Best Practise for teaching physics in UK secondary schools

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Contents

1. Summary

The educational landscape in the UK is continually changing; both in response to targeted policy and as a result of wider societal changes. Physics teaching and learning is, of course, affected by these broader changes to schools, but it also has some very specific challenges. These include the recruitment and retention of high quality physics teachers, concerns around the low uptake of physics at upper secondary level in general, and the fact that certain demographic groups are less likely to study physics than others. The UK's Institute of Physics has been studying these issues and making recommendations to schools and governments, and is an excellent source of recommendations, as well as co-ordinating a number of initiatives that support physics teachers and students.

The UK is lucky to have numerous education-related projects which exist to support physics teaching, but access to these varies greatly; geography, costs, the demographic mix of students, and the type of school all play a part. This report makes an attempt to advise on best practise for physics teaching in terms of pedagogical approaches that can be implemented across diverse schools and curricula. The examples given in the report link to specific curriculum topics, but they are used to illustrate a particular approach, rather than to say that this particular topic ought to be taught exactly in this way.

In the first report created for this project, the following recommendations were made for any development of teaching activities using space contexts and new technologies for the classroom:

1. Clear links are made between the activity and the curriculum: the link to useful knowledge based learning for the curriculum should be the driver for the activity in the first instance. Whilst working across diverse physics curricula (eg across nations in the UK) it would be wise to link to topics that are common to these curricula. In addition to this, working with teachers who have in-depth knowledge of a specific curriculum is to be recommended, to allow them to further develop any activities from the common topics across curricula to specific examples or requirements within their own curriculum.
2. The format of any written resources for the activity for uptake must be carefully considered, with outcomes for learning made clear in the activity summary, as this is the selling point for teachers that will persuade them to invest the time in implementing the activity.
3. Where possible, face-to-face training of teachers is the best way to pass on the knowledge needed for teachers to take on new methodologies. This allows teachers to see the activity in action and build their own confidence in using new technologies in the classroom. It also allows them to question the trainer and other teachers, and to share their own knowledge with their peers, which is an opportunity that teachers in the UK have less and less often these days.
4. As the proportion of science teachers in the UK that are physics specialists is so low, it must be remembered that most physics teachers have a background in a subject other than physics. This may affect their confidence, or even their capability, in teaching some physics topics, especially at higher levels or with gifted and talented students. For this reason, it would be useful to look at building in activities that support non-specialist physics teachers to develop their abilities and confidence in teaching physics.
5. Since the landscape for education in the UK is constantly evolving, and since new technologies are being developed or created all the time, it would be wise to consider how to "future-proof" any resources developed for supporting physics teaching using new technologies. For

both of these reasons it would be ideal to be able to revisit the resources regularly to update them as necessary, or review them on a regular basis.

6. Students value "genuine learning experiences" (Dillon, 2010) over contrived experiments, and this supports understanding of science. Projects involving real data or examples can give a real-world context to science and raise students' investment in the activity, so the real-world context and links to cutting edge science should be included.
7. The contexts of socio-scientific issues, careers, and the usefulness of science are useful for engaging with groups that are proportionally underrepresented in physics, be it by socio-economic status, gender, or ethnicity. These contexts should be explored in activities developed for the classroom where possible.
8. Students enjoy the experience of using technology in the classroom when it raises interactivity, but find it frustrating when technology is unreliable or when the teachers' knowledge of the technology is poor. Teachers should be trained and confident to deliver content with technology and should use opportunities to interact with students using technology. Students see-through the use of technology as a crutch for poor pedagogy: new technologies must only be used if it improves the effectiveness of learning

In addition to these recommendations, two further recommendations can be made when considering the best practise for physics teaching, taking into account the challenges that different curricula face when building in skills development, and finding ways to develop teachers' practise. These recommendations have been added after discussion with UK and overseas teachers about the strengths of UK physics teaching practise:

9. The activities should develop scientific enquiry competences and skills such as problem solving; working with independence; a toolkit of practical skills; and the ability to communicate effectively.
10. A mentoring process removed from formal performance management should be used to embed best practice methodologies. The mentoring should focus on "scaffolding", where mentors provide pedagogical assistance so that mentees begin to make their own conclusions and decisions.

2. Best practises in pedagogy for physics

The recommendations listed in the previous section are aimed at those writing content for teachers to use and include some recommendations that are specific to teacher training. In terms of teaching physics to students directly, these recommendations can be narrowed down to the following relevant points:

1. Ensure that any activities are curriculum relevant
2. Activities develop scientific enquiry competences and skills
3. Have clearly defined learning outcomes for the activity
4. Review resources on a regular basis/update content
5. Allow students to conduct experiments themselves to generate their own data, or use real datasets; aim for "genuine learning experiences"

6. Ensure that the activity links to a useful, relatable context for the curriculum topics
7. Ensure that any technology used will perform consistently so that time is spent on the activity, not wasted on trying to get technology to work. In addition, using the technology improves the student learning

These points can also be used to maintain a balance of priority between the acquisition of subject knowledge and the development of skills. In different curricula the balance between these two educational goals differs, but broadly in the UK the former is becoming more important for succeeding at exams and the latter is of course important for engaging with science and developing a student's employability skills as well as within the subject.

This report uses three examples of themed activities, each grouped into three lesson plans, to illustrate the best practise recommendations outlined above. The themes are related to space, which provides an inspirational or aspirational context for the curriculum topics, and within each theme effort is made to ensure that "useful" and "relatable" contexts are included. Within each theme different activities illustrate the approaches given in the recommendations.

Lesson plans for each of the themed activities can be seen in Appendix 4, grouped thematically as follows:

1. Looking Out There
   1.1. Constructing a Telescope
   1.2. Hubble Deep Field
   1.3. Inverse Square Law
2. Getting Out There
   2.1. CD Hovercraft
   2.2. Compressed Air Rocket
   2.3. Mini Whoosh Bottle
3. Looking Back Here
   3.1. Earth Observation
   3.2. IR Astronomy
   3.3. Modelling Ocean Currents and Weather

Each lesson plan contains a list of clear learning outcomes and a list of curriculum links, as per recommendations 1 and 2. These are useful both for the teacher delivering the session, for their own planning, and for giving students clear information on what they will be learning/what they have learnt.

Most of the activities involve some practical or hands-on element, as a means of meeting recommendation 4. In particular 1.1, 2.1, 2.2, and 3.3 engage the students by requiring them to make/create items that they will then use in the experiments/investigations.

Activity 1.3 is easy to set up, and uses everyday objects (smartphones) to conduct an investigation which generates data. It is a very simple illustration of experimental method, which can be used to teach the scientific method from hypothesis to experimentation, as well as how to extract meaningful information from raw data using graphs and analysis. This is a very engaging way to teach physics in the classroom – but it is also solidly grounded in physics knowledge. The context can also be related to the everyday use of physics.

Another approach to meeting recommendation 4 is the use of existing, real data sets. This is shown in activity 3.1 which is comprised of a number of smaller activities, building on the idea of analysing data gained in the classroom environment (in this case images) and then applying that knowledge of analysis methods to images of the Earth from space. As well as featuring elements of investigation, this activity set also reinforces the usefulness of physics, as a means by which we can better understand our home planet with links to environmental science, relating strongly to recommendation 5.

Technology is used at different levels in the activities, from the use of mobile phones as light source and detector in 1.3, to the use of video that can be analysed using a free software package (Tracker) for dynamic analyses. None of the hardware used in these activities is outside the everyday experience of most students or teachers, however it is strongly advised that teachers ensure they are familiar with any of the recommended software before using it with their students. This is implicit in recommendation 6.

