CONTINUOUS PROFESSIONAL DEVELOPMENT
(CPD) FOR SCIENCE TEACHERS

OpenSTEM Africa

EFFECTIVE QUESTIONING

Acknowledgements

Ministry of Education

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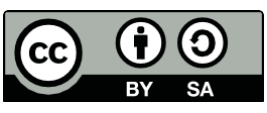
For information on OpenSTEM Africa see: www.open.ac.uk/ido

OPITO for their generous support, which has made OpenSTEM Africa and the development of the Virtual Laboratory and these materials possible.



Contents

OpenSTEM Africa: Ghana

The overarching aim of OpenSTEM Africa, Ghana, is to make a contribution to Government of Ghana/Ministry of Education policy to the effective teaching of practical science.

Effected by:

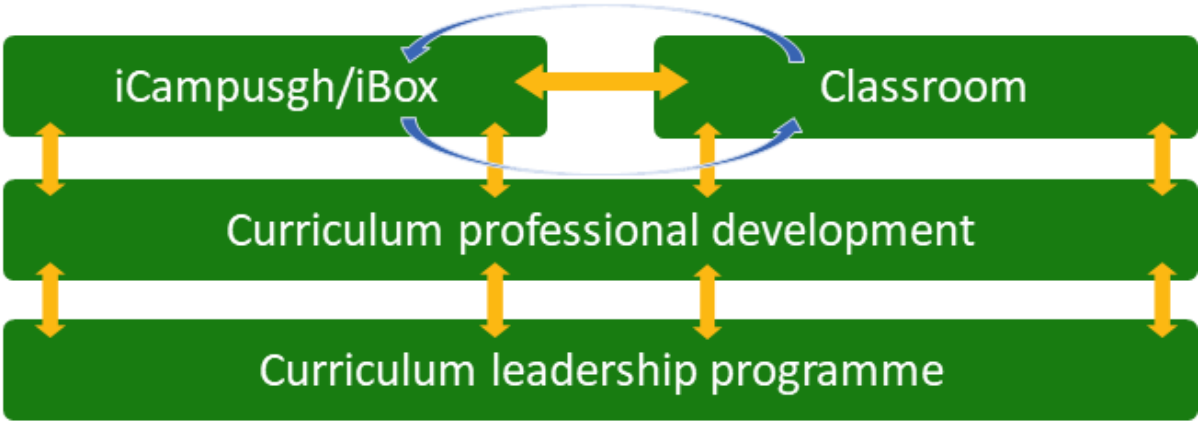
1. **Virtual Lab:** onscreen interactive science instruments using real data and with examples of science lessons, to improve the experiential teaching and learning of science in Senior High Schools, helping develop girls' and boys' practical science study skills, and building on the iCampusgh/iBox model developed by CENDLOS.

Underpinned by:

2. **Continuous Professional Development (CPD) for science teachers:** which develops confidence, skills and strategies to enable improved teaching and learning in the sciences, with a particular focus on ICT-based practical sciences, and which supports them in meeting the aspirations of the SHS elective science curriculum (Physics, Chemistry and Biology).

Embedded in Senior High Schools through:

3. **Curriculum Leadership Programme:** for Heads of Department/Heads of Subject, which enables them to effectively implement short- and long-term strategies to improve teaching and learning in the sciences, with a particular focus on ICT based practical science in their school.



The school-based professional development and leadership programmes will help more teachers use ICT-based science resources more and more effectively, with more learners. The support for school leaders' facilitates the development of a sustainable community of practice in science within the school, led by the Head of Department/Subject Lead and with the support of the Headmaster/Headmistress, in line with National Teaching Council Guidelines.

CPD programme for SHS science teachers

This CPD programme for SHS science teachers is designed by experienced Senior High School science teachers working with Heads of Science and SHS curriculum and Science Resource Centre developers, representing a wide range of Senior High Schools in Ghana. They are working with representatives from the Ministry of Education, from CENDLOS, from the University of Ghana and from The Open University (UK) on OpenSTEM Africa (Ghana).

