Project 2

Accuracy and precision

Phone-y science

- Themed lesson guide for teachers
- Teacher's project guide
- Class project instructions
- Student project portfolio

This project is extracted from Analytical Chemistry in Ireland
More projects and resources available from https://rsc.li/3P00Lfl

THEMED LESSON GUIDE FOR TEACHERS

Phone-y science

Focus: **accuracy and precision**. Four–five lesson plan

2

Task

Using mobile phone devices and apps to collect colorimetry data.

Background

Computers have revolutionised science and its ability to capture and analyse data, and now smartphones are showing the same potential. Thanks to their evolving technology and growing use many of us now have easy access to sophisticated instrumentation.[1] Some current research is using smartphones for colorimetric water quality analysis, soil analysis and air quality. This, coupled with GPS, has the potential to influence pollution management and policy.[2]

The idea behind this project is to get students familiar with the idea of spectrometry and the type of laboratory equipment that can generate results. It is hoped that producing their own results with their own equipment will inculcate an increased appreciation for accuracy and precision, and thus how the design of a method and its robustness can infer more reliable data. It also engages them with the questions surrounding 'the reliability and potential for using mobile phones for data collection'.

Learning objectives

On completion of the project students will:

- have increased their familiarity with colorimetry and mobile devices as tools for data collection;
- be able to describe the scientific method, in particular the difference between accurate and precise;
- have applied their subject knowledge as part of analysing and presenting the results of their project;
- be able to describe the relationship between concentration and absorption.

Pre-planning

- Ideally, students will have completed the relevant sections in this booklet before attempting the project to support their learning. They should have a basic understanding of accuracy and precision, how to draw and interpret graphs and colorimetry.
- Because the app charges a small fee it is advisable that at least one person in each group downloads this in advance, as usually children need permission from their parents to complete these payments.
- Prepare different coloured solutions of known concentrations and have different coloured paper for the investigation stage.

General equipment

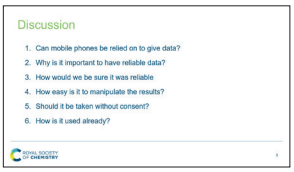
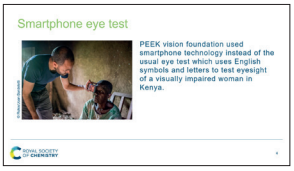
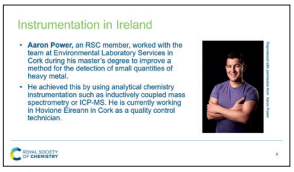
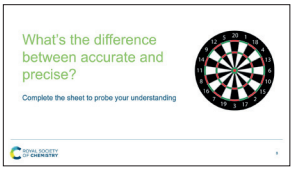
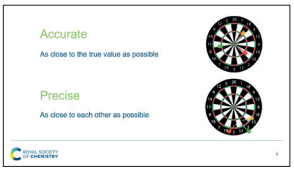
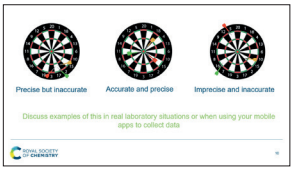
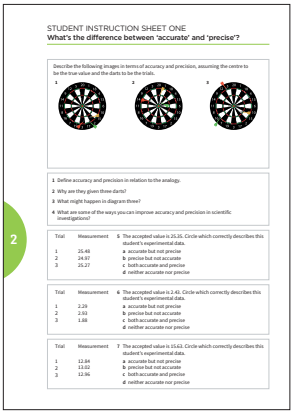
- Blackcurrant or other similar juice, or any coloured standard solutions.
- Colorimeter app, colorimeter lab equipment if possible to check real values.
- Craft equipment, a selection of coloured paper, cardboard and cellotape.