Further explanation of the ways that the activities included exemplify these best practises have been outlined in the following tables:

1. Curriculum relevance

1.1 Constructing a Telescope	• Transmission of light through materials and absorption • Ray model to explain the refraction of light and action of convex lens • Refraction as the change of direction of light • Ray diagrams • Focal length of lenses
1.2 Hubble Deep Field	• Use of numeracy • Understand that scientific methods and theories develop as earlier explanations are modified to take account of new evidence and ideas, together with the importance of publishing results and peer review • Our Sun as a star, other stars in our galaxy, other galaxies
1.3 Inverse Square Law	• Using ratios • The inverse square nature of light intensity and distance • Inverse square law graph
2.1 CD Hovercraft	• Forces and Motion: Newtons Laws, contact forces • Friction: Useful and non-useful • Gravity and Orbits
2.2 Compressed Air Rocket	• Calculations, problem solving, sequences of actions • Action and reaction • Friction • Force diagrams • Gravity
2.3 Mini Whoosh Bottle	• Forces being needed to cause objects to stop or start moving, or to change their speed or direction of motion • Using force arrows in diagrams • Adding forces in 1 dimension • Balanced and unbalanced forces • Exothermic Reactions

	• Combustion • Representing chemical reactions with formulae and equations
3.1 Earth Observation	• Understanding and detection of EM Spectrum • Projectile motion and satellites with respect to orbits • Impact of space exploration on understanding planet Earth and the global impact of satellite applications • Emission and absorption spectra. • Interaction of EM radiation with materials • Circular motion • Resolving power • Understanding of methods of space exploration
3.2 IR Astronomy	• Doppler shift • Hubble's law • Graphical analysis of a straight-line graph to obtain a value • The big bang
3.3 Modelling Ocean Currents and Weather	• Convection and thermal transfer • The electromagnetic spectrum

2. Scientific Enquiry

1.1 Constructing a Telescope	Use the investigation into focussing the telescope to introduce the idea of error and getting a range of values
1.3 Inverse Square Law	Collecting and recording of data. Plotting of data and interpretation of graphs
2.1 CD Hovercraft	Experimental design and control of variables.
2.2 Compressed Air Rocket	Design and prediction skills. Evaluation of design after testing.
3.1 Earth Observation	Computer analysis techniques
3.2 IR Astronomy	Graphical interpretation

3. Learning Outcomes

1.1 Constructing a Telescope	• Understand focal length and how this is related to thickness of a lens • Understand the normal adjustment for a refracting telescope and know the lens separation rule • Draw the ray diagram for a refracting telescope • Find the focal length of lenses • Calculate magnification
1.2 Hubble Deep Field	• Reflect on the vastness of space and the number of galaxies outside our own Milky Way • Use surface of a sphere formula • Evaluate the potential for life elsewhere in the Universe
1.3 Inverse Square Law	• Demonstrate that the brightness of a source of light is a function of the inverse square of its distance.

	• Understand how distance will affect the power that can be produced by a solar panel, and that this
2.1 CD Hovercraft	• Demonstrate the process of science inquiry by posing questions and investigating phenomena through language, methods, and instruments of science. • Understand Newton's First Law states that an object in motion will stay in motion unless acted upon by an outside force. • Understand Newton's Second Law tells us that Force = Mass * Acceleration. In other words, an object's mass, multiplied by its amount of change in position gives us the amount of force that it can expend on another object. • Understand Newton's Third Law states that for every action there is an equal and opposite reaction.
2.2 Compressed Air Rocket	• Use research and develop design criteria to inform the design of innovative, functional, appealing products that are fit for purpose. • Evidence, models, and explanation - Change, constancy, and measurement • Science as Inquiry -Abilities necessary to do scientific inquiry • Physical Science -Position and motion of objects, Motions and forces • Science and Technology Abilities of technological design • Generate, develop, model, and communicate their ideas through discussion and annotated sketches.
2.3 Mini Whoosh Bottle	• Recall and understand Newton's Third Law of Motion: For Every Action There Is An Equal An Opposite Reaction. • Understand the term Combustion
3.1 Earth Observation	• Be able to describe the electromagnetic (EM) spectrum and how it is used to monitor Planet Earth. • Be able to explain the different characteristics of satellite orbits. • Appreciate how different materials respond to EM radiation. • Understand how images are made and processed. • Appreciate the range of possible applications of EO data. • Be able to carry out a basic interpretation of imagery.
3.2 IR Astronomy	• Understand and can explain the origin of doppler shift of sound. • Calculate the recessional velocity of a tone generator using software and mathematics. • Apply this understanding of doppler shift to the light reaching us from different stars, and calculate the age of the Universe using Hubble's method.
3.3 Modelling Ocean Currents and Weather	• Able to explain how we can monitor the temperature of the ocean surface from space, and why it is advantageous to do so. • Use the principal of convection to explain how ocean currents can drive climate and weather effects. • Understand that resolution is important to obtaining useful data, and that specific orbits are used to acquire such data.

6. Context

1.1 Constructing a Telescope	The simple refracting telescope has been used to extend the range of naked eye astronomy since the time of Galileo. It is within this context of observing the dark sky, and the wonders that can be observed, that the physics of lenses is introduced and developed.
1.2 Hubble Deep Field	The Hubble Ultra-Deep Field (HUDF) is an image of a small region of space in the constellation Fornax, containing an estimated 10,000 galaxies. It is composited from Hubble Space Telescope data accumulated over a period from September 24, 2003, through to January 16, 2004. The rectangular image is approximately one tenth of the angular diameter of a full moon viewed from Earth which is roughly equivalent to a 1 mm by 1 mm square of paper held at 1 meter away.
1.3 Inverse Square Law	The European Space Agency's comet mission, Rosetta, was the first to successfully land a probe on a comet. To rendezvous with comet 67P Churyumov–Gerasimenko, Rosetta had to travel far out into the Solar System, beyond the orbit of Jupiter. Being this far from the Sun has implications for the generation of power from sunlight – and is the reason Rosetta had the largest solar panels of any space exploration mission to date.
2.1 CD Hovercraft	Hovercrafts work by using air to lift a vehicle off the ground. The CD Hovercraft is no exception. As the balloon deflates, it is releasing air through the sports bottle cap and beneath the CD (Newton's Third Law). Because of the shape, smoothness, and weight distribution of the CD, the releasing air creates a cushion of air between the CD and the surface (Newton's second Law). This cushion of air reduces the friction between the CD and surface and allows your hovercraft to move more freely. If it were possible to reduce friction altogether, the hovercraft would travel in one direction, uninterrupted, FOREVER. Like objects orbiting in space!
2.2 Compressed Air Rocket	Spacecraft need to be as aerodynamic as possible. Designers need to ensure that the rocket is controllable and safe, but that it will travel through the air with as little affect from air resistance as possible. Air resistance will decrease the speed and require much more fuel on board to reach the destination. It can also produce heat which can cause problems.
2.3 Mini Whoosh Bottle	To launch a rocket or to move a rocket through space, we must use a propulsion system to generate thrust. Thrust is generated through an application of Newton's third law of motion; a working gas is accelerated to the rear of the rocket engine, and the re-action is a thrust force applied to the engine in the forward direction. In solid and liquid fueled rocket engines, the working gas is produced through the burning of a fuel to produce power. Burning a fuel is called combustion, a chemical process that we study in middle or high school.
3.1 Earth Observation	Earth Observation (EO) is an application of multidisciplinary space science. It requires understanding of space missions, data communications, and of the underlying sciences – chemistry, biology, and physics. Earth observation is a major, and growing, component of the space science economic sector with increasing impacts on our understanding of planet Earth.
3.2 IR Astronomy	When students think of astronomy, they will usually imagine the stunning visual imagery that telescopes such as the Hubble Space Telescope provide. However, these vivid images provide only a small part of the story of our Universe. To truly understand the origins of our Universe, we need to use

	another part of the electromagnetic spectrum – Infrared. By investigate doppler shift, and applying this to the redshift of distant stars, students will come to understand why the next big space telescope – the James Webb Space Telescope – will use the infrared.
3.3 Modelling Ocean Currents and Weather	Earth observation, and particularly the monitoring of climate and ocean temperature are key foci of the European Space Agency's orbital missions. Through the effects of convection, energy transfer and the rotation of the Earth, small changes in the temperature of the Ocean's surface can drive huge changes in climate and weather events. Understanding and predicting the fate of ocean temperatures allows us to better understand and predict extreme weather and climate events.

3. Conclusions

With respect to physics, the changing focus of science education over past decades has led to a generally held view that developing an understanding of how science works through investigation is at least as important as developing a knowledge base, but this has always been challenged by the nature of assessment and is facing further challenges with current political approaches to education, in England at least. It seems that the answer for the HE institutions and industries that want entrants with a physics background is some combination of the two. Physics teaching, more so than the other sciences at secondary level, runs the risk of being seen as dull, difficult, and even useless, by students (Dillon, 2010). This is not a new situation, but it may be exacerbated by changes in the role of teachers - for example reporting being a greater part of their workload – and by the continued dearth of physics specialists amongst the population of science teachers. From the Institute of Physics' research we know that the single biggest factor affecting the uptake of physics in terms of school provision (ignoring societal issues external to the school environment) is the quality of physics teaching.

The quality of physics teaching can be improved through training, mentoring and support for teachers, as well as by helping them to find pedagogies that work for them and their students. Teaching as a practise requires continual development by the practitioner as contexts, students, and education systems change, and excellent practitioners are often those that seek to benchmark and then improve their performance. In this report a number of features of good or best practise found in UK physics teaching have been outlined and examples provided. The attached lesson plans make up a package of resources that are available with this report for teachers to access and build into their own practise as they see fit.