Improving teaching and learning in the sciences at SHS level is part of the Government of Ghana's *Education Strategic Plan (2018–30)* to enable increasing numbers of SHS students to specialise in the sciences at tertiary level and then move into STEM careers. Government of Ghana policy points to the importance of in-service training for teachers for acquiring new skills and keeping abreast of new developments. The National Teacher Standards for Ghana (MoE/NTC) set out the importance of teachers continuing to learn as they teach and the importance of the school as the location of that learning. Ghanaian research suggests that continuous professional development (CPD) taking place within the school is more motivating, more coherent, more sustainable and likely to be more effective in the long term This is the "growth approach in which teachers are given the opportunity to try new opinions, gain new perspectives, and extend their professional capabilities in order to understand and find solutions to problems in their individual schools" (Asare et al., 2012).

SHS science teachers, particularly those specialising in the elective sciences are already experts in their field. This programme is to enable them to work directly with their Head of Science, or Heads of Physics/Biology/Chemistry alongside their departmental colleagues to further develop the expertise of the whole department in teaching SHS sciences, with a particular focus on ICT-based teaching and learning and to help build a community of practice among science teachers in the school.

Effective questioning

Introduction

Questioning is something that teachers do all the time. Good questioning helps you to find out what learners know and is important in assessing their progress. Open questions are particularly important to encouraging participation and dialogue in class. Carefully planned questions also promote thinking.

National Teachers' Standards for Ghana

Examples of the Standards in action

The Teacher:

- uses questioning to encourage learner participation and critical thinking
- asks probing questions to both girls and boys, and responds knowledgeably to learners' own questions and difficulties around specific topics.

Learners:

- are active, challenged to think hard, share, talk and feel able to ask questions of the teacher and one another
- are not afraid to answer or ask questions and are not publicly or privately reprimanded for wrong answers.

(National Teachers' Standards, 2017)

By the end of this unit you will:

- plan different types of questions to promote learner participation and critical thinking
- consider the different ways in which you can respond to the answers that students give
- discuss ways in which you can encourage students to ask you questions
- have developed strategies to encourage students to ask each other questions
- continued to develop your skills in using ICT in teaching and learning, via the final section of this unit.

Planning types of questions

One strategy for teaching might be to frame each unit in the syllabus as an overarching question which you and the students answer progressively as you work through the unit. This is a teaching strategy to help ensure that everything taught and learned is relevant to the material and the learning objectives in the unit.

Examples for framing a unit as a question

Chemistry SHS 1, Section 2

> "What is the structure of an atom, and how does the structure of atoms help us to explain the shape of the Periodic Table?"

Biology, SHS 3 Section 1 Unit 4

> "How do plants make their food? What other mineral nutrients do they need and why?"

Physics SHS 1 Section 3 Unit 1.

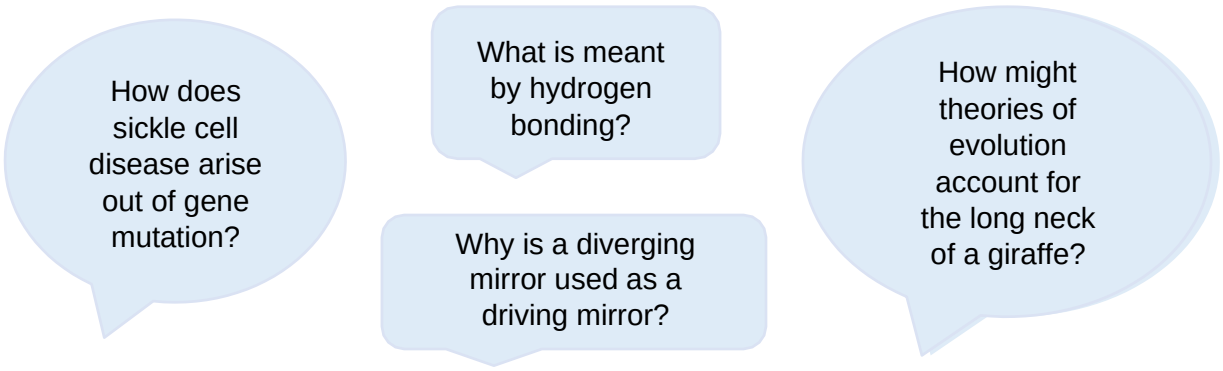
> "What is temperature? How is it measured? What are the advantages and limitations of different types of measurement?"