Additional resources

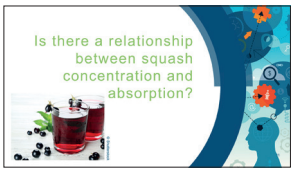
- For use with the suggested lesson plan PowerPoints, the **teacher's project guide**, the **class project instructions** and the **student project portfolio**.
- Visit **edu.rsc.org/resources/analysis** for information and resources for teaching about spectroscopy.
- Video demonstration and resource **edu.rsc.org/resources/smartphone-spectroscopy-changing-concentrations/4012061.article**

References
1 McGonigle *et al*, Sensors, 2018, **18**, 223.
2 C Sicard *et al*, Water Res., 2015, **70**:360-9.

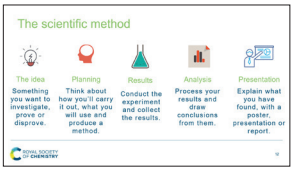
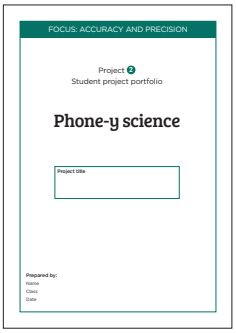
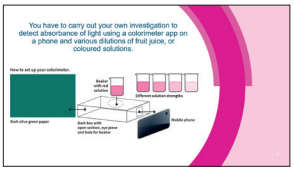
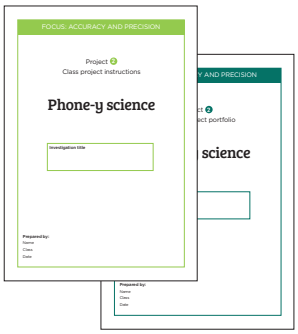
PHONE-Y SCIENCE: LESSON ONE
The difference between accuracy and precision

STAGE/PURPOSE	RUNNING NOTES
Engage Get students interested in instrumentation and how they can become a part of it, while asking if the data generated is actually reliable.	 Display slide 2 shows the question to facilitate discussion and open up the themes of data collection and instrumentation.  Using slide 3, students could discuss in pairs or as a group, the answers to the questions on the board.
Real world and careers link Get students interested in how this links to their career aspirations and industry in Ireland.	  Display slides 4 and 5 give global context to show how this is relevant to the real world.   Display slides 6 and 7 show condensed personalised versions of two careers stories.
Scientific method This section allows teachers to introduce key concepts for undertaking of the scientific method.	    Slides 8, 9 and 10 focus on the concept of accuracy and precision. This could be completed with an actual dartboard or using the subsequent slides to discuss the differences in the concepts. The PowerPoint should be used in conjunction with **student instruction sheet one**. Further discussion points include: • the importance of carrying out at least three trials in order to gain more accurate results; • anomalous results; • repeating experiments until you get concordant results; • using averages to get more accurate values to use in calculations; • more accurate and less accurate glassware in analytical chemistry; • instrumentation as a way to improve accuracy and precision; • systematic errors such as consistently reading the burette wrong; • the importance of methods and techniques to reduce errors such as reading the meniscus from the bottom each time instead of the top.

2

STAGE/PURPOSE	RUNNING NOTES
Pre-project knowledge Colorimetry-1 Skip this if you are confident students understand the relationship between absorption and concentration.	 Present slide 11 using the following teaching strategy: → 10 students lined up in front of the room. → Five students are wearing the same coloured sticker. Each student represents a particle of the substance. → The remaining five students represent the solvent the substance is dissolved in; these students stand with their hands behind their back. **1** Turn a light on to indicate the start of the simulation and then release 10 white balls (scrunched up pieces of paper will work just the same). **2** Only students wearing a sticker can lift one ball. **3** Five balls are lifted, therefore five remain. Students can see if we know the 'amount' of light initially used, we can see how much was absorbed and how much passed through. Allow students to begin to understand how absorption of light can be used to form a relationship with the concentration of substances in a solution.
Colorimetry-2 Help students to understand and distinguish between the colour of light being absorbed and measured versus the colour of the solution.	Define colorimetry for the class. You can use the following extension on the teaching strategy above as a means to consolidate your student's understanding of the topic. To allow student's to visualise this concept: **4** The same students are selected again, each wearing the same coloured sticker. This time two (complimentary) coloured balls are thrown at the students (eg blue and orange). Each student is only allowed to catch a matching coloured ball to their sticker. Ask students to put the matching coloured ball in their pocket or out of sight of the rest of the class. This represents the colour that has been 'absorbed' and is what will be 'measured' in the experiment. The ball that was not caught, will fall to the floor, this represents the colour of the solution that we will see. This is a visual illustration of the absorption of certain wavelengths of light in a solution. 