Appendices

1. References

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2. Lesson Plans

Attached are the lesson plans for each activity.

Theme 1 – Looking Out There

Activity 1.1 – Simple Refracting Telescope Investigation

Title of Activity

Investigation into lenses through the construction of a simple refracting telescope.

Space Context

The simple refracting telescope has been used to extend the range of naked eye astronomy since the time of Galileo. It is within this context of observing the dark sky, and the wonders that can be observed, that the physics of lenses is introduced and developed.

Learning Outcomes

Students to be able to:

- Understand focal length and how this is related to thickness of a lens
- Understand the normal adjustment for a refracting telescope and know the lens separation rule
- Draw the ray diagram for a refracting telescope
- Find the focal length of lenses
- Calculate magnification

Curriculum Links

- Transmission of light through materials and absorption
- Ray model to explain the refraction of light and action of convex lens in focusing (qualitative)
- Refraction as the change of direction of light
- Ray diagrams
- Focal length of lenses

Delivery Mode

Group investigation and exploration. This activity can be developed through a group problem solving activity.

Use of IT/Technology

The pHET simulations make for a good starter

https://phet.colorado.edu/en/simulation/legacy/geometric-optics

https://phet.colorado.edu/en/simulation/bending-light

Differentiation

The amount of support given in the investigation can vary: from ‘here are two lenses and a ruler, go build a telescope’ to full instructions on which is the eyepiece, objective etc.

The ray diagram can be on-axis or off-axis which makes the diagram much harder

Assessment

Assessment is through students showing they have discovered the lens separation criteria for normal adjustment and correct calculation of magnification.

Links / Further Information

In a telescope, the lens held next to your eye is called the eyepiece and is usually a short focal length lens. The lens at the other end of the telescope is called the objective lens. Light from a distant object is focused by the objective lens to form an image in front of the eyepiece. The eyepiece acts as a magnifier and enlarges that image. The magnification of the telescope can be found by dividing the focal length of the objective by the focal length of the eyepiece.

Lesson Plan

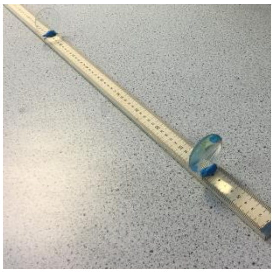
1. Introduction activity could be the simple Astronomers card sort before moving onto the investigation:

Apparatus required per group:

Meter ruler
1 x 10cm converging lens
1 x 50cm converging lens
2 lumps of Blu Tac, or similar, to act as lens mounting device

2. Fix the 'fatter' eyepiece lens at the 10cm point on the ruler using a lump of blu-tac

3. Mount the 'thinner' objective lens somewhere on the metre ruler and observe a distant image (like a tree or building, needs to be 20m+ distant). Unless the student has been very lucky the image will be blurred. Ensure students understand the need to look along the optical axis of the lens system



4. Ask students how the image can be brought into sharp focus i.e. by moving the objective lens

5. Students move the objective lens backwards and forwards along the ruler until the image is in sharp focus. Great opportunity for uncertainty here: where is the image at its sharpest?

6. Students make a note of the separation of the lenses. Should be about 60cm (or the sum of focal lengths if using different lenses)

7. Students can then either be told the focal lengths or they can use the normal method of finding the focal of a lens. You can use the lenses-ray-diagrams PowerPoint and Focal length worksheet. Students then come to simple conclusion that lenses need to be the sum of the focal lengths apart.

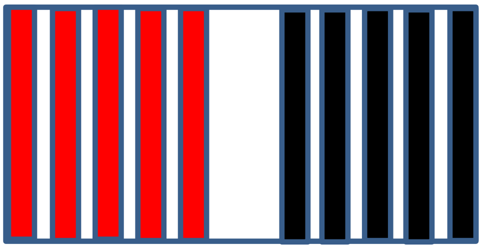
8. Calculate the magnification by using

M = power or magnification = F_o/F_e

F_e = focal length of the eyepiece

F_o = focal length of the objective

9. Students evaluate their calculated magnification: They stand at one end of the room and look at a chart with red and white stripes, and black and white stripes. Looking directly at the chart with one eye and through the telescope with the other eye can be difficult at first, but they will get it.



10. A homework or extension task could be to use the Ascension and Right Declination worksheet to plot where they might like to point their telescope

Theme 1 – Looking Out There

Activity 1.2 – Hubble Ultra Deep Field

Title of Activity

Calculating the number of galaxies in the Universe

Space Context

The Hubble Ultra-Deep Field (HUDF) is an image of a small region of space in the constellation Fornax, containing an estimated 10,000 galaxies. It is composited from Hubble Space Telescope data accumulated over a period from September 24, 2003, through to January 16, 2004. The rectangular image is approximately one tenth of the angular diameter of a full moon viewed from Earth which is roughly equivalent to a 1 mm by 1 mm square of paper held at 1 meter away.

Learning Outcomes

Students able to:

- Reflect on the vastness of space and the number of galaxies outside our own Milky Way
- Use surface of a sphere formula
- Evaluate the potential for life elsewhere in the Universe

Curriculum Links

- Use of numeracy
- Understand that scientific methods and theories develop as earlier explanations are modified to take account of new evidence and ideas, together with the importance of publishing results and peer review
- Our Sun as a star, other stars in our galaxy, other galaxies

Delivery Mode

Individual calculation and processing

Differentiation

Scaffolding of the solution to differing extents

Assessment

Assessment is through evidence of correct solution

Lesson Plan

1. Introduction
    - Use slides 1and 2 to introduce the idea of choosing a site for an optical or IR telescope
    - Slides 3 – 12 to develop a discussion over what constitutes a good site for a telescope
    - Slide 13 to introduce the Hubble Space Telescope and question students on why we would want to send a telescope into orbit
    - Slides 14-17 used to show some famous Hubble images. Good engagement activity is to get students to ‘name’ the image from what they think it resembles

2. Main Activity

- Slide 18 – show the Hubble Deep Field image and explain that this image has a size roughly of a dot on your thumb held at arm's length
- Slide 19 – use this slide to add further detail to the background of the image
- Set the challenge: can you use this image of a small part of space (1mm by 1mm held at 1m arm length) to calculate the number of galaxies in the universe?
- Slide 20 – used to help students who are not sure how to solve the problem

3. Plenary

- Slides 21 and 22 used to run through the solution
- Further discussion on how many stars this must mean if each galaxy contains roughly 100 billion stars
- Also, we've now detected a large number of exoplanets – it appears that planets around stars are fairly common. So, what does this mean about the number of planets? And hence the possibility for life?

Theme 1 – Looking Out There

Activity 1.3 – Inverse Square Law

Title of Activity

The Inverse Square Law of Light: Investigating the relationship between distance and brightness using two mobile phones, and applying these findings to explaining the size of Rosetta's solar panels.

Space Context

The European Space Agency's comet mission, Rosetta, was the first to successfully land a probe on a comet. To rendezvous with comet 67P Churyumov–Gerasimenko, Rosetta had to travel far out into the Solar System, beyond the orbit of Jupiter. Being this far from the Sun has implications for the generation of power from sunlight – and is the reason Rosetta had the largest solar panels of any space exploration mission to date.

Learning Outcomes

- Students able demonstrate that the brightness of a source of light is a function of the inverse square of its distance.
- Students understand how distance will affect the power that can be produced by a solar panel, and that this has implications for using solar power on deep space exploration missions.

Curriculum Links

Key Stage 4

Using ratios to calculate power produced from solar panels at different distances from light source

Key Stage 5

The inverse square nature of light intensity and distance

Plotting the correct graph to prove an inverse square relationship

Delivery Mode

Teacher introduction and scene setting

Group investigation and exploration.

Use of IT/Technology

Two mobile phones are needed for this experiment, one to act as the light source (through the torch function) and one to act as the light sensor (using a app).

Suggested apps:

Android: Lux Easy Light Meter (uses the camera that faces you) https://play.google.com/store/apps/details?id=com.SymbolMobile.luxmeter&hl=en

iPhone: Galactica Luxmeter (uses the camera that faces out)

https://itunes.apple.com/gb/app/galactica-luxmeter/id666846635?mt=8

Since students will work in pairs, the Galatica app is a little more sensitive so if one student has an iphone that will work best.

Differentiation

Younger/less able students will focus on obtaining data and plotting their graph and testing whether their results support an inverse square law through substitution of obtained data into the equation.

Older/more able students can choose what they need to plot to prove the inverse square relationship.