Types of questions

Questions can be divided into two broad categories:

- **Lower-order questions**, which involve the recall of facts and knowledge previously taught, sometimes involving closed questions requiring a short yes or no answer, or a single word.

- **Higher-order questions**, generally open-ended, encourage learners to think beyond recounting knowledge or yes and no, single word or short answers, by eliciting different responses. They also help the teacher to assess the learners' understanding of content.



Activity 1: Analysing questions

Look at the questions below and divide them into **lower-order** questions and **higher order** questions:

1. What is all matter made of?
2. Name the particles which make up an atom?
3. Explain the limitations of Dalton's atomic theory?
4. Explain the difference between mitosis and meiosis?
5. In a cell, where are the mitochondria found?
6. If you were shown a diagram of a cell, how would you decide whether it is a plant cell or an animal cell?
7. What is the value of 'g' (acceleration due to gravity)?
8. Describe an experiment to determine acceleration due to gravity using simple pendulum?
9. In what ways would the world be like if there was no friction?

Try to tease out the essential characteristics of the higher-order questions – what words do they use? What sort of response is required? If it's helpful, write a definition of higher order and lower order questions.

Activity 2: Planning types of question

In the unit you will be teaching next week, choose a particular lesson or topic. Write three lower-order questions (Yes/No or single word responses) and three open higher-order questions.

Working with your Head of Department/Head of Subject and preferably alongside a colleague, ask each other your questions and refine them for a lesson. Use the 'Evaluation' column of the SHS syllabus to help you.

Responding to learners

National Teachers' Standards for Ghana

Examples of the Standards in action

The Teacher:

- uses questioning to encourage learner participation and critical thinking
- teacher asks probing questions to both girls and boys, and responds knowledgeably to learners' own questions and difficulties around specific topics.

Learners:

- are active, challenged to think hard, share, talk and feel able to ask questions of the teacher and one another
- are not afraid to answer or ask questions and are not publicly or privately reprimanded for wrong answers.

(National Teachers' Standards, 2017)

Classroom example 1: Questioning to problem-solve

Mr Mawunyega was scheduled to teach a practical lesson in his laboratory. Unfortunately, 30 minutes before the lesson, he was told he would have to change rooms. He decided to use the opportunity to improve his students' problem solving skills, so asked them 'how can we still have a practical lesson when we cannot use the laboratory?'

They began to brainstorm and for every suggestion they made, he came back with another question:

- 'Where will we have the lesson?'
- 'How will we arrange the class'?
- 'What will each group do?'
- 'Who will be responsible for what in the groups?'

He wrote each solution on the board. In just five minutes of rapid questioning, they had made a plan for the lesson. The students realised that the specimens could be carried to the classroom, that they would divide themselves into three groups and change the seating in the classroom to suit the work. In that way they could still have their practical lesson.

He assisted the students in the grouping, to ensure all students were involved in solving the problems and that no one was left out.

At the end of the lesson Mr Mawunyega asked the students how they felt about the day's lesson. To his surprise a very quiet girl called Mina, raised her hand to answer him saying 'this is the best practical lesson ever'. Asking why, she said because they, the students, solved the problem of the change of place for the lesson. Other students also said they were excited because of their contribution to the solution.

Did you notice…

- by Mr Mawunyega presenting a problem to the whole class, the students could work out a solution, each student was involved, and the feedback was very positive
- through the activity both teacher and students learned both questioning and problem solving skills.

Encouraging learners to respond

Many teachers don't give enough time for learners to answer a question and end up answering it themselves. Give your learners time to think! By waiting after asking a question, there is an increase in:

- the length of learners' responses
- the frequency of learners' questions
- the number of learners offering responses
- the number of girls offering responses
- the number of responses from shy learners
- the number of responses from less capable learners
- positive interactions between learners
- the enthusiasm of girls and/or boys who are usually reticent.

Your response matters

If one learner has the wrong idea, you can be sure that many more have as well.