PHONE-Y SCIENCE: LESSON TWO
Planning the project and carrying out the investigation

STAGE/PURPOSE	RUNNING NOTES
Project introduction and criteria Giving an overview of the project and the scientific method.	  Display slide 12 shows the key stages of the scientific method. These overlap with key sections in the **student project portfolio**.
Project instructions and investigation Students should be encouraged to play around with the equipment before deciding on a method and collecting results.	  Display slide 13. **1** Put students in groups and give each group a copy of the **class project instruction** sheets. **2** Give each student a copy of the blank **student project portfolio** sheets. **3** Allow them to plan and investigate which method they will choose. During this section students should be able to explore the best method for their investigation. This will require some setting up of equipment, use of craft materials and the coloured solutions. Finally, when the group is clear about their method, give each student a blank **student project portfolio**. Ask them to individually fill in the planning section of the report and collect their data.

PHONE-Y SCIENCE: LESSON THREE
Analysis

STAGE/PURPOSE	RUNNING NOTES
Project analysis This stage will allow students to apply their knowledge of colorimetry and explain the intricacies of accuracy and precision.	Drawing graph and completing results analysis. → The **class project instructions** contain comprehensive help with how to conduct this analysis. Students should be given the real values for concentration of solutions and allowed to compare them, or be shown how to calculate this (see the **teacher's project guide** for method). **Extension task** – they also must compare their results with another group to ascertain the difference with respect to the instrument or method. Alternatively, they could collect results using different solutions. Begin preparing the presentation – class time could be given for this and additional time as a homework. They should be given access to the **careers and industry stories** to be used in their presentations.

2

STAGE/PURPOSE	RUNNING NOTES
Presentation Consolidate and demonstrate knowledge acquisition. Peer marking – allows the students to evaluate the work of others.	Students could be given a lesson to prepare their presentations or it could be set as a homework task. To encourage the students to evaluate the work of others, and noticing the different ways of conducting the same experiment, showing their method and how this fits in with the research. See instructions and a marking rubric below.

Presentations: three–four minutes long

- A brief overview of what you did, including what was unique about your method and explaining why you chose to do it that way.
- What went well and what could have been improved.
- How your results compared to the real values for the stock solutions or another groups, and which you thought was more accurate/precise and why.
- Talk about how this relates to analytical chemistry and instrumentation in the real world.
- Focusing on one careers story, describe how the use of smartphone technology could (in the future) make the role of the scientist more effective – imagination is encouraged.

Marking rubric

TASK	EXCELLENT	GOOD	MISSING	COMMENT
Introduced the investigation				
Their design				
Why they chose it				
What went well etc				
Did they compare results?				
Did they explain correctly who was more accurate or precise and why?				
Did they talk about how this related to the chemistry in industry?				
Career story focus?				

Project 2

Teacher's project guide

Phone-y science

Investigating how mobile phone devices and apps can be used to collect colorimetry data

Why are you doing this investigation?

What do you want to find out? If phones can be used to produce reliable data, ie values that resemble the true concentration.

Include any inspiration for undertaking the project. The work of other scientists, such as those in the careers portfolio, or those projects mentioned in the background information.

What you think you might discover or find? If mobiles can be used to collect accuracy or precise data, and this could be relied on by scientists.

Deciding your method

Students should be encouraged to undertake this as a team, being more creative than the diagram given. This set up is-simple, but many variations are possible and the students should be encouraged to explore their own method with repeatability and accuracy as the main goals. Discuss drawbacks, for example, it has no infrastructure for holding the phone in place.