Links / Further Information

More information about the Rosetta mission can be found at the following websites:

http://www.esa.int/Our_Activities/Space_Science/Rosetta

http://rosetta.esa.int/

Information on how photovoltaic cells work:

https://science.nasa.gov/science-news/science-at-nasa/2002/solarcells

Lesson Plan

For introduction: Rosetta introduction power point

Equipment Required – for each pair/group of students:

- 2 retort stands
- 2 sets of clamps and bosses
- Two mobile phones, one of which has a light meter app downloaded
- Meter ruler
- 2 sheets of graph paper

Introduction:

Set the scene by introducing the Rosetta mission and posing the question to the students – what would be the difficulties in using photovoltaic cells for this mission? To find out they are going to investigate the relationship between light intensity and distance from a source.

Setting up the experiment:

1. Choose one mobile phone with a torch function that will act as the light source. This will not need to have a light meter app installed. Clamp it into a retort clamp and stand so that the torch light is facing out and take care to make sure that it is clamped to true vertical.

2. Take the second mobile phone (with a light meter app installed) and clamp it in the second retort clamp and stand so that the camera the app uses is facing the torch. Adjust the position of the clamp so that the camera and the torch are directly level with each other.

3. Take a meter ruler, and lay it so that it runs parallel along the base of the mobile phone with the light meter app installed. Move it so that 0cm starts when the torch and camera lens are touching. Tape this down in place.

4. When everyone is ready, turn out the lights. Before you turn your torch on, take a background reading of the light levels. This will be subtracted from your readings to give you a true reading of the intensity from the torch.

5. With the two mobile phones at a distance of 10cm from each other, and making sure the torch and camera lenses are still aligned, turn on the torch and note down the intensity from the light meter. Carefully, move the light meter phone to a distance of 15cm and repeat your readings. Continue to move the light meter phone away from the torch in 5cm increments until you reach a distance of 40cm.

6. Repeat the experiment two more times to obtain three sets of data and take an average.

7. Subtract your background reading from each average to give you the true variation of intensity with distance.

8. Take a piece of graph paper and draw a set of axes, with distance in cm on the x axis, and intensity of light on the y axes. Plot your data points and discuss in your group what kind of a relationship you have found.

Analysing the data (younger students):

Tell the students it is suggested that intensity varies with distance following an inverse square relationship. Ask them how they could verify this with their data.

By comparing the difference in light intensity between two points where the distance has doubled, say 20cm and 40cm, they should find that the intensity of light has dropped to 1/22, or ¼ of the original. They can do this for several points to verify the relationship.

Analysing the data (older students):

The students now need to suggest what relationship there is between the intensity of light and distance from the source. Once they have suggested that it will be an inverse square relationship, ask them how they would graphically prove this.

By drawing a new graph of light intensity against $1/r^2$, they can perform a linear regression. If they obtain a straight-line graph, then they have verified that this is an inverse square relationship.

Discussion: Errors

Get the students to identify any anomalous results, or any problems with their data. In their groups, they should discuss any sources of error in this experiment (for example, picking up light from another groups experiment, not aligning the camera lens with the torch properly). Get them to design an improved version of this experiment, and compare the ideas of each group.

Theme 2 – Getting Out There

Activity 2.1 – CD Hovercraft

Title of Activity

Using a hovercraft to illustrate Newton's Laws of Motion

Space Context

Hovercrafts work by using air to lift a vehicle off the ground. The CD Hovercraft is no exception. As the balloon deflates, it is releasing air through the sports bottle cap and beneath the CD (Newton's Third Law). Because of the shape, smoothness, and weight distribution of the CD, the releasing air creates a cushion of air between the CD and the surface (Newton's second Law). This cushion of air reduces the friction between the CD and surface and allows your hovercraft to move more freely. If it were possible to reduce friction altogether, the hovercraft would travel in one direction, uninterrupted, FOREVER. Like objects orbiting in space!

Learning Outcomes

- Demonstrate the process of science inquiry by posing questions and investigating phenomena through language, methods, and instruments of science.
- Newton's First Law states that an object in motion will stay in motion unless acted upon by an outside force.
- Newton's Second Law tells us that Force = Mass * Acceleration. In other words, an object's mass, multiplied
- by its amount of change in position gives us the amount of force that it can expend on another object.
- Newton's Third Law states that for every action there is an equal and opposite reaction.

Curriculum Links

- Forces and Motion: Newtons Laws, contact forces
- Friction: Useful and non-useful
- Gravity and Orbits

Delivery Mode

Teacher demo, then pupil investigation of factors to vary.

Worksheet can be used for pupils to investigate variables.

Use of IT/Technology

Not a whole lot here, linked videos can be used to help with construction

Differentiation

Help may be required with construction.

Variables to investigate can be adjusted accordingly.

Worksheet can be edited to provide help or to challenge as appropriate

Assessment

By outcome of investigation

By construction of workable model

Links / Further Information

https://www.youtube.com/watch?v=pzvqVch__T8 – how to build guide

https://www.youtube.com/watch?v=2lkIuk0AjEw&feature=youtu.be – static and fluid friction explanation, ideas for further investigations.

https://www.youtube.com/watch?v=VUfqjSeeZng – friction in everyday situations

https://www.youtube.com/watch?v=h18FOjnv6YY – hovercraft racing

https://www.youtube.com/watch?v=gCT7z0SlRT8 - how does a hovercraft work. (illustration)

Lesson Plan

1. Slide CD on desk to show that it doesn't move. Ask pupils to discuss what is preventing it from moving.

2. Pupils to discuss what can be done to overcome this friction. Discussions may include use of lubricants. Discuss why this may not be a possibility to use in spacecraft – unstable chemical reactions, heat generation, cost, supply etc. (Video clip – friction in everyday situations)

3. Show a videoclip of a hovercraft in action (Hovercraft racing)

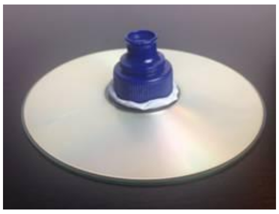
Materials:

Water bottle top

Balloon

CD or DVD (that you don't mind if it gets scratched)

Method:



STEP1 - Roll the Blue-Tac into a sausage shape and press it down onto the CD, in a circle. Push the bottle top down onto the CD so that it sticks to the CD with no gaps for the air to escape.

STEP2 - Blow up the balloon pretty full and then twist the bottom round several times (so the air doesn't all come out while you're attaching it to your hovercraft base!)

STEP3 - Stretch the balloon over the bottle top, untwist the balloon and you're off. Try pushing your hovercraft gently and watch how far it glides!

Try adding weight to the hovercraft, maybe more Blue-Tac, how does that change things?

What about blowing the balloon up more, or less?

Find a way to extend the hovercraft, make the base even bigger, how does that change things?

Pupils to build their own model – use the worksheet as a guide and allow pupils to investigate the questions posed.

PLENARY

Pupils to feedback to the class on their discoveries.

Competition to find the fastest/longest traveling hovercraft in the class.

Theme 2 – Getting Out There

Activity 2.2 - Compressed Air Rocket

Title of Activity

Design, build and launch a compressed air rocket.

Space Context

Spacecraft need to be as aerodynamic as possible. Designers need to ensure that the rocket is controllable and safe, but that it will travel through the air with as little affect from air resistance as possible.

Air resistance will decrease the speed and require much more fuel on board to reach the destination. It can also produce heat which can cause problems.

Learning Outcomes

- Use research and develop design criteria to inform the design of innovative, functional, appealing products that are fit for purpose.
- Evidence, models, and explanation - Change, constancy, and measurement
- Science as Inquiry -Abilities necessary to do scientific inquiry
- Physical Science -Position and motion of objects, Motions and forces
- Science and Technology Abilities of technological design
- Generate, develop, model, and communicate their ideas through discussion and annotated sketches.

Curriculum Links

- Mathematics- Calculations, problem solving, sequences of actions.
- Science- Scientific vocabulary, action & reaction, friction, opposing forces, gravity.

Delivery Mode

Teacher introduction – the basics behind designing a rocket

Pupil activity – design and build a rocket

Pupils investigation – launch the rocket and investigate variables determined by discussion.

Class discussion / presenting of the findings

Use of IT/Technology

Download and use the TRACKER (Free software). record the launches and investigate the factors graphically to extend the learning for more able students. http://physlets.org/tracker/

Differentiation

Mixed ability grouping- grouping to be done by teacher. Learners with different skills can be grouped together.

Factors to investigate can be differentiated by pupil's own discussion.

