Introduction

The accounts of the investigations, in conjunction with the questions at the end, are designed as activities to raise issues and address unexplained reasoning behind decisions (tacit knowledge / thinking). These pupils’ accounts are not ‘perfect examples’ of executing investigations.

The investigations illustrate different approaches to collecting evidence and how the ‘thinking behind the doing’ of the concept map can be applied in such contexts.

The conceptual overview represents a network of intricately linked ideas, and decisions when investigating are based on nuanced application of these ideas, involving mental juggling as juxtapositions and contingencies are considered according to context. In terms of validity, there is no distinction between approaches (such as an ‘experimental approach’ or an ‘observational approach’) to finding patterns in data (Cleland, 2002). No one approach is privileged over another; the key issue is what is appropriate depending on the circumstances, as illustrated ... Of itself, the map embodies the realisation that ‘there is no single set or sequence of steps followed in all investigations’ (Lederman et al., 2014, p. 68). Roberts & Johnson (2015) p. 359.

The accounts illustrate the iterative nature of an investigation and the importance of trialling to make decisions about the quality of data.

The annotations exemplify points made in Roberts & Johnson (2015). (Ideas in bold in the annotations are concepts on the map).

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Solving problems in science requires an understanding of both substantive ideas and ideas about evidence; they are inextricably linked (as shown on the concept map). This places great cognitive demand on the investigator. In this pupil investigation the substantive demand is relatively low so as not to detract from a focus on the ideas about the quality of data.

**Bottle tip**

Some pupils were eating their picnic lunches on a sloping bank. They all had pop bottles with different amounts of drink in them. Some bottles wouldn’t stay standing on the slope – they toppled over. Others stayed upright.

Does the angle of the slope at which the bottle topples over depend on how much pop is in the bottle?

You could use a large plastic pop bottle with a screw lid and water instead of pop.

You might need to think about these things before you start:

- what is a ‘centre of gravity’ and what does it mean?
- how will you create a slope?
- what will you need to try out in your trial run?
- what do you think might happen when you take all your results?
### Poppy’s investigation

**What are the variables?**

- **Trial run**
- **Independent variables**
- **Dependent variables**
- **Amount of water**
- **Angle of slope**
- **Type of bottle**
- **Surface**

**How does the angle of the slope needed to tip a bottle over depend on how full the bottle is?**

**What do I think will happen?**

- When it is empty, I expect the bottle to tip over even when the slope is very gentle. But when I put water in it, it will make the centre of gravity lower. It’s like when they make sure all the weight of a bus is low down so that it won’t turn over. So I think it will stay upright until the slope is steeper (which is when the plant is lifted higher). When it’s full, though the centre of gravity will go higher again. Then it’s like the bus being too full upstairs. I think that the slope which makes it topple will be less again. So I think the steeper the slope at which it topples might go down when it gets over half full. So the graph I draw might be something like this.

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**#2.** The key variables affecting the relationship between IV and DV have been identified. In this simple context their identification does not rely on sophisticated substantive knowledge. All the variable values can be manipulated by the investigator.

**#3.** Trial runs characterise iterative working wherein decisions are made to establish the quality of the data (including the reliability of the DV, see #5). The investigator gets a feel for the relationship across the full range of the IV; and makes decisions to ‘operationalise’ the DV; and manipulates the values for the CVs. Decisions about one variable cannot be made without reference to others and determining their impact on the DV. The investigator avoids variation between types of bottle (shape and size) by selecting only one (and recognises this later, see #8). Measurement decisions are made to reduce uncertainty (but see also #8).

**#4.** Scientific theory enables predictions (hypotheses) to be made, which in turn may be tested by experimentation.
#5. This establishes a pattern over the range of the IV in relation to the scale of the variation in the repeated readings (the reliability of the data). The investigator judges 5 repeats to be enough but does not explain why.

#6. The reasoning that the variation in the IV in relation to changes across different values of the DV is behind the judgement to dismiss Reading 2 at 10cm as anomalous.

#7. Further data are collected at smaller intervals of the IV to help establish a pattern. This couldn’t have been ‘pre-planned’; it was in response to the quality of the data as it was collected.