For your own guidance, you can watch a video by the Royal Society of Chemistry education coordinator in Ireland **edu.rsc.org/resources/smartphone-spectroscopy-beer-lambert-law/4013028.article**

Additional useful resources on the topic:

- Science in School's secondary school teacher's resource **scienceinschool.org/content/smartphones-lab-how-deep-your-blue**
- Professor of chemistry, Tom Kuntzleman's blogpost and video **chemedx.org/blog/use-your-smartphone-absorption-spectrophotometer**

Variables

Students should be encouraged to identify their own variables and design in how they will encourage precision and accuracy.

Here are some exercises you can use to demonstrate these concepts:
edu.rsc.org/cpd/making-measurements/3009329.article
edu.rsc.org/lesson-plans/accuracy-and-precision-in-practical-investigations-14-16-years/108.article

Independent variable – concentration or dilution of the juice/solution

Dependent variable – the RGB (red, green and blue) value given by the phone on the colorimeter app. They will need a blank, and at least three trials.

Higher level (HL) students could be selected to decide and create the class dilutions – it's better to have class dilutions or a few sets so that accuracy and precision and instrumentation can be compared.

Raw data

Blank	182
	168
	180
Dilution 1	25
	17
	26
Dilution 2	65
	85
	68
Dilution 3	119
	98
	136
Dilution 4	150
	153
	161

Averaged results table

Blank	176.67
Dilution 1	23.00
Dilution 2	72.67
Dilution 3	117.67
Dilution 4	154.67

Graph

Students plot a graph of absorbance against the dilution, calculating the absorption using the following equation:

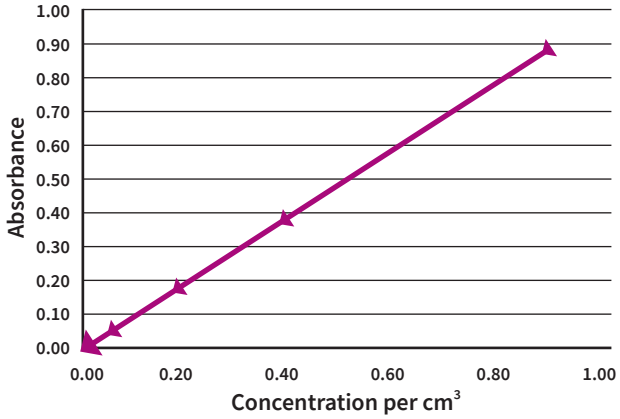
–log(G value/blank value)

Students could plot a graph of dilution 1, 2, 3, 4 or they could be encouraged to calculate the actual concentration, either by their own dilutions or the pre-arranged concentrations.

In this example, we used a bottle of strawberry juice, stating it was 5% juice. 5% v/v means that in 100 cm^3 there is 0.05 cm^3 of juiced strawberry.

Dilutions were made to stretch the range of colour graduation. Start with half or 50% dilution in the first instance, suggested dilutions are shown below. Students should convert their dilutions to a concentration using the units of volume they used for their dilution.

Concentration (cm^3)		Absorption
Blank	0.0000	0.00
Dilution 4	0.0030	0.06
Dilution 3	0.0060	0.18
Dilution 2	0.0125	0.39
Dilution 1	0.0300	0.89



Graph analysis

The line should be linear if it obeys Beer's Law, if not then it is likely that something went wrong in the method, eg moving the phone a different distance each time.

It is important to note that the equipment is not a colorimeter of laboratory sophistication, but enough to allow students to see the variability in equipment and method, while retaining the same technical operations as a colorimeter.

The student sheet has some comprehensive explanations for this section, including an estimate of what they should find. Ensure the answer matches the trend they found and also that they used their own values in the explanation.

Example: As concentration increases the absorbance of light at this wavelength is also increasing, eg a concentration of 0.0125 gives an absorbance value of 0.39 as the concentration was doubled to 0.03 the absorbance was also almost doubled 0.89.

These results would reflect what is to be expected, a higher concentration means more molecules, therefore there are more molecules absorbing the light, so the absorbance is higher at higher concentrations.

2

Conclusion

Uncontrolled variables

Distance would have affected this, as well as the transparency of the cup, the light in the room, the camera operator.

Accuracy and precision

Students should be encouraged to compare results with another group that had a similar set-up and solutions. Ideally, they could be compared with a class colorimeter, or the teacher's set of results.