Assessment

Workable model and successful launch

Completion of worksheet

Pupil feedback to class on factors they investigated and the outcome of investigations

Links / Further Information

Tracker Software : http://physlets.org/tracker/

Instructions included separately for

- simple stomp rocket
- Institute of Physics launcher
- Student worksheet

Lesson Plan

**There are two options here. The first is where the pupils use a plastic bottle as the source of the 'compressed air' and stomp on it to launch the rocket. The second is where a paper rocket is launched using a compressed air pump manufactured using plumbing supplies. This method is described using the Institute of Physics instructions (enclosed) HOWEVER, there has been one incident where the pressure rating of the plumbing supplies was exceeded and the launcher failed, causing injury to the instructor. Judgement to be applied when selecting the method to be followed.

STARTER:

Show pupils pictures of space rockets and discuss their aerodynamic features. Looking at the pictures that have been provided in their sketch books learners must sketch a drawing labelling it, the labelling does not need to be descriptive. This is only the starter activity and it will help learners understand the features of a rocket.

Show pupils a video of an air powered rocket. What do they need? Have an air powered rocket present to show pupils. Discuss positioning of fins to aid stability, overall weight in respect of fuel costings, air resistance and minimising factors.

MAIN LESSON:

The challenge:

Learners must produce an air powered rocket that can go the furthest/ highest/ longest (time of flight)

Thinking about the aerodynamic features discussed before what features would make the rocket launch and go further. Repeat the air powered rocket video and allow pupils to discuss what they think the most important factors are.

Groups to sketch their plans. Teacher to facilitate as needed – prompt and encourage.

METHOD ONE:

see attached instructions

METHOD TWO:

Assemble launcher as per instructions attached (TEACHER ONLY. ONE LAUNCHER PER WHOLE CLASS)

Pupils use the paper template to construct their rockets. They can decide on the factors to investigate. Below some suggestions for variations are listed.

In (approximate) order of complexity:

Investigate effects of: different nose shape, different number/size/shape/position of fins.

- how pointed should the nose be?

- what is the optimum size for fins?

- are fins near the nose of the rocket helpful? if not, why do some aircraft have them? (computer-controlled, for stability/manoeuvre)

Investigate the relationship between launch angle (angle between plastic launch tube and ground) and range - on a windless day and with a standardised design of rocket

If the answer differs significantly from the simple theory (maximum range from 45o launch), what simplification is made in the textbook calculation?

From the time of flight, use equations of motion to calculate the vertical component of launch velocity – what simplification do you make, and how valid is it?

From the calculated vertical component, and the measured launch angle, calculate the horizontal component of launch velocity (vectors).

Multiply this velocity by time of flight to calculate theoretical range in the absence of air resistance.

Measure actual range and so calculate mean actual velocity between launch and impact; use theoretical velocity and mean velocity to estimate mean value of (negative) acceleration due to drag.

Using this mean value of acceleration and measured mass of rocket, estimate mean value of drag force (F= m . a).

From calculated initial velocity and measured mass, calculate kinetic energy at launch (KE = ½ m v2)

Estimate energy stored in compressed air before launch:

a) from work done (force x distance x number of strokes) on pump handle

b) from change of own gravitational potential energy when using body weight to depress foot/hand pump pedal.

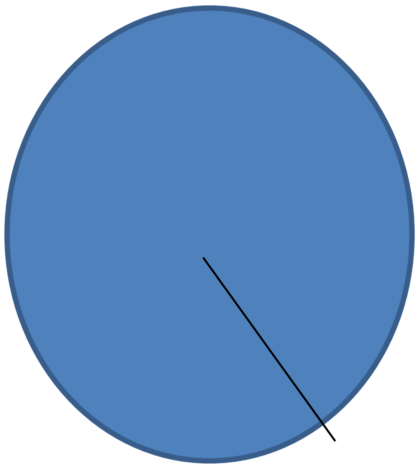
Estimate percentage efficiency of energy transfer from compressed gas to rocket; consider ways of improving this:

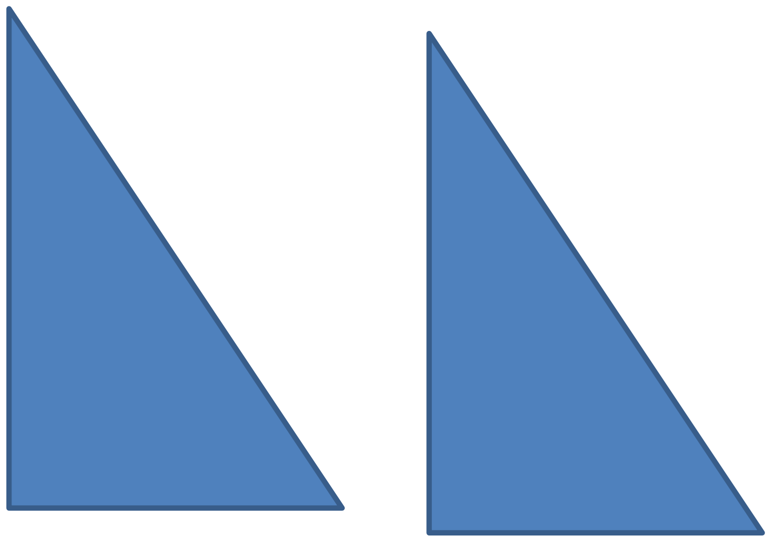
Tightness of fit of rocket on launch tube - is there an optimum?

Mass of rocket - how does this influence range?

Pupils to fill in the enclosed worksheet and be prepared to feed back to the class and discuss their findings.

Paper Rocket Template:

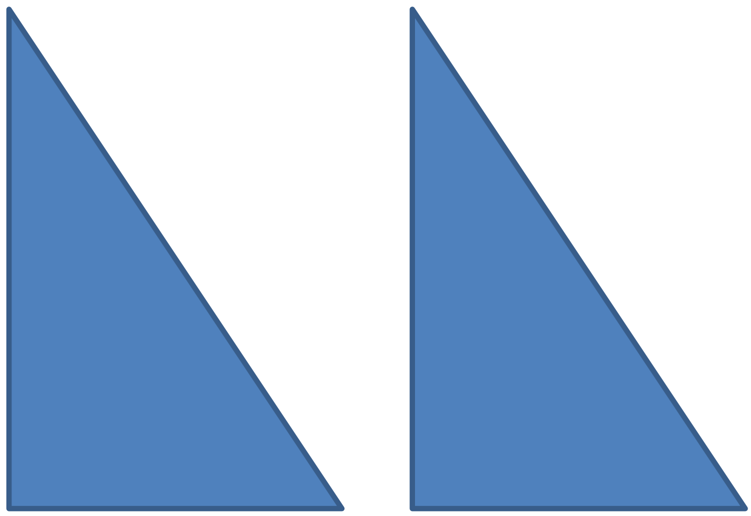




Nose cone:

Cut out and along black line.

Fold over to form a cone adjusting the gradient of the cone to suit investigation



Fins:

Number to be added dependent on investigation.

Cut out and fold along vertical side to form a flap enabling it to be secured to the rocket body with tape or glue.

Rocket body is made from one sheet of A4 paper rolled to fit around launch pipe.

Theme 2 – Getting Out There

Activity 2.3 – Mini Whoosh Bottle

Title of Activity

The usefulness of energy - Demonstrating the Whoosh Rocket and custard powder explosions.

Space Context

To launch a rocket or to move a rocket through space, we must use a propulsion system to generate thrust. Thrust is generated through an application of Newton's third law of motion; a working gas is accelerated to the rear of the rocket engine, and the re-action is a thrust force applied to the engine in the forward direction.

In solid and liquid fueled rocket engines, the working gas is produced through the burning of a fuel to produce power. Burning a fuel is called **combustion**, a chemical process that we study in middle or high school.

Learning Outcomes

- Pupils will recall and understand Newton's Third Law of Motion: **For Every Action There Is An Equal An Opposite Reaction.**
- Pupils will understand the term **Combustion**

Curriculum Links

- **Forces.** forces being needed to cause objects to stop or start moving, or to change their speed or direction of motion (qualitative only), using force arrows in diagrams, adding forces in 1 dimension, balanced and unbalanced forces.
- **Chemical Reactions**. Exothermic Reactions, Combustion, representing chemical reactions with formulae and equations.

Delivery Mode

Question and Answer to elicit pupil ideas regarding the key ideas of COMBUSTION and BALANCED FORCES.

Teacher demo of custard explosion and whoosh rocket.

Pupil summary – force diagram

Use of IT/Technology

Using a slow motion camera facility to record the launch can allow the footage to be uploaded to the TRACKER free software for data analysis. Download here http://physlets.org/tracker/

Differentiation

The variables to be investigated can be simplified for less able students. eg number and position of fins.

For more able students the angle of trajectory, and speed of rocket can be calculated from measurements.

Assessment

Outcome – students will produce work to their level. Adjust level of questioning accordingly.