There are many ways to respond to wrong answers and misconceptions.
Encourage your learners to try again! You could use the following techniques:

- Pick out the parts of the answers that are correct and ask the learner to think a bit more about their answer. This helps your learners to learn from their mistakes. The following comment shows how you might respond to an incorrect answer in a supportive way: 'You were right about gas and vapour sharing some similarities but we need to talk about critical temperature… Can someone else offer additional ideas?'
- Ask the learners to brainstorm some answers. Write on the chalkboard all the answers that the learners give, and then ask the learners to think about them all. What answers do they think are right? Are there other correct answers? This helps you to understand the way that your learners are thinking and also gives your learners an unthreatening way to correct any misunderstanding that they may have.

- Listening carefully. If you ask for further explanation for all answers, right or wrong, learners will often correct any mistakes for themselves. You don't want learners to feel afraid of giving a wrong answer.

Activity 3: Responding to learners

In your subject or departmental group and with the help of your Head of Department/Head of Subject try out your best questions from Activity 1.

Practise your questioning skills by using follow-up questions based on the responses. Try prompting, probing and sequencing by, for example, asking **how** or **why** questions; asking for a better word; asking for evidence/personal experience etc.

Good habits to form

Try to do the following:

- give learners time to think about their answer
- ask different types of questions
- sequence the questions
- listen to learners' responses and give follow up questions
- ask other learners (respectfully) to correct others' mistakes – in a helpful manner
- plan some good questions in advance. If you don't you are more likely to limit yourself to closed, low level questions.

Try to avoid:

- asking a question and answering it yourself
- asking a difficult question too early
- giving learners no time to think
- ignoring answers
- asking the same learners in every lesson
- asking only the boys to answer the questions
- asking those sitting at the front to answer the questions
- ignoring the efforts of slower learners.

The more positively you receive all answers that are given from everyone in the class, the more students will continue to think and to try.

Value all responses by listening carefully and asking the student to explain further. If you ask for further explanation for all answers, right or wrong, students will often correct any mistakes for themselves, you will develop a thinking classroom and you will really know what learning your students have done and how to proceed. However, if wrong answers result in humiliation or punishment, then your students will stop trying for fear of further embarrassment or ridicule.

Improving the quality of responses

National Teachers' Standards for Ghana

Examples of the Standards in action

The Teacher:

- asks probing questions to both girls and boys, and responds knowledgeably to learners' own questions and difficulties around specific topics. Teachers know learners' common misconceptions in a subject.

(National Teachers' Standards, 2017)

Helping students to think more deeply about, and therefore improve the quality of, their answers is a crucial part of your role. The following skills will help students achieve more:

Prompting

This requires appropriate hints to be given, ones that help students develop and improve their answers. You might choose first to say what is right in the answer and then to offer information, further questions and other clues.

Activity 4: Prompting

Using Biology SHS3 Section 2 Cell Biology, genetics and evolution, Unit 4 Cell cycle:

- set out the steps for meiosis and mitosis on the chalkboard – but write them in the wrong order!
- divide the class into pairs to answer the question: *"What is the right order of the steps to explain the two processes?"*

Probing

This is about trying to find out more, helping students clarify what they are trying to say to improve a disorganised answer or one that is partly right.

Activity 5: Probing

Using Physics SHS2 Motion forces and energy Section 1, Unit 1 Physical quantities and dimensions:

- divide the class into pars of girls and pairs of boys. Give each pair 11 pieces of card, each with a physical quantity written on.
- which are 'basic' and which are 'derived' quantities?
- what are the SI units of each one?
- for the derived quantities what are the dimensions of each one? (For any pair that finishes quickly give some new quantities which they might not have heard of within the units).

Refocusing

This is about building on correct answers to link students' knowledge to knowledge they have previously learned. This broadens their understanding.

Activity 6: Refocusing

Using Chemistry SHS 2 Section 1 Energy and energy changes, Unit 2 Energy cycles and bond enthalpies, divide your class into groups of three or four with equal numbers of girls and boys in each group.

Heat of neutralisation:

1. Ask each group to plan a practical experiment to work out the heat of neutralisation of a strong acid and a strong base. Ask them to address the following questions:

- What equipment do they need to use?
- What are the practical procedures?
- What are the safety considerations?
- What are the steps they should take to minimise heat loss?
- What are the measurements that they would take?
- How would they calculate the result?

