the materials have been produced to be flexible. |

## Activity guide

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| **Introduction**  SUGGESTED TIME:  5 minutes  RESOURCES:  Slide deck – slides 2–4 | * On slide 2, go through the learning outcomes for this lesson with students. * Using slide 3, ask students what they think calibration is and why it is important in the laboratory. Listen to their ideas before revealing the answer on slide 4. |
| **Activity 1 – Investigating calibration**  SUGGESTED TIME:  15 minutes  RESOURCES:  Slide deck – slides 5–6  Activity 1 Worksheet | * Divide students into small groups and provide each group with a worksheet, four mechanical (variable-volume) pipettes, two 50 cm3 beakers, a mass balance (to at least four decimal places if possible), access to distilled water and a thermometer. * Lay out the scenario shown on slide 5 and on the worksheet and ask students to spend approximately 10 minutes investigating how they might determine which of the pipettes, if any, are working correctly. The idea is for students to practise the correct pipetting technique using the mechanical pipettes, and to use the equipment they were given to come up with a basic version of how to calibrate pipettes (one of the practicals they will be performing properly later). If students need guidance, suggest they consider using the density of water (1 g cm-3) and the mass balance to help. * Students should also discuss any possible consequences of a pharmaceutical company using pipettes that don’t work correctly, and explain why calibration is important. * Demonstrate the correct mechanical pipetting technique while circulating if necessary. * An additional task for students is to determine the uncertainty associated with their mass balance (usually +/- half of the smallest increment on the balance) and therefore calculate the percentage error associated with measuring out a mass of 0.05 g on their balance. If needed, students can be reminded that percentage error = (uncertainty/measurement) x 100. * If there is time, have a class discussion as outlined in the analysis section of Worksheet 1. Elicit ideas on how to determine if the pipettes are working, discuss any discrepancies and possible consequences in the context of the pharmaceutical company (incorrect amounts of feedstock or reagents can affect the stability, efficacy or safety of the end product) and share any calculated errors if appropriate. Also, ask students to consider if calibration alone is enough when receiving these pipettes from another department. Elicit the potential need for decontamination if used in microbiology/forensics/analytical science. Ask students to recall and discuss specification point A8.7: Why it is important to calibrate and test equipment to ensure it is fit for use.   + To ensure accuracy and reliability of measurements;   + To prolong the life of equipment;   + To meet legal requirements.   + Ask students to recall and define the terms ‘precision’, ‘accuracy’, ‘reliability’ and ‘validity’, and if there is time discuss the differences between them. The difference between precision and accuracy is covered in more detail in Worksheet 2.   + Discussion of the differences between human, mechanical, instrumental and random error using slide 6 may be useful at this point, as this content is not explicitly covered later. |
| **Activity 2 – Themes around calibration: videos**  SUGGESTED TIME:  15 minutes  RESOURCES:  Slide deck – slides 7–8  Activity 2 Worksheet  Activity 2 Student support sheet  Activity 2 Worksheet answers | * + Ask students to watch ‘The importance of calibration’ video (<https://vimeo.com/1060451809> - approximately 4 minutes long) on slide 7 and use it to complete questions 1–4 on Worksheet 2. The video explains what calibration is and why it is important and necessary in industry and gives examples of when calibration is used and some possible consequences when it is not used correctly.   + There is a student support sheet to go with this worksheet if required, which contains additional scaffolding of answers to support students with self-study. Answers to the questions are also provided.   + Feel free to stop the video at various points to allow students time to make notes if needed. Discuss and check answers (approximately 5 minutes) afterwards.   + Then show the ‘Precision versus accuracy’ video ([https://vimeo.com/1060452102](https://vimeo.com/1060452102?share=copy) - approximately 1.5 minutes long) on slide 8 and ask students to complete question 5 on Worksheet 2. Listen to their answers and correct any misconceptions, clarify the definitions of precision versus accuracy and encourage students to add to their answers and notes where necessary.   + Confirm with students that the definitions given here for precision and accuracy are the ones they are expected to know, however there can sometimes be a confusion with the term “trueness” which is occasionally conflated with the term “accuracy”. The specification does not ask for a definition of trueness, but it does define the “true value” as “the result of a perfect measurement”.   + It may be worth discussing that it is not possible to calibrate all pieces of equipment in-house, and that some items will need servicing regularly via contracts from specialists.   + Note that the importance of quality standards has also been covered in Lesson 2 of the ‘Working within the health and science sectors’ unit, which can be found here: [www.technicaleducationnetworks.org.uk/health-science/working-in-the-health-and-science-sectors](http://www.technicaleducationnetworks.org.uk/health-science/working-in-the-health-and-science-sectors/)   + If possible, consider inviting an external speaker in to discuss the use of calibration in industry, alongside or even instead of the video. Students could pre-prepare questions for the speaker ahead of the lesson. |