Task – labelling diagrams will be targeted to ability.

Links / Further Information

http://www.esa.int/spaceinvideos/Videos/2014/07/Mini_whoosh_bottle_-_classroom_demonstration_video_VC01

Lesson Plan

STARTER/RECAP/ INTRODUCTION

Question: which do you think will burn? Show the three fuels – custard powder, gas and ethanol.
Class discussion on what makes fuels good, and can you use all fuels in all situations.
Students to write a statement on what they think a fuel is.

MAIN PART OF LESSON

Demonstration of the experimental demo:- custard powder. This demonstration is often used to show how the energy contained in foods can be released through burning.
A few tea-light candles are lit and placed into the bottom of the tin and a bent glass tube is used in place of the straw.
The tube needs to be securely fitted into the tin to make sure it will not fall over when air is blown through.
A long enough length of tubing will ensure the operator will not get burned or covered in powder.
Leave the lid on the tin so that it blows off with some force when the powder ignites.

A glass funnel may be attached to a length of Bunsen tubing and held firmly in a clamp stand as another alternative. This takes less time to set up each time and can be as effective as the other methods.

If the powder has trouble catching, it may be too damp or if only some is catching, the flame may need to be placed closer to the opening where the powder is blown from.

Some teachers may use a clamped Bunsen burner on a yellow flame instead of a candle so that the flame area is larger. Other powders can be used such as cornflour, regular flour or icing sugar.

Projected flames can be compared when using different powders, the flame size and shape may be affected by

How much energy is contained in the food. Glucose burns in oxygen to produce carbon dioxide, carbon monoxide and water...

Students then given the question what has fuel got to do with energy? Are they the same?

What happened to the lid of the container – why?

Discussion steered to the forces involved to blow the lid off. Unbalanced forces result in a change of shape, speed or direction. What if the tin was placed upside down – it would lift off the ground.

Relate to lifting a rocket off the ground. Why would custard powder not be a good fuel in this situation? Pupils to discuss the amount needed, the transport of the powder etc.

Discuss how to get a large output from a small input – efficiency.

Demo the whoosh rocket emphasising the small amount of fuel required.

See attached video link for instructions.

<u>PLENARY</u>

Pupils to construct a forces diagram and label the forces on it for both demonstrations

Pupils can include the equation for combustion.

Pupils to link energy to fuels, explain what a fuel is an how we know it is a fuel.

This is a relatively safe demonstration as long as common sense is followed. Keep viewers far enough away from the demonstration area and behind a safety screen. The operator should wear safety glasses and not be too close to the demonstration equipment. Ensure the powder will be blown straight upwards and that there is nothing hanging above the area which could catch fire. Ensure that no person or property can be harmed by the flame.

Replace cap on Ethanol bottle before igniting rocket.

Wheaten based custard powder and the egg in some custard powders may be an allergen to some people – ensure that no-one viewing the demonstration has these allergies.

Theme 3 – Looking Back

Activity 3.1 – Earth Observation

Title of Activity

Introduction to Earth Observation

Space Context

Earth Observation (EO) is an application of multidisciplinary space science. It requires understanding of space missions, data communications, and of the underlying sciences – chemistry, biology, and physics. Earth observation is a major, and growing, component of the space science economic sector with increasing impacts on our understanding of planet Earth.

Learning Outcomes

Students should:

- Be able to describe the electromagnetic (EM) spectrum and how it is used to monitor Planet Earth.
- Be able to explain the different characteristics of satellite orbits.
- Appreciate how different materials respond to EM radiation.
- Understand how images are made and processed.
- Appreciate the range of possible applications of EO data.
- Be able to carry out a basic interpretation of imagery.

Curriculum Links

Due to its multidisciplinary nature EO has curriculum links across many subjects. For example, in geography, environmental science, the traditional sciences (CBP), and computer science. More widely it could also be used as a context in business studies and art.

Specific curriculum links in Physics (Scottish curriculum):

National 4/5: Understanding and detection of EM Spectrum. Projectile motion and satellites with respect to orbits. Impact of space exploration on understanding planet Earth and the global impact of satellite applications. Emission and absorption spectra.

Higher/Advanced Higher: Interaction of EM radiation with materials. Circular motion. Resolving power. Understanding of methods of space exploration.

Delivery Mode

1. Teacher-led description of principles of EO

2. Group activity: a) Creating multispectral images

b) Image interpretation – Landform quiz

Identifying impact craters

Use of IT/Technology

Usual classroom ICT facilities required for the teacher-led section.

Pupil mobile phones to act as sensors. Simple image processing software (e.g. ImageJ).

Colour photocopies of imagery.

Differentiation

This lesson is an introduction to EO. Most of the concepts are general and do not require to be differentiated. The activities are accessible to all students although Activity 4 may require a deeper understanding of how certain features are formed.

Assessment

Assessment is by successful completion of Activity 4.

Links / Further Information

Further information on how the EO system works can be found at, for example:

http://www.nrcan.gc.ca/node/9309 Tutorial: Fundamentals of Remote Sensing

http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9487 Tutorial: Watching over our planet from space A kit for kids!

https://landsat.usgs.gov/education-and-outreach

https://landsat.gsfc.nasa.gov/education/

Lesson Plan

Purpose: Lesson is aimed at giving pupils an appreciation of the science and technology behind Earth Observation (EO). Activities are interspersed with teacher-led information about how EO works.

Activity 1

Simple starter.

Equipment: Rainbow goggles

http://educationharbour.com/index.php?route=product/product&product_id=64

Pupils to wear "rainbow" goggles to view the world differently.

Goggles help to show that ordinary white light is made up of a range of different frequencies that are perceived as colours.

Leads on to electromagnetic (EM) spectrum and invisible radiations.

Slide 3

Discussion about the EM spectrum being a family of waves of different frequencies and travelling at the same speed (speed of light 3.0×10^8 ms^{-1}). Only small portion visible to human beings.

Slides 4 – 7

Set of slides covering the use of satellites and the different orbits. Relates orbital period with height.

Slides 8 – 10

Information about how energy from the Sun is reflected from different surfaces and recorded by sensors on the satellites. Considers only passive systems not the active RADAR systems. The ideal blackbody radiation curve for the Sun shows the peak in the visible part of the EM spectrum. Spectral profiles can be used to identify the different surface materials by the way in which they absorb energy at different wavelengths. This is due to the different chemistry and structure of the materials. When designing sensors, it is important to know about these profiles so that appropriate wavebands can be included.

Slides 11 – 13

Images are made up of matrices of numbers. Each pixel represents an area on the ground, its value is related to the energy reflected in the given waveband. The pixel size used by different sensors and satellites gives an indication of the detail that can be recorded. The smaller the pixel size the more detailed the image but usually the smaller the total area covered. Data from different wavebands appear as stacks – rather like overlaying maps.

Slides 14 – 16

Computer displays are used to present the spectral image data. Colours are produced by combining red, green, and blue in the screen. If the red, green and blue image data are used to control the RGB screen colours then a natural colour composite is produced. If other, possibly nonvisible, spectral data is assigned to the RGB screen colours then a false colour composite is produced.

Activity 2

Equipment: Red, green, blue coloured gels or filters from ray box kit.

Mobile phone camera.

Clamp stand

PC/laptop with ImageJ software loaded.

https://imagej.nih.gov/ij/

Method:

Clamp mobile phone camera in a fixed position to look at a scene. Set the camera to record in greyscale (black & white).

Place the red gel over the lens and record an image. Repeat with the green gel and then the blue.

Down load images to PC.

Run ImageJ software.

File

Open red image

File

Open green image

File

Open blue image

Image

Color

Merge channels

C1 red image

C2 green image

C3 blue image

Tick create composite

Tick keep source images

Composite should now look like the real scene.

Pupils can easily change colour order to see the effect of false colour compositing.

Activity 2a

As an alternative to using mobile phones the concept of using different wavebands can be observed using the NASA Earth Observatory website.

https://earthobservatory.nasa.gov/Experiments/ICE/panama/index.php

In Exercise 1 a pupil can select different wavebands from different satellites assigning them to the different colour guns of the computer monitor. This simple interface allows pupils to see how natural colour and false colour composites can be formed.

Also allows for basic image processing (contrast enhancement) to be performed using the triangles shown on the slider bars. Image interrogation can be performed using the options to the right of the images. (Could be used to support information given in Slides 18,19 and 20 – 26.

Slides 18 - 19

Using the computer it is possible to display nonvisible spectral information. Using image processing software the images can be enhanced and other parameters calculated.

Slides 20 – 26

A selection of different applications of satellite imagery.

Can be modified to include local images for added interest.