2. If possible, allow them to carry out their experiment.
3. How would they predict the value for a weak acid and strong base (giving a reason)?

Ask them to repeat the experiment for those reagents.

Sequencing

These questions mean asking questions in an order designed to extend thinking, questions should lead students to summarise, compare, explain or analyse. Have questions ready that stretch students, but not challenge them so far that they lose the meaning of the questions ("Explain how you overcame your earlier problem. What difference did that make? What do you think you need to tackle next?").

Activity 7: Sequencing

Using Chemistry SHS3 Section 2 Basic biochemistry and synthetic polymers.

This section has a great deal about large molecules. When you reach the end of the section, as a revision exercise, divide your students into groups and ask each group to make a model – either of common fats and oils, proteins, carbohydrates or polymers. Ask each group to display their model and explain the main features of it to the class answering the questions:

- In what ways is its molecular structure and properties similar to…?
- What are the tests for fats and oils?
- What are the uses of proteins?
- What are the uses of carbohydrate?
- What are the uses of polymers?

Activity 8: Sequencing

Using Physics SHS 2 Motion forces and energy Section 1, Unit 3 Interpreting graphs, divide your class into pairs.

Ask your students to write a story about a journey to school, giving the time and distance covered (it could be a walk, bus or car). For example,

"Martha set out at 7am. At 7.05 she reached Gladys's house which was 150m away. They walked on chatting and met Florence 50m further on at 7.10. They stopped for 3 mins to wait for Rosa. 400m further on at 07.19am they stopped at the store to buy snacks. They set off again at 07.25, realising they might be late and almost ran the last 400m arriving at 07.30)."

Draw a graph to answer the questions:

- What is the slowest speed?
- What is the fastest speed?
- What is the average speed?

Listening

This enables you not just to look for the answer you are expecting, but to alert you to unusual or innovative answers that you may not have expected. It also shows that you value the students' thinking and therefore they are more likely to give thoughtful responses. Such answers could highlight misconceptions that need correcting, or they may show a new approach that you had not considered.

As a teacher you need to ask questions that inspire and challenge if you are to generate interesting and inventive answers from your students. You need to give them time to think and you will be amazed how much your students know and how well you can help them progress their learning.

Supporting students to ask questions

Curiosity about the world is an essential quality in a scientist. By asking interesting questions you will promote curiosity amongst your students, but you can also specifically create opportunities for them to ask questions. For example:

- when you start a new topic, ask each student to compose three questions that they would like to know the answer to
- at the end of a lesson, ask each student to think of one question related to the topic that they would like to know the answer to
- as part of revision, ask students to work in groups or pairs to prepare a set of questions for another group or pair to answer.

Activity 9: Supporting students to ask questions (Biology)

Using Biology SHS 2 Section 3 Humans and their environment, Unit 3 Humans and harmful microbes, divide the class into groups.

Students need to understand the transmission and prevention of various diseases to humans and crops, caused by microbes.

- Ask each group to research one disease.
- Provide a list of four prompt questions that will direct their research appropriately.
- Re-arrange the groups so that in the new groups there is one 'expert' knowledgeable on each disease.
- Within the new group, each student has 5 mins to share their findings with the rest of the group and respond to questions.

Encourage the students to ask the 'How?' questions which prompt extended answers.

Activity 10: Supporting students to ask questions (Physics)

Using Physics SHS 2 Waves Section 3, Unit 1, Unit 2 and Unit 3 – applications linked to the waves topic:

Group work/peer teaching

1. As a class agree a set of guidelines for a large-scale drawing
2. Working in groups of four, have each group create a poster on one of the following topics:

- How do the periscope and kaleidoscope work and what are they used for?
- What are the applications of total internal reflection?
- What are the applications of fibre optics?

3. Re-convene in groups of 12 – with each group having 15 mins to teach their topic to the other two groups.

Using ICT to transform learning

Using ICT with open-ended questions

Think about the ways you could enhance the activities in this unit through your use of ICT, developing the skills of your students, giving them increasing opportunities for experiential learning, and developing your own skills and experience of teaching using ICT. For example, Activity 11 was included earlier in the unit as Activity 6. Here it has been edited to include the use of ICT (you will see the adaptations in **bold**).

