Faculty of Education
The University of Hong Kong
香 港 大 學 教 育 學 院

Designing and enacting effective scientific investigations in science classrooms
科學課堂中有效探究活動的設計與實踐

Kennedy Chan

Background

- Associate Professor (HKU)
- Science education educator
- Science education researcher

Research interest

- Science teacher expertise
- Use of video in teacher education
- Innovative biology teaching

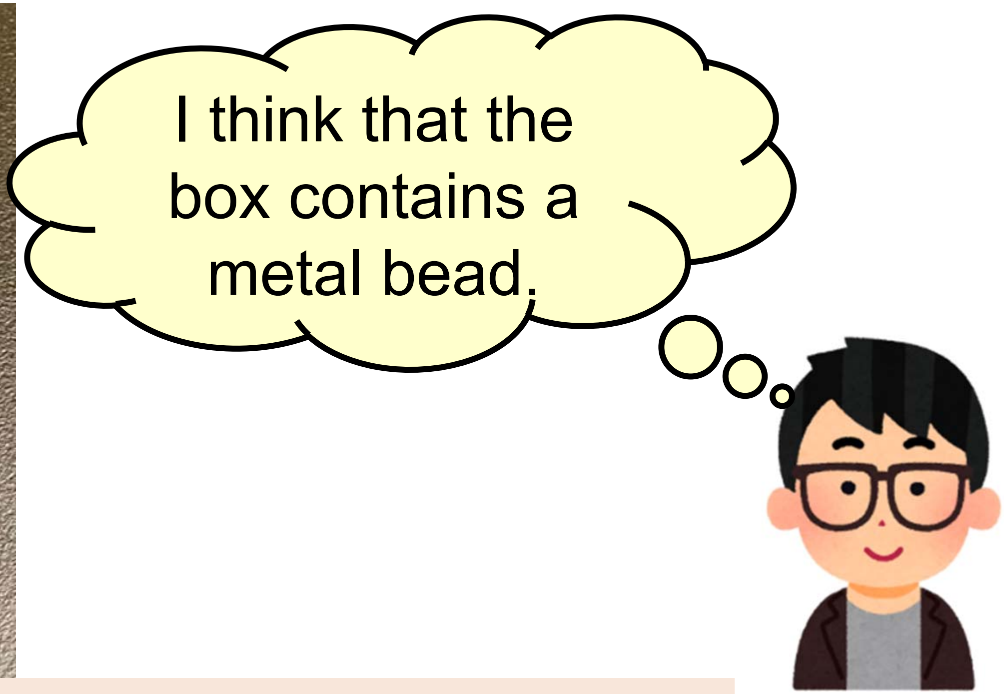
Getting to know you

Raise your hand if you are

- a classroom teacher
  - Primary school
  - Secondary school
  - Post-secondary school
- a science teacher
- a teacher professional development leader (e.g., panel heads, KLA heads, vice principals for academic affairs)

- What do you think is inside the box?
- What do you think is the internal structure of the box?
- Why do you think so?

Do **NOT** open the box!



How will you test his idea?

Which one do you think is the more likely structure? Why?

Scientific inquiry refers to "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (National Research Council [NRC], 1996, p. 23).

- Scientific inquiry is a **multifaceted** activity (NRC,1996)
  - making observations
  - posing questions
  - examining books/other sources of information
  - planning investigations
  - reviewing what is already known in light of experimental evidence
  - using tools to gather, analyze, and interpret data
  - proposing answers, explanations, and predictions
  - communicating the results
  - identification of assumptions
  - use of critical and logical thinking
  - consideration of alternative explanations

- Conducting **scientific investigation/inquiry** is a hallmark of science and a core educational goal in the science curricula of Hong Kong.
  - "[T]he curriculum aims to consolidate students with scientific inquiry skills, equipping them to pursue further studies in science and I&T related subjects at senior secondary levels" (Curriculum Development Council, 2024, p.8).

- Students often struggle to learn and apply their scientific inquiry skills in different contexts.