Activity 3

Equipment: Landform Quiz image collection

Landform Quiz pupil work sheet

Sourced from https://landsat.gsfc.nasa.gov/education/

Pupils are asked to identify the different landforms given in the image collection. The worksheet can be adapted. Word bank of landforms can be used or more able pupils asked to use their experience to suggest landforms.

Different image collections can be made up if required.

Activity 4

Equipment: Set of coloured photocopies of imagery of potential impact craters on Earth.

Pupil worksheet

Sourced from https://landsat.gsfc.nasa.gov/education/

This activity should be carried out in small groups. Pupils need to read the information about how images can be interpreted with regards the nature of impact craters.

Theme 3 – Looking Back

Activity 3.2 – IR Astronomy

Title of Activity

Infrared astronomy and doppler shift: Using infrared to estimate the age of the Universe

Space Context

When students think of astronomy, they will usually imagine the stunning visual imagery that telescopes such as the Hubble Space Telescope provide. However, these vivid images provide only a small part of the story of our Universe. To truly understand the origins of our Universe, we need to use another part of the electromagnetic spectrum – Infrared. By investigate doppler shift, and applying this to the redshift of distant stars, students will come to understand why the next big space telescope – the James Webb Space Telescope – will use the infrared.

Learning Outcomes

Students understand and can explain the origin of doppler shift of sound.

Students can calculate the recessional velocity of a tone generator using software and mathematics.

Students apply this understanding of doppler shift to the light reaching us from different stars, and calculate the age of the Universe using Hubble's method.

Curriculum Links

Doppler shift

Hubble's law

Graphical analysis of a straight-line graph to obtain a value

The big bang

Delivery Mode

Teacher presentation

Class demonstration

Student calculation

Use of IT/Technology

This lesson involves the use of a free piece of (windows) software – the Spectrum Lab frequency analyser. The install file and manual are included in these resources and can also be downloaded from:

http://www.qsl.net/dl4yhf/spectra1.html

Several students will also need to download a tone generator onto their mobile phones (or you can use your own). Suggest tone generators:

Android – PA Tone:
https://play.google.com/store/apps/details?id=com.dutchmatic.patone&hl=en_GB

iPhone – Tone Generator: https://itunes.apple.com/gb/app/tone-generator/id457003837?mt=8

Differentiation

Younger/less able students will focus on understanding the origin of doppler shift and calculating the recessional velocity from a change in frequency.

Older/more able students can apply this to graphical analysis of Hubble's data to obtain an estimate for the age of the Universe.

Links / Further Information

James Webb Space Telescope Website: https://www.jwst.nasa.gov/

Interactive doppler shift animation: http://www.lon-capa.org/~mmp/applist/doppler/d.htm

Lesson Plan

This lesson is designed to be taught with the accompanying power point presentation and relevant slides will be mentions in this plan. There are additional notes included on the power point slide. More information accompanies the slides in the notes section on PowerPoint.

Setting the scene (slides 1-4):

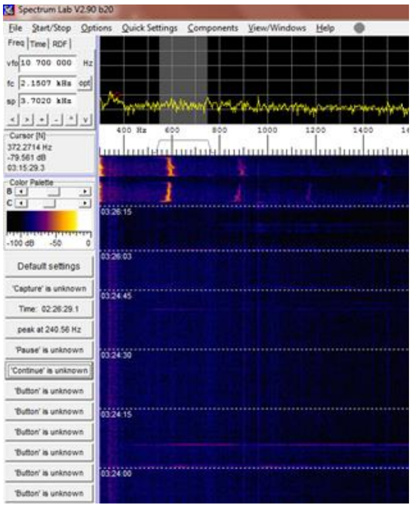
Ask students to think of a picture in their minds that represents astronomy. Get them to share with you what they thought. It is likely that several of them imagined a picture of the night sky filled with many stars, twinkling away over the course of a night. Explain to them that the visible light we see from stars only tells us a small part of their story. To understand the stars, galaxies, and our Universe as a whole, we have to turn to different types of light – by using different parts of the electromagnetic spectrum.

Use slides 5 to 7 to introduce the idea of infrared radiation. Get students to guess what the images are, and to explain why they look the way they do.

Main lesson: Red shift and the James Webb Space Telescope (JWST)

Give the students some background on the JWST (slides 8-10). Ask students why they think the telescope is designed to work in the infrared. What problems would occur when using the radiation provided by warm objects? How could this be overcome (The JWST must be cooled to be sensitive enough to view very distant objects in IR).

So why Infrared? Demonstrate doppler shift to the students using a tone generator attached to a piece of string. Carefully swing this around your head in a circle and ask students to describe what happens to the pitch (and therefor frequency) of the sound as it moves towards, and away from them. Show the picture and the gif on slide 11 to help consolidate their understanding (depending on the ability of the group, you may wish to explore the simulation in the links at this point).



Launch the spectrum lab frequency analyser and explain to the students what it does. Get them all to hum or sing and click on 'capture' to start the rolling sound spectrum. This will appear as a waterfall of different colours that corresponds to the different frequencies. You may also see some obvious harmonics that you will want to point out.

With spectrum lab still running, click on the link on slide 13. This will play a video of a driver beeping their horn as they drive past an observer. The doppler shift in sound frequency is very noticeable as the car drives away.

Once the video has finished, go back to spectrum lab and click pause to freeze the spectrum. You should clearly be able to see the shift in frequency from a higher to a lower frequency as the car recedes.

If you give a student a tone generator (or get them to download a tone generator app onto their mobile phone) you can get them to walk swiftly towards you (it is best to use a frequency of around 5 kHz for this). Ask the class to predict what will happen as they move away from the source. Using the software, you will easily be able to see the doppler shift of the sound to lower frequencies.

You may wish to use the change in frequency to calculate the recessional velocity of the student using the doppler equation for a stationary observer:

$$f' = \frac{(v)}{v - v_s} f$$

Where:

f' = observed frequency f = actual frequency v = speed of sound (340ms^{-1}) v = speed of source

Note, for a student walking away from the observer, shifts of around 20Hz are typically observed which corresponds to a velocity of approximately 1.3 ms^{-1} – this is a reasonable value for fast walking speed.

Extension – Redshift and Hubble's Law

The above activity can then be expanded to incorporate red shift of distant astronomical units and Hubble's law for estimating the age of the Universe.

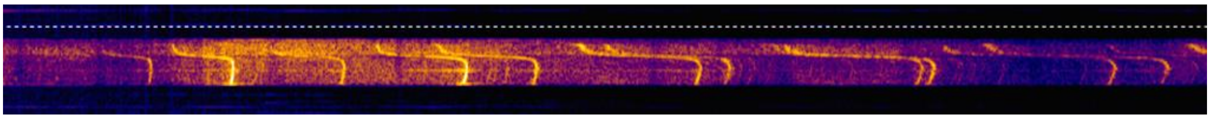
Explain that Edwin Hubble was an astronomer who noticed that distant objects appeared redder than they should. Such observations suggested that almost all astronomical objects were moving away from us – that is, the Universe is expanding. By measuring the distance to relatively nearby objects (using standard candles such as cepheid variables) he was able to obtain data for the distance, and from redshift values he was able to calculate the speed of recession.

Hubble found that there was a linear relationship between these two values. That is, the further away an astronomical object is, the faster it is receding from us.

Get students to model these findings using spectrum lab and assigning 6 students their own frequency. Have them decide how fast they will need to recede away from the source depending on their starting distance from the source.

Finally, show students the Hubble graph for receding type 1a supernova. Note the units (kms^{-1} and MPc). Explain that the gradient of the graph gives Hubble's constant for the Universe. Ask students how they could use this to estimate the age of the Universe (taking care to convert the units to m and ms^{-1}.

Give each student a copy of the graph, and ask them to calculate Hubble's constant for that graph, and an estimate for the age of the Universe. This is then explained on the PowerPoint slides.



Give each student a copy of the graph, and ask them to calculate Hubble's constant for that graph, and an estimate for the age of the Universe. This is then explained on the PowerPoint slides.

Students Can then comment on the accuracy of their method and on any sources of error (for example, this method assumes the Universe is expanding at a constant rate).

Plenary discussion:

So why will the JWST use infrared and not visible light to make observations?

Get students to discuss why they think infrared the wavelength of choice for the next generation large space telescope. What would happen to light from the very oldest, most distant objects? It is shifted out of the visible spectrum and into the infrared. So, by using infrared, the JWST will be able to look further back in time than ever before!

Theme 3 – Looking Back

Activity 3.3 – Modelling Ocean Currents and Weather

Title of Activity

The ocean, and in particular the temperature of the surface, is the biggest driver of weather patterns and global climate events on the Earth. In this activity students will model thermal currents in the ocean, and link this to orbital Earth observation of the ocean surface. Finally, students can then relate this information to weather prediction through use of a free iPad app.