Activity 11: Refocusing using ICT

Using Chemistry SHS 2 Section 1 Energy and energy changes, Unit 2 Energy cycles and bond enthalpies, divide your class into groups of three or four with equal numbers of girls and boys in each group.

Heat of neutralisation:

1. Ask each group to plan a practical experiment to work out the heat of neutralisation of a strong acid and a strong base.
2. **Ask the group to present their plan as one group PowerPoint presentation or Word document, incorporating diagrams and visual charts where appropriate.**
3. Ask them to address the following questions:

- What equipment do they need to use? This could include visuals, photos, icons.
- What are the practical procedures? This could include a flow diagram.
- What are the safety considerations? This could include appropriate safety symbols.
- What are the steps they should take to minimise heat loss?
- What are the measurements that they would take? This might be helpful to include in a table or as a spreadsheet.
- How would they calculate the result?

4. If possible, allow them to carry out their experiment. **If the students have access to the OpenSTEM Africa Virtual Laboratory, check whether they can carry out the experiment virtually.**
5. How would they predict the value for a weak acid and strong base (giving a reason)?

Ask them to repeat the experiment for those reagents.

National Teachers' Standards for Ghana

Examples of the Standards in action

All teachers have good technological pedagogical knowledge, knowing how to incorporate ICT into their practice to support learning.

(National Teachers' Standards, 2017)

Lesson planning using ICT

Activities 12 and 13 and 14 will help you to think about the effective use of technology and how to make it transformational. Information and communication technology (ICT) provides a great opportunity to make lessons and learning more interactive, and at the same time help students to engage in 21st century skills that are relevant for their studies and future professional lives. Selecting and integrating a range of ICTs in your lesson requires careful consideration and thought.

Activity 12: Using ICT to transform learning

Think of a science topic that you will be teaching next week.

Imagine that you and your students could have access to any technology that you wished.

- How could you use the technology to support how you would normally teach this topic?
- How could you use technology to achieve the same learning but in different ways?
- How could you use technology to provide learning opportunities that would otherwise not be available?

As a subject or departmental group and under the guidance and support of your Head of Department, collect all your ideas for the points above on to a flip-chart and keep it as a resource to support future planning or to inform the individual coaching sessions you will be having with your HoD.

OpenSTEM Africa Virtual Lab Applications

Practical science

The practical science apps being introduced in the OpenSTEM Africa Virtual Lab such as the virtual microscope are designed to help you to teach your students practical science in the absence of other reliable equipment.

With each instrument there is an example lesson plan, demonstrating how it might be used to support science learning.

The instruments could be used to:

- introduce a topic
- deliver the main content of a lesson
- consolidate key concepts and ideas
- teach practical skills
- help students solve problems you have posed
- encourage critical thinking
- relate science to everyday life.

Working with your Head of Department, take a look at the virtual microscope… and the lesson plans. Consider:

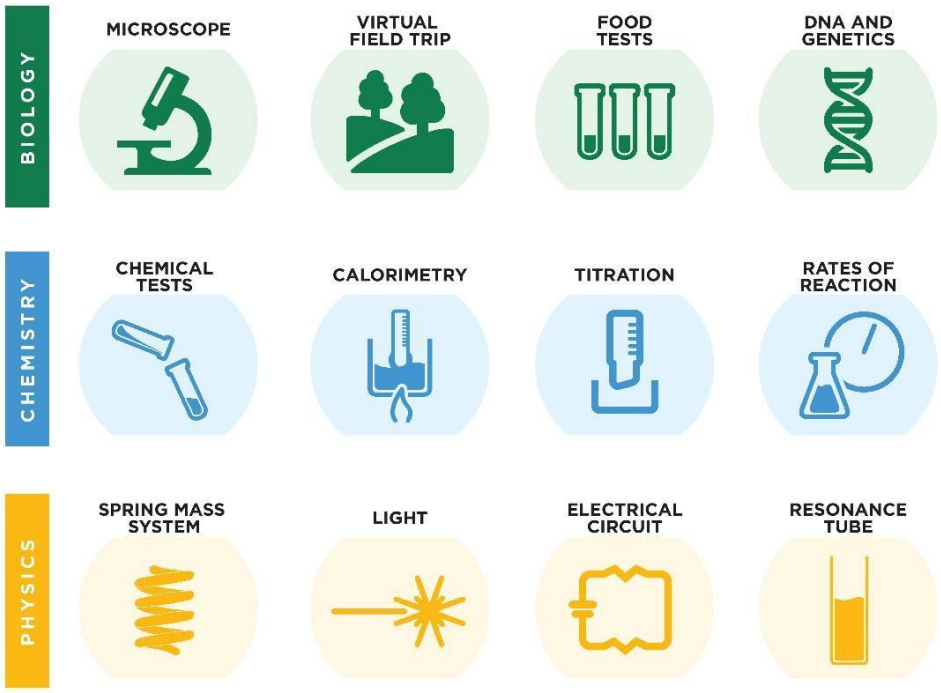
- what practical skills the students will learn
- how the engagement is being used
- alternative ways in which the engagement could be used.

