**5Qs:** Developing Skills to Manage Ambiguity Inherent to Discovery Research

**Description:**
Ambiguity in experimental outcomes is inherent in discovery research. Such ambiguity can be a source of frustration and self-doubt for novice/beginning scientists who have not had much experience managing and interpreting research data. **5Qs** (five questions) is a simple pedagogy tool research mentors can use to help students think through their observations systematically, to draw supported conclusions, and to decide on next steps, all of which can be done independently and prior to seeking input/advice from their mentor. The 5Qs thus offers students a strategy to handle ambiguity in research data, ideally reducing frustration and bolstering their development and confidence as scientists.

By providing students with the tools to review their data both systematically and critically prior to seeking advice from fellow students or their research mentor, this exercise touches on 3 components of the SEA-PHAGES instructional model of “becoming a scientist”, which include 1) encouraging independence, 2) facing ambiguity, and 3) modelling scientific thinking. In addition, by placing the onus to review the data on the students, especially in the context of course-based research with high student-to-instructor ratios, this exercise can increase the amount of time a research mentor has to work with/mentor each student (instructor mentorship).

After completing this module, students should be able to draw supported conclusions from their observations/dataandplan experiments based on supported conclusions from previous data

**Intended Teaching Setting**

**Course level:** for all students, particularly for those with little to no prior research experience
**Instructional Setting:** in-person classroom/laboratory
**Implementation Time Frame:** ~ 10 - 15 minutes

**Project Documents**

**Facilitator document:** this document; instructions on subsequent pages.**Learning activity document(s):** none, activity provided on subsequent pages.**Assessment document(s):** none, recommendations provided on subsequent pages.

**5Qs: Implementation Instructions**

Over the course of a research project, your students should practice asking themselves these 5 questions regularly and whenever making experimental observations, particularly when the observations are not as expected or the experimental outcomes are ambiguous.

To implement 5Qs:

* List the following 5 questions on the board, or at a visible location within the lab class, so that students can easily review them. Do so early and have it available to students throughout the research experience.

**Q1: What did you anticipate observing?**

**Q2: What did you observe?**

**Q3: What materials did you use and, from your observations, how can you tell if those materials were OK?**

**Q4: What experimental steps did you perform and, from your observations, can you tell if there may have been an experimental error?**

**Q5: What do you think happened? Is there a plausible explanation for your result?**

* Provide guidance to your students, during the first few weeks of class, on how to answer these questions when making observations. An example is provided on the next page.
* Suggest that students make a note of their responses in their laboratory notebook. Rough notes are fine. At a minimum, students should thoroughly thought through the each of the 5Qs and be able to verbalize a complete response to each question. Encourage peer-to-peer input as they prepare their responses.
* Use their answers to the 5Qs to help them draw conclusions and prepare for the next experimental step. By extension, try to avoid giving students answers before they first work through the 5Qs themselves and then with you.
* Over time, students will become familiar with the activity and develop the skills to review and interpret their data with confidence. As an extension activity, students can review their written answers and use these for their own reflection at the end of the term. For a sample reflection activity, see the “Letters to a Young Scientist” resource. As such, it is worth having students save their written answers.

**Example:**

A student performed a spot test and received the results indicated in the image below. An example of how a student may use 5Qs to work through the analysis of the results is outlined below.

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**Q1: What did you anticipate observing?**

I anticipated:

1. A lawn of bacteria on my plate
2. Clearing on the plate for my control phage
3. No clearing on the plate for my negative control
4. Maybe clearing on the plate for sample A and B

**Q2: What did you observe?**

I observed:

1. A nice lawn of bacteria on my plate
2. No clearing on the plate for my control phage
3. Clearing on the plate for my negative control
4. Clearing on the plate for sample A but not sample B

**Q3: What materials did you use and, from your observations, how can you tell if these materials were ok?**

|  |  |
| --- | --- |
| Materials Used | How can I tell if the materials are OK? |
| Agar plate | Looks like it should, bacteria grew, no contamination |
| Top agar | Looks like it should, bacteria grew, no contamination |
| M. smegmatis culture | Looks like it should, bacteria grew, no contamination |
| Control phage sample | Can’t tell if this is OK because no clearing |
| Negative control sample  | Can’t tell if this is OK because there was unexpected clearing |
| Sample A | Don’t know – seems OK |
| Sample B | Don’t know – seems OK |

**Q4: What steps did you perform and, from your observations, how can you tell if these steps were ok?**

|  |  |
| --- | --- |
| Steps Performed | How can I tell if the steps were performed OK? |
| Mixed top agar with bacteria | Looks like it should, bacteria grew, no contamination |
| Poured top agar + bacteria onto agar plate | Looks like it should, bacteria grew, no contamination |
| Allowed top agar mixture to solidify | Looks like it should, nice top agar lawn |
| Spotted controls and samples | Can’t tell, because controls were not as expected |
| Allowed to dry | Looks like it should, spots in the middle |
| Incubated at 37C | Looks like it should, bacteria grew, |

**Q5: What do you think happened?**

Based on Q3 & Q4, something is either wrong with the control samples, or with my spotting of the control samples onto the plate. Maybe I mixed up my controls.

**Summary**: As demonstrated in this example, the 5Qs provide a tool for a novice researcher to mentally walk-through the analysis steps necessary to evaluate an experiment. By crafting a response to each question, the novice researcher systematically evaluates the experiment and can then properly formulate appropriate next steps.