Additionally, you could measure the RGB of the actual page – do this with the cup and compare the 'standard' values. For example, a photograph of the green page revealed the actually RGB 'G' value to be 255. The values for the blank were just above half of this.

Answers to student questions

1 Define accuracy and precision in this analogy. *Accuracy refers to how close a dart is to the bull's eye. Precision refers to how close the darts are to each other and is independent of accuracy.*

2 Why are they given three darts? *Trials.*

3 What might happen in diagram three? *They might generate an average of the three trials but this should be disregarded due to the imprecision.*

4 *Glassware, equipment, instrumentation, repeating trials.*

5 *A – accurate and precise*

6 *C – accurate and precise*

7 *B – precise but not accurate*

Scientists use standard procedures and calibration testing to reduce measurement errors.

Project 2

Class project instructions

Phone-y science

Investigation title

Prepared by:

Name

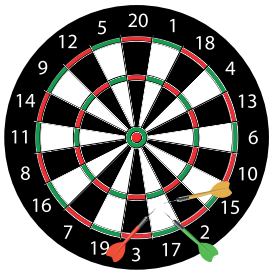
Class

Date

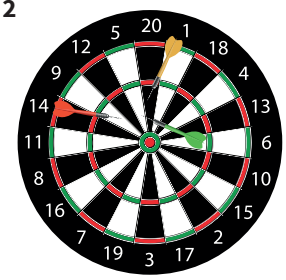
STUDENT INSTRUCTION SHEET ONE
What's the difference between 'accurate' and 'precise'?

Describe the following images in terms of accuracy and precision, assuming the centre to be the true value and the darts to be the trials.

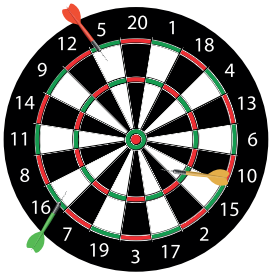
1



2



3



1 Define accuracy and precision in relation to the analogy.

2 Why are they given three darts?

3 What might happen in diagram three?

4 What are some of the ways you can improve accuracy and precision in scientific investigations?

2

Trial	Measurement
1	25.48
2	24.97
3	25.27

5 The accepted value is 25.35. Circle which correctly describes this student's experimental data.

a accurate but not precise
b precise but not accurate
c both accurate and precise
d neither accurate nor precise

Trial	Measurement
1	2.29
2	2.93
3	1.88

6 The accepted value is 2.43. Circle which correctly describes this student's experimental data.

a accurate but not precise
b precise but not accurate
c both accurate and precise
d neither accurate nor precise

Trial	Measurement
1	12.84
2	13.02
3	12.96

7 The accepted value is 15.63. Circle which correctly describes this student's experimental data.

a accurate but not precise
b precise but not accurate
c both accurate and precise
d neither accurate nor precise

STUDENT INSTRUCTION SHEET TWO

Using mobile phone devices and apps to collect colorimetry data

Background

Computers have revolutionised science and its ability to capture and analyse data, and now smartphones are showing the same potential. Thanks to their evolving technology and growing use many of us now have easy access to sophisticated instrumentation.[1] Current research uses smartphones for colorimetric water analysis, soil analysis and air quality analysis. This, coupled with GPS, has the potential to influence pollution management and policy.[2]