As more apps in the Virtual Lab become available, work with your Head of Department and colleagues to develop more example lesson plans.

Activity 13: Planning to use the Science apps

Work with your HoD to plan activities across the whole department for using the Science apps. For example, you might work with a colleague to choose one of the apps to investigate, work through the exemplar lesson and discuss how it would work best in your school with your students.

OpenSTEM Africa Virtual Lab



The OpenSTEM Science apps in the Virtual Lab have been developed collaboratively by CENDLOS, GES and a group of SHS teachers in Ghana and The Open University (UK). They cover a range of experiments highlighted in the SHS elective science syllabuses. Students can interact with the experiment individually at home if the internet is available, or at school if sufficient computers are available. They might benefit more from the experience if they work in twos or threes, so they can discuss the issues and work together to solve problems.

With each Science app there is at least one possible exemplar lesson. These are intended to highlight the possibilities for teaching a lesson rather than anything prescriptive. It is expected that at first you might follow the example as suggested, but you could move towards developing your own plans as you become more familiar with the apps. They have all been designed to be relevant at various points in the syllabus, or over a few weeks of work, so that there is extended opportunity for students to interact with the materials.

Using ICT to support Teaching and Learning

Activity 14 will help you to think about the effective use of technology and how to make it transformational.

Activity 14: Examples of using iCampusgh and the iBox

Teachers in Ghana are using the iBox and iCampusgh, which have been developed by CENDLOS, in a number of ways:

1. **Catch up** – students who have missed lessons are able to access the material in the ICT lab and go through what they have missed.
2. Using the **video** lesson interactively – the teacher plays the video lesson to the class but stops the video periodically to ask questions or to set up a short discussion between the students about one of the issues raised.
3. **Flipping** – students work though the lesson on the iBox, in advance of the classroom lesson. The teacher then organises a series of activities in groups or pairs designed to probe students' understanding. Through careful questioning, peer-support groups can be established and the teacher can focus on those who need the most help.
4. **Note-taking** – the teacher displays the notes and students work in pairs or groups to convert the notes into alternative formats such as poster, a mind- map or a concept map. While they work the teacher walks around asking questions and checking individuals' understanding.
5. **Teacher absence** – the teacher knows that they will be absent on a particular day so arranges for the class to access the lab and work through a designated lesson.

Classify each of the above as:

1. supporting learning as usual
2. extending learning
3. transforming learning.

Reflection point

Reflect on some of the things that you have learnt and some of the things that you would like to get better at. You should raise these with your Head of Department, who will be able to help you to think more deeply about your lessons and how they may be further improved step by step.

Summary

Asking good questions is one of the most effective ways in which teachers can promote thinking. By responding carefully to the answers that students give, you can enhance thinking further, and in the process learn a great deal about your students' knowledge and understanding of the ideas that you want them to learn.

Do also continue to think about how to actively engage your female students – e.g. are there ways in which your current questions might reinforce the idea of science being a male subject and scientists being men? If so, rethink them!

It is important to plan questions in order to ensure that you ask higher-order questions that promote thinking – these are more difficult to think of on the spur of the moment, in the middle of a lesson!

A full list of the OpenSTEM Africa CPD units can be found at:
https://www.open.edu/openlearncreate/CPD_units

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Acknowledgements

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