| **Activity 3 – Calibration practical**  SUGGESTED TIME:  30 minutes  RESOURCES:  Slide deck – slide 9  Activity 3 Worksheet  Activity 3 Teacher and technician notes | * Divide students into four groups and set each group up at one of the four calibration stations (slide 9). Give the students approximately seven minutes to perform a calibration with each of the given pieces of equipment (a balance, a pH meter, a pipette and a conductivity meter) using the methods provided on Activity 3 Worksheet, before instructing the groups to rotate to the next station and calibrate the next piece of equipment. * Ideally, students would perform calibrations on all four pieces of equipment and be able to adjust some of the equipment as needed. However, if there is not enough time, you don't have all the pieces of equipment, or your class won’t be able to complete all the calibrations in the 30 minutes, remove one of the pieces of equipment, or only do two or three rotations on the carousel. * Technician instructions for preparing the solutions can be found in the Teacher and technician notes. * Inform students that they will shortly be writing SOPs for at least one of these calibrations and therefore will need to be paying attention to each of the processes. Check the instructions on Activity 3 Worksheet and change if needed to make it clearer how to calibrate the specific models of instruments the students are going to use. * If there is time, some discussion points to stretch students’ understanding are included on the worksheet. Use these to develop students’ critical eye. |
| **Activity 4 – Writing SOPs**  SUGGESTED TIME:  15 minutes  RESOURCES:  Slide deck – slide 10  Activity 3 Worksheet | * Using slide 10, ask students to write an SOP for a calibration process. If students are quick with their writing, they can be encouraged to write a second or third SOP for another calibration process. This could also be given as further follow-up/homework if required. * Students can use Activity 3 Worksheet to remind them how to calibrate each piece of equipment if needed. * A template to help students write SOPs can be found, if required, on the Technical Education Networks website. It is ‘Activity Worksheet 1’ in Lesson 2 (‘Using a SOP’) of the ‘Good scientific and clinical practice’ topic, found at: [www.technicaleducationnetworks.org.uk/health-science/good-scientific-and-clinical-practice-health](http://www.technicaleducationnetworks.org.uk/health-science/good-scientific-and-clinical-practice-health/) * Students could evaluate their protocol by comparing it to a published one. For example, the class protocol for calibrating a pipette does not consider evaporation when measuring small quantities, whereas an industry protocol would. |
| **Plenary**  SUGGESTED TIME:  10 minutes  RESOURCES:  Slide deck – slides 11–14  Plenary Answer sheet | * Give students the scenario-based questions on slides 11–13 and ask them to write answers explaining the potential consequences of using uncalibrated equipment. Ask them to discuss the benefits of using calibrated equipment, and to consider and quantify the financial impact of using uncalibrated equipment in industry. They could also calculate and justify whether uncalibrated equipment could cause the production of an ineffective drug. * Some suggested, but not exhaustive, points and calculations that students could give are provided on the Plenary answer sheet. Students’ answers should be communicated clearly and written in full sentences where possible. * If there is time, some answers could be shared and/or peer-marked to provide feedback and ensure any misconceptions or knowledge gaps are addressed. * Any questions not used could be used as a homework activity or additional follow-up/consolidation. * Revisit the learning objectives on slide 14 to close the lesson. |
| **Follow-up/consolidation**  (to be completed outside of lesson)  SUGGESTED TIME:  30 minutes  RESOURCES:  Slide deck – slide 15  Consolidation Worksheet | * Provide students with the worksheet and ask them to pick at least one of the four scenarios and research it. * Ask students to write a presentation to explain why calibration is necessary in the given context, and any financial, health and safety, legal or other implications that may arise if regular and correct calibration does not take place. * The audience should be non-technical, so any points made need to be explained in appropriate depth, and students should have the opportunity to demonstrate their understanding. Students can share these with each other to be peer-evaluated. |

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