Detecting Gravitational Waves

Engineers Week 2022

Primary Classroom Resource Booklet

Introduction:

Gravitational Waves were theorised by Albert Einstein 100 years ago – but have only just been detected. To help children learn more about how these waves are detected, they are going to use sound and sound waves as a comparison.

VIRGO and the two LIGO are ground based gravitational wave observatories. In the future, LISA will be a space based gravitational wave observatory; LISA Pathfinder has shown that the technology is possible.

LIGO Livingston

> "Unlike an optical telescope, a single LIGO detector can say very little about where on the sky a gravitational wave is coming from. This is analogous to the relationship between our own hearing and sight. A single eye is very good at pinpointing the direction of a small flash; a single ear is not good at finding the direction of a short, sharp sound. But two ears are better one---and because we have two, humans have some ability to determine the direction from which a sound originates---but only to a crude accuracy. One of the main ways we are able to determine sound direction is via the time difference between the sound recorded by our left and right ears. This difference is at most about 0.6 milliseconds (although shorter time differences can be perceived). This same trick is used by gravitational-wave detectors to localize the origin of the gravitational wave. Like our ears, GW detectors also use information about the relative "loudness" or amplitude of the waves and the phase information contained in the signals observed in each detector." (from https://www.soundsofspacetime.org/detection.html)

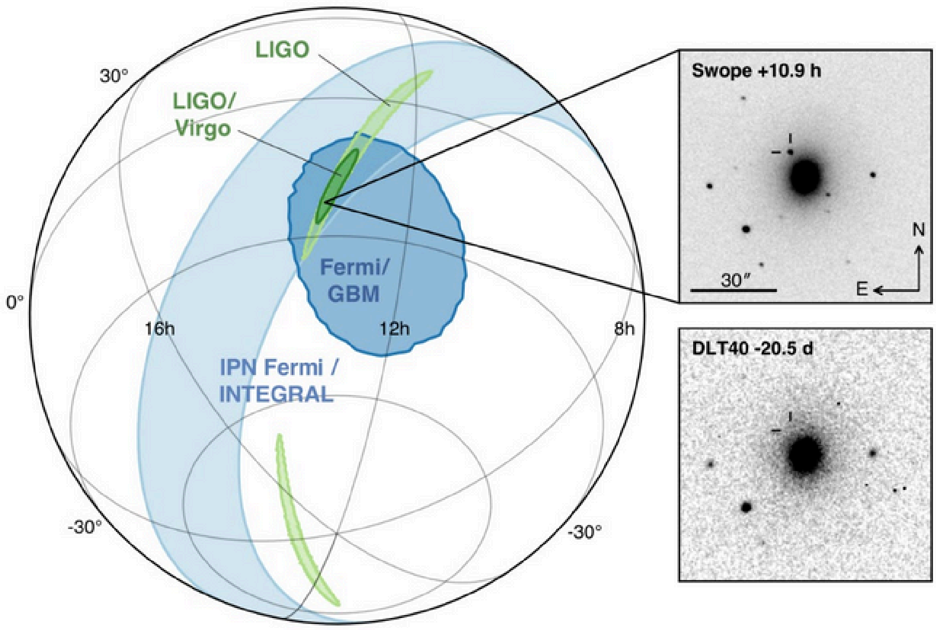
Gravitational wave detectors can identify the extremely tiny effects due to gravitational waves. These waves are made from massive objects (like black holes) that collide far away in space. The detectors are better at telling how far away the source of the wave is, rather than the direction to the source of the wave. When there were only one or two gravitational wave detectors working, it was very hard to tell where the gravitational waves were coming from. Now that there are three detectors, it is easier to tell. This is like our ears – with one ear covered we have a hard time telling where a sound is coming from, although we might know if it is loud or quiet.

Children will be using sound as an analogue to gravitational waves and will come to appreciate how 'noise' can limit our ability to distinguish a sound. These open-ended activities support learning about sound and noise and connect to mathematics. They can use technology in the form of smartphone apps to measure sound.