Your task

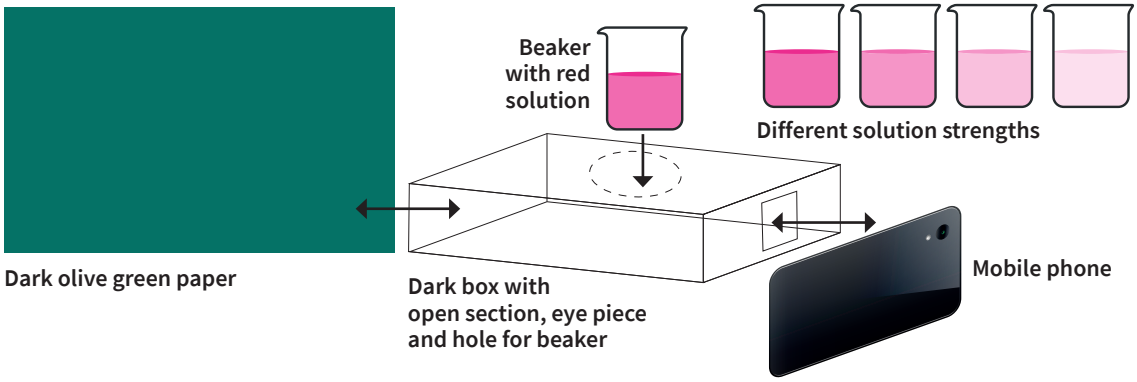
Your task

You have to carry out your own investigation to detect absorbance of light using a colorimeter app on a phone and various dilutions of fruit juice, or coloured solutions. It's a group activity and presentation but with an individual report. Hint! Look for videos and blogposts on the topic.

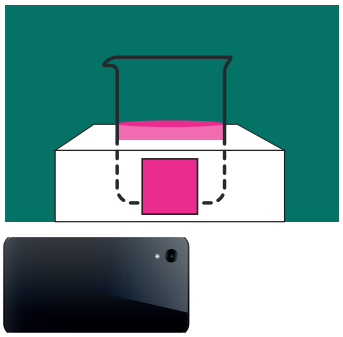
Task list per group

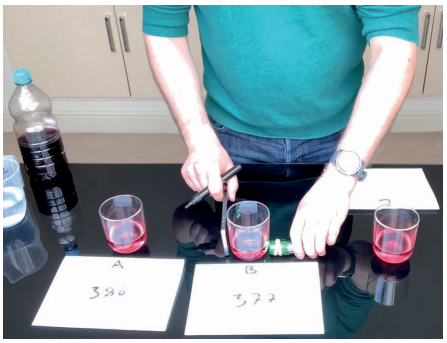
- ☑ Collect student project portfolio
- ☐ Download the app
- ☐ Collect equipment
- ☐ Investigate method
- ☐ Fill in portfolio
- ☐ Prepare presentation

How to set up your colorimeter



What it looks like from the phone





Using any free light meter application on your smartphone, you can collect and record the absorbance values of the coloured solution as shown in this video: **youtu.be/0954J_5NI88**

References

1 McGonigle *et al*, Sensors, 2018, **18**, 223.

2 C Sicard *et al*, Water Res., 2015, **70**:360-9.

Using mobile phone devices and apps to collect colorimetry data

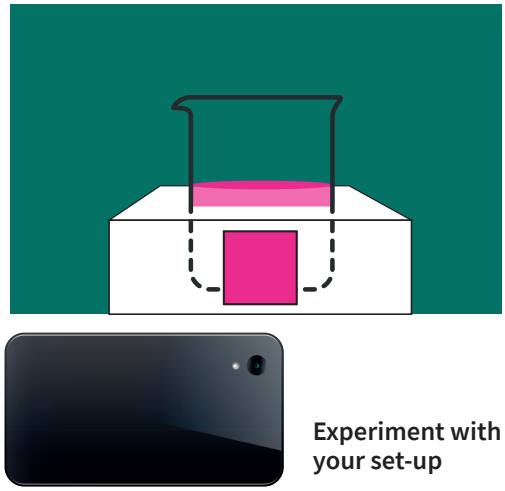
How it works

Your phone has some pretty sophisticated light and colour reading technology. You may have heard of RGB sensors – this means that red, green and blue light is measured by your camera in order to store the information from the photo as a picture.

By interrupting this light with different concentrations of solutions you can obtain a value for this 'interruption', which will vary much like the absorbance. If the solution is red then it's the green light we are most interested in so we will place a green page behind the juice.

To restrict the light passing through the solutions, we have placed it in a dark container, with a hole for the cup or beaker, an eye piece and an open section where the green light will be focused. This is an example set-up, and you are encouraged to trial different methods and set-ups to generate the most accurate results possible.