In more traditional ‘apparatus, methods, results’ accounts, written up post hoc, the iterative working shown here would, by convention, have been presented as a more linear account.
The validity of the data depends on the variation in the repeated readings and the magnitude of the effect of changing the IV. Greater resolution of the measurements of both IV and DV would have increased the reliability.

The pupil attempts to reflect the quality of the data in the qualified claim.
Eggs
If you spin eggs they will go on spinning for different times. Fresh eggs stop quickly and spin more slowly than hard-boiled eggs. If you’d got some different eggs, some cooked for different times and others raw, could you find out which was which without opening the shells?

Find out how the number of spins before an egg stops spinning depends on how long it has been boiled for.

You might need to think about these things before you start:

- do a trial run with a fresh egg – can you think of any reason why it might spin more slowly than a hard-boiled one?
- how will you set it spinning?
- what will you measure?
- what do you think might happen – what might your results look like?

#10. This investigation has very low substantive demand.
This investigation has data with more variation than in Bottle Tip. There is no variation in the sample tested (but it is noted between eggs); the cause of variation is in the event (the CV values) and variation in measurement of the DV.
Early decisions are made during trialling to help reduce the variation in the data. Only 1 egg is used thus avoiding variation in some of the identified CVs. Variable values can be manipulated to be kept more or less constant (with acknowledged variation in the values) to establish reasonable control of the confounding variables. Controlling the setting of the spin remains the biggest issue.
There's a lot of spread in the results from the fresh egg. I need to do some more trials at different boiling times to see if the spread is too big. This is my data when the egg was hand-boiled.

<table>
<thead>
<tr>
<th>Trial run</th>
<th>Number of spins</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>7.75</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>15.25</td>
</tr>
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<td>6</td>
<td>9</td>
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<tr>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>8</td>
<td>15.1</td>
</tr>
<tr>
<td>9</td>
<td>15.5</td>
</tr>
<tr>
<td>10</td>
<td>16.25</td>
</tr>
<tr>
<td>Average</td>
<td>12.18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial run</th>
<th>Number of spins</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>10.5</td>
</tr>
<tr>
<td>3</td>
<td>14.25</td>
</tr>
<tr>
<td>4</td>
<td>34.25</td>
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<tr>
<td>5</td>
<td>31</td>
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<tr>
<td>6</td>
<td>22.25</td>
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<tr>
<td>9</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>38.5</td>
</tr>
<tr>
<td>Average</td>
<td>36.03</td>
</tr>
</tbody>
</table>

Repeated readings help assess the reliability. The uncertainty could have been reported and shown on the graph.

The investigator reflects the uncertainty of the data in the claims made about the relationship.

Do I believe my results and why?

I don't think this method would be any good for testing to see how cooked an egg was. The results change a lot from one try to another; it isn't very reliable. I could use it to distinguish between the same egg when it was hard and raw but the data is not reliable enough for in-between.

I would need a much better way of getting the egg spinning and I found it difficult to count it when it spun very fast. If I'd recorded the egg spinning on video I could have slowed the tape down and counted more accurately.

I'd need to see whether cooling it in water after cooking really did stop the egg getting any harder.
There might be variation in the number of spins and time at which the maximum is reached but the pattern is likely to remain the same from egg to egg. Spinning could not be used as an instrument to measure the degree of hardness of an egg (unlike a spring to measure force).

Not all eggs behave the same. The variation in data that would have resulted from using a large sample of eggs would have made it harder to establish a pattern.

Questions

1. During the trial run Harbinder said that the spread of results from the uncooked egg might be too big, but after spinning the hard one she thought that she could continue with the investigation. In groups explain why she was concerned.

2. Discuss why Harbinder thought that it would be OK to continue after she'd at last the hard egg.

3. After trying out the hard-boiled egg Harbinder decided to repeat the egg spinning 30 times for each boiling time. Why did she decide to do this?

4. Harbinder wasn’t sure how to draw the graph. Did she get it right? Write notes around the graph commenting on it.

5. Most people don’t boil eggs for 30 minutes. Why did Harbinder do this?

6. In the circle of variables, underline the variables that Harbinder controlled.

7. Circle the part of Harbinder’s report that comments on the effect of the variables she didn’t control for.

8. Why was it important for Harbinder to compare her results with those of others in her class?

9. Draw a star next to the parts of Harbinder’s report where she suggests ways to improve her investigation.

10. Underline information on page 1 that could be used when planning another method for egg testing.
In this investigation the variation is unavoidable. Even when narrowed down to one species of tree there is variation in sample of trees; CVs cannot be manipulated; and there is large uncertainty due to estimates for measurements.