Challenges of using inquiry-oriented teaching

- Lack of clear articulation of the targeted scientific inquiry skills and their progression across grade levels
- Lack of high-quality instructional materials
- Lack of high-quality assessment materials
- Lack of curriculum time

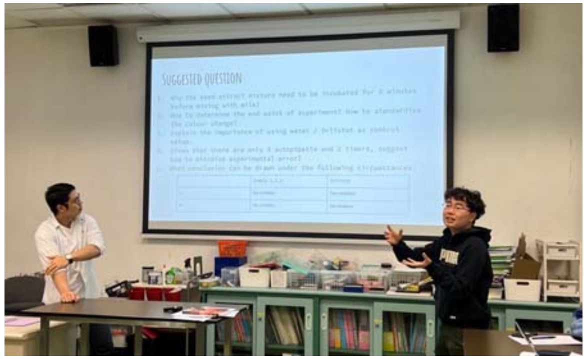
Quality Education Fund Project

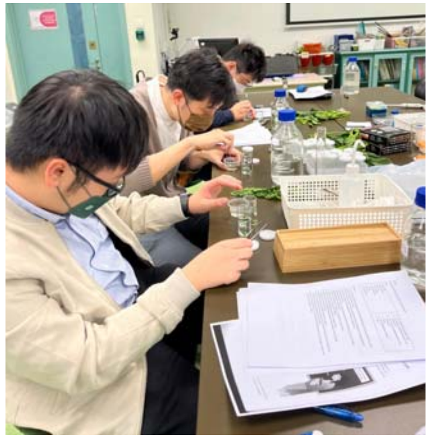
- Promoting effective use of practical work in senior secondary Biology classrooms through cognitively demanding practical work and video analysis of teaching practices (2019/0283)

優質教育基金
Quality Education Fund

Three objectives

- To develop the abilities of 16 secondary Biology teachers to understand and implement effective practical work in the classroom;
- To enhance students’ learning experiences of practical work in Biology;
- To develop 9 sets of high-quality educative curriculum materials.



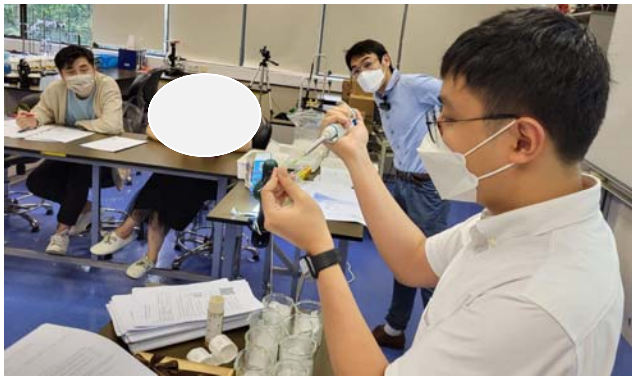


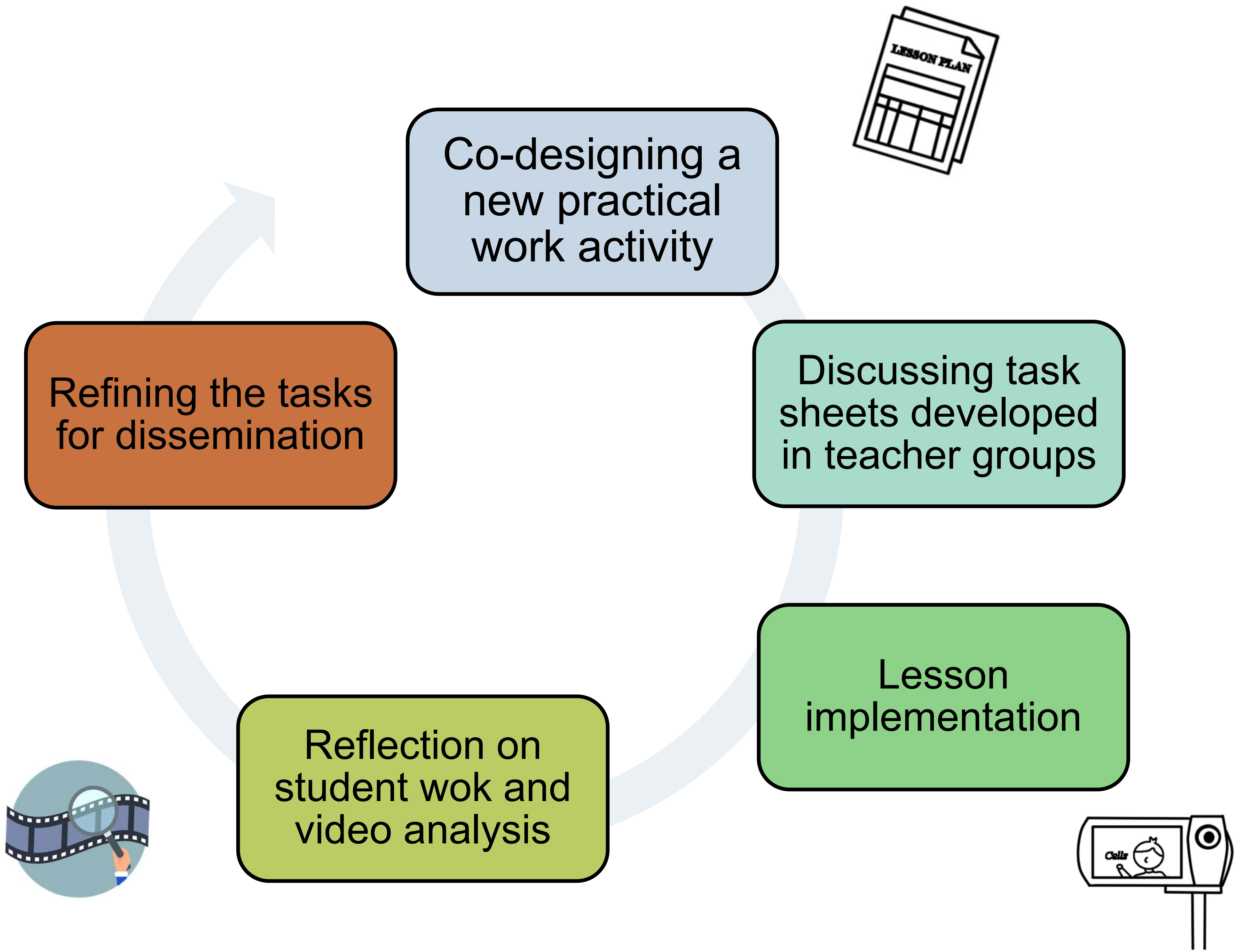
Stage 1:

□Hands-on workshops on practical work

Stage 2:

□Development of scientific investigation tasks, trial enactment, analysis and reflection on lesson videos





Co-designing a new practical work activity
LESSON PLAN
Discussing task sheets developed in teacher groups
Lesson implementation
Reflection on student wok and video analysis
Refining the tasks for dissemination

- ***I have observed that my students were performing confidently and turning into critical thinkers as they conducted the new format well designed task.*** *This project means a lot to me as a newly joined science teacher. One significant change is that I have started placing high weighting for nature of science as important as content knowledge in my teaching. (T16, Final Survey)*

- ***I discovered that both lower and higher ability students were highly engaged in the practical task and asked meaningful questions related to experimental design. This also reminds me not to undermine students learning opportunities by lowering the level of difficulty, which may even lower their learning motivation.*** *(T17, Final Survey)*

Mr. Andrew TO Ching Yuet

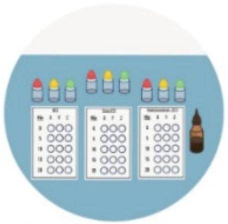
Po Leung Kuk Laws Foundation College

- Cat Grass Investigation
- Brine Shrimp Investigation
- Mystery box

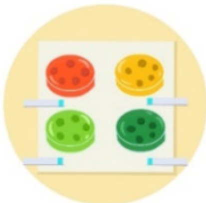
- In terms of design and implementation of effective investigative practical work,

Stage	Design principles	Implementation strategies	
❶ Preparing for the investigation	▪ Situate the investigations in meaningful scenarios/contexts relevant to students (**Contextualisation**) ▪ Provide sufficient background information for students to comprehend the context of the investigation ▪ Assess students' background knowledge related to the investigation ▪ Allow students to raise questions about the investigation or the context	• Reading Materials • Diagnostic Assessment • *See-Think-Wonder* Chart • Driving Question Board	Embedding **scaffolds and structures** for students to express their thinking Orchestrating **meaningful dialogues** around important scientific thinking Providing substantive **feedback** to advance student thinking
❷ Planning and designing the investigation	▪ Allow students to design their own set-ups ▪ Show students the materials and apparatuses to facilitate their design ▪ Allow students to trial run their designs and set-ups ▪ Engage students to evaluate and revise their own and others' set-ups/designs	• Investigation Planning Template • Annotated Diagrams • Virtual Laboratory • Mini Trial Run • Mini Whiteboard • Gallery Walk • Self & Peer Evaluation	
❸ Carrying out the investigation	▪ Remove experimental procedures that require significant procedural demands ▪ Allow students to modify procedures in the reference manual ▪ Make use of microscale instrumentation (**Microscale Instrumentation**) ▪ Make observations vivid and interesting (e.g., colourful) ▪ Engage students in collecting a large set of data (e.g., repeating their measurements, setting up replicates) (**Complex Data Set**) ▪ Perform a demonstration of difficult procedures ▪ Provide support for data collection (e.g., data collection sheet, guidance on procedures [e.g., video]) ▪ Allow students to use digital tools to collect and record data	• Reference Manual • Video with Guidance on Procedures • Teacher Demonstration • Integrated Instruction Sheet • Data Collection Sheet • Digital Tool (e.g., camera for recoding (time-lapse) videos/data)	
❹ Analysing, interpreting, evaluating and explaining data	▪ Allow students to use digital tools to visualise, represent and analyse data ▪ Engage students in analysing and interpreting complex data sets ▪ Allow students to compare their data sets with those of other groups ▪ Involve students in assessing the quality of their data by critically evaluating their own and their peers' data (or class data) ▪ Have students use data to make or evaluate claims and scientific explanations/make decisions/solve problems (**Explanation Construction/Decision-making/Problem-solving Task**) ▪ Promote student reflection on the process of the investigation (e.g., learning from errors, improving the experimental designs)	• Digital Tool (e.g., *Google Sheet* for recording and manipulating data) • Data-sharing Web Platform • Inquiry Display Board • Reflection Card or Journal	