RGB colour recording



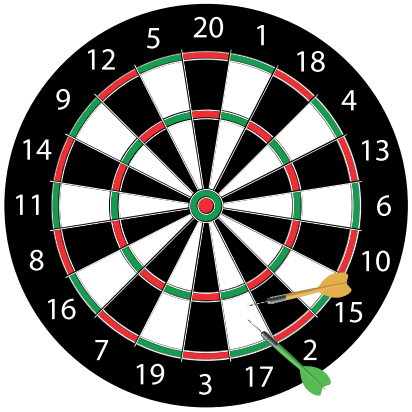
Experiment with your set-up

How will you know if they are accurate or not?

What can you compare them with?

Think about how you will improve your chances of getting the most correct value – this will probably relate to how much extra light you can restrict both in the box and with the distances between the light capture and your phone.

Investigate by changing a number of different variables before deciding on your method.



Accuracy and precision

Planning sheet

Why are you doing this investigation?

What do you want to find out? This could be some type of hypothesis or idea you want to prove or disprove.

Include any inspiration for undertaking the project, eg the work of other scientists, how using mobile phones and apps might improve quality of life for you or others.

What do you think you might discover or find? This should link to the focus of 'accuracy and precision'.

Deciding your method

Play around with the app and explore how the measurements change in response to different coloured liquids and pieces of paper.

What variables does the app measure and which ones are you responsible for changing?

Hint! Describe any two changes that you made in your experiment.

Variables

What are your project variables including control variables?

Are there any control variables that you will not be able to control, and what impact do you think this will have on your results?

Include a photograph or a diagram of your equipment set-up

For qualitative data, analysis of the data can usually be done from the table of results as this requires making observations and the inferences from the observations.

Raw data

This should be a table of results you collected, without any processing – that means it comes straight from the phone.

Help: Averages are used by scientists to get an even more accurate result. They allow for random variation and human error to be absorbed into the total – increasing the accuracy.

Averaged results table

You should average your three measurements for each dilution. This means add them all together and divide by three (if you carried out three trials).

You should then include a column for the absorbance, calculated using the equation below:

$$-\log(\text{G value}/\text{blank value})$$

For quantitative data, analysis involves collecting numerical values, using this to carry out calculations or presenting the numerical values in a graph to establish a relationship between independent and dependent variables or to find an unknown value.

Graph

Graphs should only be drawn from averaged results. You should plot absorbance against concentration.

Draw your graph by hand or on Excel and paste it in the box below.

2

Affix graph here

Marking criteria for the graph

- Axis drawn using a pencil and a ruler.
- Axis labelled with correct headings and includes units.
- An appropriate scale was used.
- Points plotted correctly.
- Line of best fit drawn.

Analysis and conclusion

Describe the relationship that has been established between the independent and dependent variables and link this back to the theory if possible.

Checklist for analysing the graph

1 **Make a statement describing what the graph shows**, eg 'As the concentration of the standard solution increases, the absorbance of light changes.'

2 **Establish the relationship between the independent and dependant variable**, eg concentration and absorbance are linked. As concentration increases, the absorbance of light at this wavelength is also increasing.

3 **Use the results, usually two as evidence**, eg when the concentration was 1 ppm the absorbance was 0.5, when the concentration of the standard solution was 5 ppm the absorbance was …

HL 4 Link this to the theory explaining why this relationship exists, state whether the hypothesis or question posed at the beginning of the investigation is correct, eg these results would reflect what is to be expected, a higher concentration means more molecules, therefore there are more molecules absorbing the light, so the absorbance is higher at higher concentrations.

Conclusion

How could you improve your results next time?

Reference accuracy and precision in your method and analysis to get more marks.

Make a concluding statement based on the accuracy and precision of your results. Also state what you have learned from the project, commenting on whether you think phones should be used to collect scientific data.

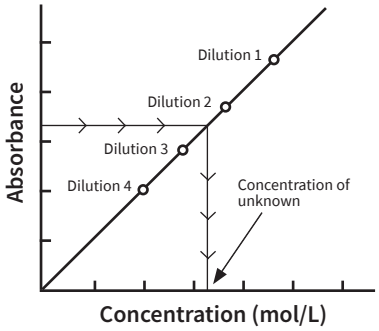
Thinking and research questions

How could your methods be applied to a real-life situation or used in industry? Also what would you need to change to achieve this?