Does size matter?
If you look at trees with fruits on them you’ll notice that some trees have more fruits than others. Do taller trees have more fruits than shorter trees?

Find out how the number of fruits on a tree depends on how tall it is.

You might want to think about some of these things before you start:
- What type of tree will you measure?
- When does it have fruit?
- What factors might affect how tall a tree is?
- How will you make sure that you have reduced the effects of as many of these variables as possible?
- How will you measure the height of each tree?
- How accurate do your height measurements need to be?
- How many trees will you count?
- How will you count the number of fruits on each tree?
- If there are too many fruits to count, how will you estimate the number?
- How will you present your data?
Richard's investigation

How does the number of fruits on a tree depend on its height?

What are the variables?

Trial run
I decided to do my experiment on Mountain Ash trees because there are lots near my school. I had a look at some for a trial run and noticed that when they are growing in a wood they grow taller because of the other trees so I decided to choose trees that were growing on their own.

I will need to survey quite a lot of trees because they seem to vary a lot even when they are the same height – there are lots of other things that affect how tall a tree is growing, such as soil and how much light there is.

I can't count all the berries. I will count the number in a few bunches that have fallen off the tree and then count the number of bunches on the tree. Since the bunches are different sizes, I'll try to select fallen bunches at random.

I will measure the height of the tree by standing a metre rule against the trunk and stepping back to estimate the height of the tree. I can measure to the nearest fifth of a metre like this, so I think that it is fairly accurate.

What do I think will happen?
I think that the taller the tree, the more berries it will have. But once the tree gets past a certain height it will not have so many berries because it will be old.

My plan
1. Choose 50 trees that are growing on their own.
2. Estimate how high they are using my meter rule.
3. Count the number of bunches of berries.
4. Find 5 bunches from under different parts of the tree and count the number of berries in each one – use this to get an average for the number of berries for each bunch.
5. Work out how many berries there are on each tree.

#18. The trees, whose heights and berries are the focus of this investigation, are affected by many variables whose values cannot be manipulated to be kept constant by the investigator.

#19. The variation in height due to proximity of other trees could be reduced by selecting trees standing on their own. Instead of deciding the values of the IV (as in Bottle Tip and Egg) the investigator will have to sample enough trees to ‘capture’ the variation in a representative sample. The scale of uncertainty in making the measurements of ‘berries in bunches’ and the ‘height of the tree’ are considered too. The CVs' values could have been measured at each site to enable post hoc matching.
The uncertainty in the data is reflected in the data on the scatter plot. Since so many variables might have affected the number of berries (in addition to the height of the tree) a correlation is all that can be claimed.

The variation in much biological data requires large data sets for a pattern to be established.
#22. An evaluation of the quality of the data draws on the ideas about evidence summarised in the concept map.

#23. The explanation draws on the pupils’ understanding of substantive ideas; and illustrates how the ideas of evidence (shown with a shadow on the concept map) are informed by the substantive ideas.

Questions

1. Make a table like the one below and list the problems that were identified during the trial run in column 1.

<table>
<thead>
<tr>
<th>Problems from the trial run</th>
<th>How they were overcome?</th>
<th>Further Improvements identified while evaluating</th>
</tr>
</thead>
<tbody>
<tr>
<td>trees seem taller if growing close to others</td>
<td>find trees on their own</td>
<td>none needed</td>
</tr>
<tr>
<td>trees seem to vary a lot</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Next to each point in your list write down what decision was made to overcome it in column 2.

3. In his evaluation, Richard suggested further improvements. Write these suggestions in the third column.

4. What factors might Richard have taken into account when he decided to measure 30 trees?

5. What is the height of the tallest tree?

6. How many berries were on the shortest tree?

7. What data must have been collected but isn’t shown in Richard’s table of results?

8. Was a scatter graph the best way of presenting the data? Why?

9. None of the control variables could be kept constant. How did Richard make sure that he was carrying out a fair test?

10. What other factors may have affected the number of fruits formed?