Microscale Amylase Investigation



Yeast Bead Invertase Investigation



Yeast Bead Catalase Investigation

Yeast Respirometer Investigation

Banana Ripening Investigation

Lipase Inhibitor Investigation

Photosynthesis Inhibitor Investigation


Innovations in
Biology Investigations

Yeast Respirometer Investigation

Overview

- The *Yeast Respirometer Investigation* is related to the use of sugar substitutes in breadmaking. Students investigate the effects of different types of sugar substitutes on the rate of yeast fermentation.
- Students are given the opportunity to design and carry out experiments in which they identify significant assumptions, consider limitations in measurement, and evaluate different experimental designs (i.e., within- and between-subject designs).

Teaching Plan

Prerequisite knowledge (scientific ideas)

- Alcoholic fermentation process
- Alcoholic fermentation as an enzyme-catalysed reaction

Lesson	Lesson sequence	Duration (mins)	Resources
Stage ❶ Preparing for the investigation • The investigation is set in a decision-making context (**Decision-making Task**). • The investigation is situated in an authentic daily-life context related to the use of sugar substitutes for breadmaking (**Contextualisation**). • Students have the opportunities to design their own respirometers and trial run their designs (*Trial Run*). • Students evaluate own and other set-ups in terms of their feasibility and accuracy (*Self & Peer Evaluation*). • Students read information to better understand the working principles of different set-ups (*Reading Materials*).			
1	• The teacher introduces the investigation context to students in *Worksheet 1*. • The teacher provides materials for students to design and trial run their set-ups.	40	*Worksheet 1*, Student Samples 1
Before Lesson 2	• The teacher distributes *Worksheet 2* for students to complete at home and be familiar with the working principles of different set-ups.		*Worksheet 2*
Stage ❷ Designing the investigation • The teacher shows students the microscale respirometer.			
2	• The teacher provides feedback on students' responses in *Worksheet 2* in class. • The teacher shows students the microscale respirometer and asks them to explain how the set-up can be used for investigating the effect of sugar substitutes.	40	*Worksheet 3*
3	• The teacher discusses with the students some questions related to the experimental design. • Teacher provides students with laboratory manual for preparation at home.	40	Teacher Notes 1
Stage ❸ Carrying out the investigation • Students watch pre-recorded video that show the procedures of how to set up the respirometers (*Video with Guidance on Procedures*). • The teacher performs demonstration to show how to assemble to microscale set-up (*Teacher Demonstration*). • Students use microscale instrumentation that reduces the time of the experiments (**Microscale Instrumentation**). • Students collect more complex data sets by setting up replicates (**Complex Data Set**). • Students use cameras to record data (*Digital Tool*).			

Instructional Materials

Stage ❶ Preparing for the investigation

Student Worksheet 1

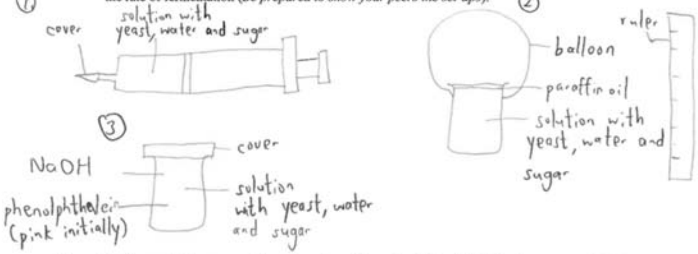
Notes for teachers

- Teachers can distribute *Worksheet 1* and instruct students to design experimental set-ups to measure the rate of yeast fermentation.
- Teachers can provide students with concrete materials for their trial runs to see if their set-ups are feasible. See the *Supplementary Resource* section for the list of materials.
- The *Supplementary Resource* section provides examples of possible set-ups.