Space Context

Earth observation, and particularly the monitoring of climate and ocean temperature are key foci of the European Space Agency's orbital missions. Through the effects of convection, energy transfer and the rotation of the Earth, small changes in the temperature of the Ocean's surface can drive huge changes in climate and weather events. Understanding and predicting the fate of ocean temperatures allows us to better understand and predict extreme weather and climate events.

Learning Outcomes

Students able to explain how we can monitor the temperature of the ocean surface from space, and why it is advantageous to do so.

Students use the principal of convection to explain how ocean currents can drive climate and weather effects.

Students understand that resolution is important to obtaining useful data, and that specific orbits are used to acquire such data.

Curriculum Links

Key Stage 3/4

Convection and thermal transfer

The electromagnetic spectrum

Delivery Mode

Teacher introduction and scene setting

Group investigation – ocean currents and calibrating the measurements

Group exploration – Hunting for hurricanes (iPad activity)

Use of IT/Technology

To investigate hurricane formation iPads or iPhones will be required with the following free app installed:

http://www.livingearthapp.com/

Lesson Plan

Slide 1: Introduction

Slide 2: This link shows you a real time 3D map of all of the objects in Earth Orbit (above a size of about 1m). Most of these objects are satellites, performing a range of different tasks from communication to astronomy.

Slides 3 and 4: However quite a few of these are satellites that look back upon our planet, monitoring temperature, salinity, climate, carbon dioxide levels and much more. Earth observation is a core part of the missions of all the major space agencies including NASA (slide 3) and ESA (slide 4).

Slide 5: Many of these satellites will include infrared instruments – that detect the type of electromagnetic radiation that is associated with temperature. Anything with a temperature above absolute zero has vibrating molecules, at it is the vibration of these molecules that gives of infrared radiation. As a result, we can use infrared to get information about the temperature of an object, or range of objects.

Slides 6 and 7: An Ice cube (purple is cold) and some tortoises (cold blooded). In order for the information to mean anything useful to scientists, the instruments must be calibrated and a colour scheme that matches temperature drawn up.

Activity 1: Calibrating the thermo-colour paper

In groups, students are given a small square of the thermo-colour paper and a boiling tube. Their task is to expose the paper to water or changing temperature in order to define what temperature each colour means.

Each group will need:

Boiling tube

Test tube rack

Thermometer

Hot water

Small square of thermo-colour paper

Method:

1) Place a piece of the thermo-colour paper into the bottom of the test tube.

2) Add 10ml of cold water to the boiling tube.

3) Place a thermometer into the boiling tube

4) Using a pipette, carefully add hot water to the boiling tube until you observe a change in colour in the paper. Note down the temperature and the corresponding colour.

5) Continue adding hot water slowly until the paper changes colour again, and note the temperature and the colour.

6) Repeat this until you have four or 5 colours with their corresponding temperature.

Activity 2: Modelling the ocean

Each group will need:

1 plastic/foil tray of dimensions at least 20cm x 20cm

1 piece of thermocolour paper that will fit on the bottom of the tray

https://www.rapidonline.com/thermocolour-sheet-73046

(Optional) one IR thermometer

https://www.ebay.co.uk/i/351901852905?chn=ps&dispItem=1&adgroupid=49021508048&rlsatarget=pla-325907276808&abcId=1128946&adtype=pla&merchantid=7411154&poi=&googleloc=9046181&device=c&campaignid=856856138&crdt=0

1 jug cold water

1 jug hot water

Optional introduction method (if you have handheld IR thermometers).

1) Fill the tray to a depth of about 1cm with cold water.

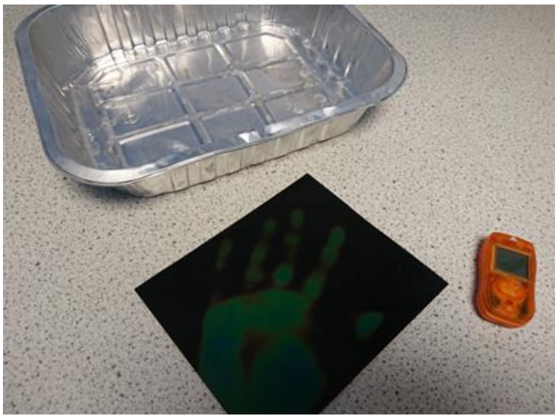
2) Take the jug of hot water and pour a small amount in one corner of the tray.

3) Attempt to follow the hot water around the tray. Explain any difficulties you had in doing this.

It is very difficult to track the hot water when working ‘blind’. Since there is no visible difference in the different temperatures of water, it is easy to lose the hot water and so lose the ability to track the warm water currents that will be set up in the ocean.

How could this be improved? We could send a bigger version of the thermometer up into space, so that it can monitor a much larger section of the ocean. And what we would see can be modelled using the thermo-colour paper.

Method 2:



1) Fill the tray to a depth of about 1cm with cold water.
2) Take the large piece of thermo-colour paper and place it at the bottom of the tray, pushing it down so that it sticks to the bottom.
3) Add a small amount of hot water to the corner of the mini ocean and note what you see.

Students should be able to observe the hot water spread from the corner of the tray across the ocean. However, it does not do this in a linear fashion. Instead, currents are set up that carry the hot water away in bands.

Extension: What are the limits of this as a model for the ocean? As and example, the paper is at the bottom of the tray, however we are most interested in the ocean currents at the surface. If using a metal tray, heat may be conducted through the tray etc.

Slides 10 and 11 show examples of one of the first and one of the most recent IR ocean surface images. The second image looks very similar to what students will have produced in their trays.

By using remote sensing from space we get a real time, dynamic image of the temperature of the ocean surface.

Slide 12: And it is currents within the ocean that transport hot and cold water across two thirds of the Earth, affecting the climate and weather patterns in an intricate network of related currents. Even small changes in the temperature of the ocean could disrupt these currents and therefor wreak havoc on the climate of regions of the Earth, leading to drought, flooding and changes in humidity.

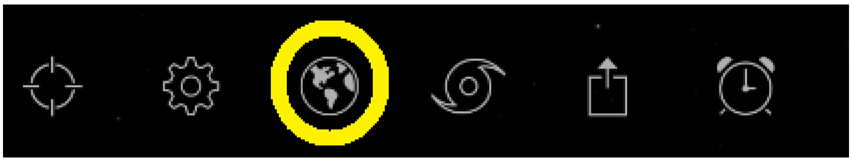
Slide 13: And the surface temperature of the ocean can also affect the formation of weather phenomena such as hurricanes.

Slide 14: Link to a video detailing how a hurricane forms. Slide 15 recaps the key parts. In order for a hurricane to sustain itself it needs to gain energy from the Ocean surface to drive it, and compensate for the fact that it is losing energy as it moves through the various layers of the atmosphere. In activity 3, students can use their iPads or iPhones to pull together all of these ideas and hunt for hurricanes.

Activity 3: Hunting for hurricanes

This activity uses the living Earth app. When you first start up the app you will get an image like the one below. By clicking the right arrow at the bottom, you can cycle through to select a location near to where you are.

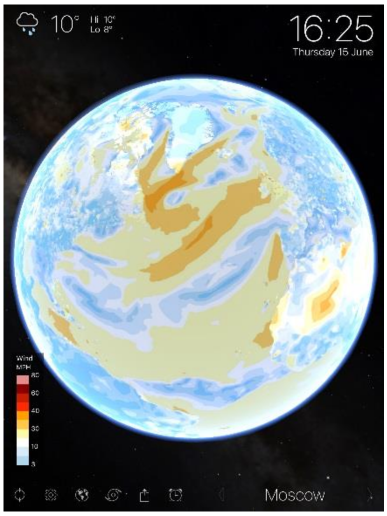
If you hover your finger above the earth, you will see a menu of options appear at the bottom that looks like this:



Clicking on the Earth icon (highlighted in yellow) will bring up the options of what attributes to view on the Earth. To find a hurricane we are looking for a region of high wind speed, over the ocean, with a temperature above 27°C in order to keep driving the cyclone motion.

Select wind speed:

And look for areas that are orange or red. These may have the potential to develop into cyclones.



You can then reference these areas with temperature and humidity. If high wind speed is combined with high humidity and an ocean surface temperature above 27oC then it could show a cyclone, or a developing hurricane. You can then click on the cyclone icon on the bottom menu to check to see whether there are any active cyclones at the moment.

Students can then check back over the coming days to see whether their predicted cyclone did indeed develop into a hurricane.