How to draw graphs

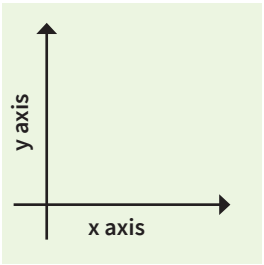
Colorimetry is a technique that relies on measuring the absorbance of a specific colour of light by a coloured solution and using this to work out the concentration of the analyte present.

The amount of light absorbed will be more or less, depending on the concentration. This technique allows us to work out the concentration of an unknown by placing on a scale along side known concentrations.



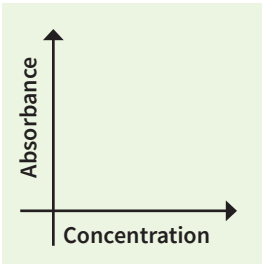
Colorimetry graph

1 Draw your axis using a ruler and a pencil



Hint! y is high, or 'wise up' (y's up)

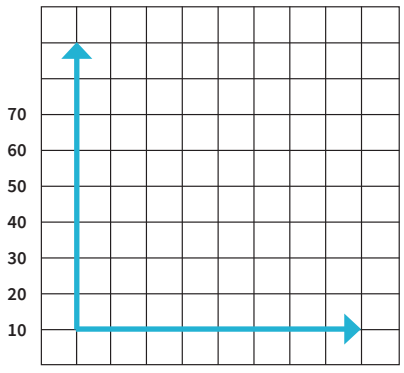
2 Label each axis with the correcting heading and include units where necessary



The dependent variable (what you measured) always goes on the y-axis.

The independent variable (what you altered) always goes on the x-axis.

3 Choose a suitable scale



Evenly spaced lines, eg with a value of 10 each

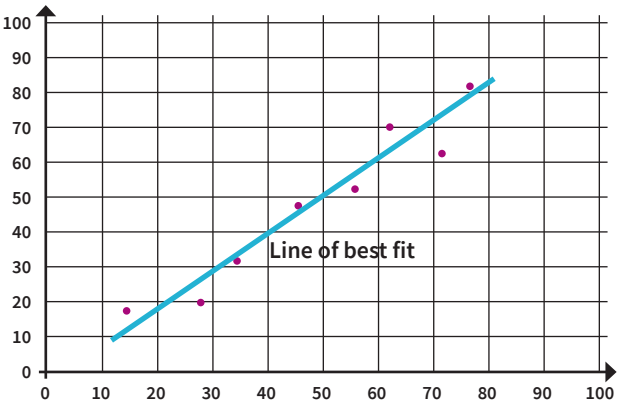
The scale you choose should allow all the results you require to be plotted. The scale should be evenly spaced and incorporate at least 75% of the graph paper so results can be clearly seen.

4 Plot your points accurately

Plotting points needs to be done carefully and accurately.

It is always wise to use a sharp pencil.

5 Draw your line of best fit



How to draw a line of best fit

Drawing a line of best fit can be difficult. It can be best described as a line that runs as close to as many points as possible. A good trick for this is to place your ruler on its thinnest side and try to get half the points on one side and half on the other. Then place it flat and mark your line.

Success criteria for good graphs

- Use a pencil and a ruler.
- Label axis with correct heading and units.
- Choose an appropriate scale.
- Plot your points accurately.
- Draw a line of best fit.

Project 2

Student project portfolio

Phone-y science

Project title

Prepared by:

Name

Class

Date

PHONE-Y SCIENCE
Planning sheet

Why are you doing this investigation?

Deciding your method

Variables

Include a photograph or a diagram of your equipment set-up

2

Results

Raw data

Averaged results table

Graph

Affix graph here

Marking criteria for the graph

- Axis drawn using a pencil and a ruler.
- Axis labelled with correct headings and includes units.
- Appropriate scale used.
- Points plotted correctly.
- Line of best fit drawn.

Graph analysis

Conclusion

Thinking and research questions