Student Samples 1 (Worksheet 1)

Directions:

1. Based on the materials and apparatus given, draw two set-ups your groups would use to measure the rate of fermentation (*Be prepared to show your peers the set-ups*).



2. Briefly explain how you will use the set-ups to investigate the effect of the three sugar substitutes on the rate of fermentation.

① measure the volume of CO_2 produced per unit time

② measure the increase in height of balloon per unit time

③ measure the time for the disappearance of the pink colour (CO_2 neutralize NaOH)

Notes for teachers

- The student sample shows the drawing of some set-ups designed by students.
- Teachers can distribute *Worksheet 2*, which prompts students to analyse the principles of different set-ups after they have explained their set-ups.
- Students' responses in *Worksheet 2* can be collected using a *Google Form*.
- Teachers can read *Appendix 3* from Chan et al. (2021) for the possible set-ups and their working principles.
- Scan the QR code to access *Appendix 3*.

Stage ❸ Carrying out the investigation

Laboratory Manual

Notes for teachers

- Teachers can distribute the manual for students to read and prepare before the investigation.
- The pre-recorded video provides the steps for assembling the microscale respirometer.
- Teachers can perform a demonstration to show students how to set up a microscale respirometer and highlight the critical steps.
- Teachers can ask questions to check if students fully understand the procedures (e.g., how many respirometers do we need to set up?).
- The *Supplementary Resource* section contains the list of materials.
- Scan the QR code to view the process of the experiment.

Task 4

- Read the following procedures to carry out the investigation.

Procedure

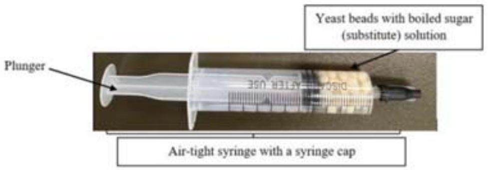
1. Measure 15 mL of boiled distilled water containing a universal indicator using a measuring cylinder. Transfer it to a 25-mL boiling tube.
2. Expel 3 mL of air from a 3-mL plastic pipette.
3. Use the 3-mL plastic dropper to suck up 1 mL of yeast extract solution.
4. Invert the dropper to allow the liquid to flow into the bulb portion.
5. Expel the air from the 3-mL plastic dropper containing the yeast extract.
6. Use the 3-mL plastic dropper to suck up 1 mL of the boiled sucrose solution, sugar substitute 1, sugar substitute 2, sugar substitute 3, or distilled water.
7. Invert the dropper to allow the liquid to flow into the bulb portion.
8. Gently squeeze the bulb of the pipette to mix the yeast extract and sugar/sugar substitute/distilled

Scan this QR code to see how to assemble the experimental set-up.

Supplementary Resources

Possible Modifications

1. **Investigating yeast bead fermentation**
   - A syringe can be used to set up a yeast respirometer conveniently.
   - If yeast beads are used, the reaction mixtures can be collected, and the solution can be used for titration against an alkaline solution containing a pH indicator.



Notes for teachers
- Teachers can use the following procedures.
- The procedures for making yeast beads can be found in *Yeast Bead Invertase/Catalase Investigation*.
- Scan the QR code to view a video that shows the whole experiment.
- Read the *Technician Notes* section for the materials required for this experiment.
- A video showing how to set up a yeast respirometer using a syringe is available via the QR code alongside the procedure.

1. Prepare the yeast beads.

2. Set up the respirometers.

3. Perform a titration to determine the number of drops of solution for colour change of the alkaline solution.

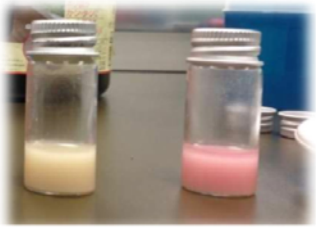
Technician Notes

Materials for Task 1

15% Yeast (activated)	Test tube	Syringe	Phenolphthalein
Balloon	Boiling tube	Syringe cap	Straw
String	Rubber tubing	Paraffin oil	Glass bottle
10% Sucrose solution	Plastic dropper	Dropper bottle	0.1 M Sodium hydroxide solution
Boiled distilled water	Timer	Ruler	Water
Straw	Electronic balance	Measuring cylinder	Petri dish

* Containers of varying sizes can be provided to students.

Possible set-ups




Innovations in Biology Investigations
Introduction
Investigations
Conclusion
Future Initiatives
Resources
Innovations in Biology Investigations
On this website, you will find research-informed ideas on how to enhance student learning of scientific inquiry skills using scientific investigations in Biology classrooms.

Contact information

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References

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