Children should have some background understanding of sound, perhaps by exploring the DPSM activity Strange Sounds. Children may also explore waves in water or along ropes or Slinkys. Depending on this understanding, the children might focus on just how to arrange "detectors" (the children) to identify the location of a hidden sound or can fully explore the limitations of how humans determine the direction and distance to a sound. This could mean that children carry out the inquiry sequence up to four times, exploring the directionality of human hearing with 'It's Alarming! – Human Ears,' volume discrimination of human hearing/sound meters with 'It's Alarming! – Sound Meters' and then the arrangement of detectors for each scenario.

The minimum audible angle, or the smallest detectable shift in angular location of the sound source depends on the age of the listener and the nature of the sound. For adults, the minimum audible angle depends on the type of sound and can be between 5 and 10 degrees for broad sounds down to 1 to 2 degrees for pure tones. The minimum audible angle is greater for children younger than 8.

Children will come to understand how well we can tell direction and/or loudness with our ears and use that to model a system of sound detectors to find out where a hidden sound is. At the end children will reflect on how good the "ears" of LIGO and VIRGO are compared to our ears.



The location of Gravitational Wave 170817 detected in 2017 was worked out by comparing the locations that four different detectors indicated for the source of the wave. Once the location was narrowed down, optical telescopes were able to photograph that part of the sky and find the source of the gravitational waves. Image credit: http://public.virgo-gw.eu/ligo-and-virgo-make-first-detection-of-gravitational-waves-produced-by-colliding-neutron-stars/

Curious Minds/ESERO Framework for Inquiry

Theme	Detecting Gravitational Waves
Curriculum	**Science: Strand: Energy & Forces; Strand Unit: Sound, Forces** **Curriculum Objectives:** -- learn that sound is a form of energy -- recognise and identify a variety of sounds in the environment and appreciate the importance of noise control -- understand and explore how different sounds may be made by making a variety of materials vibrate -- identify and explore how objects and materials may be moved **Skills Development**: Working Scientifically: Questioning; Investigating & Experimenting; Analysing. Designing and Making: Exploring; Planning; Making; Evaluating. **Music: Listening & Responding: Exploring sounds** **--** recognise and demonstrate pitch differences

Engage

The Prompt	Wondering	Exploring
Video from Minute Physics https://youtu.be/YHS9g72npqA	What are the common characteristics of waves? How can we describe waves? How are sound waves like or unlike water waves or waves from a slinky or rope?	What is meant by pitch of a sound? How is the length of a wave measured? Explore with water, sound, and rope/slinky waves. Place some water in a basin or shallow tray. Get students to blow on the top of it with a straw, can they make a wave? Or students might use the edge of a ruler to make waves across a water filled tray. Explore Sound with Strange Sounds. See: https://www.sfi.ie/site-files/primary-science/media/pdfs/col/strange_sounds.pdf or https://www.sfi.ie/site-files/primary-science/media/pdfs/irish/col/fuaimeanna_aisteacha.pdf Use the app BirdNet to listen and view bird noises. Use Oscilloscope from XYZ-Apps, a free app for smart phones that displays a waveform of a sound. What is the '*smallest*' or '*biggest*' wave that you can make? (NOTE: the children should be clear if they are changing wavelength or amplitude)

Investigate: Sound Waves

Starter Question	Predicting	Conducting the Investigation	Sharing: Interpreting the data / results
How can you change the volume, or the pitch of the sound made from a ruler?	Children should be encouraged to use the word *pitch* to describe a sound. Children should use the word *loudness* to describe the volume of a sound.	Children could vary the length or material of the ruler and describe the pitch or the loudness of the sound to the ear or to phone app/oscilloscope.	Children should compare what they found to others in the class.

Investigate: Rope or Slinky Waves

Starter Question	Predicting	Conducting the Investigation	Sharing: Interpreting the data / results

Considerations

Language usage of the word "big" when describing waves needs to be explicitly taught. Use **tall** for **amplitude** and **long** for **wavelength** instead of *big*. *Frequency* = how often a periodic motion happens per second.

Use 'new words' with children's own definitions

Taighde Éireann
Research Ireland

How do rope and/or slinky waves move and behave? How can a wave be made taller or longer? How does frequency of shaking affect the wave?	Children should refer to their initial explorations and use *wavelength* and *frequency* appropriately.	Children might take photographs or make measurements of distance the rope moves as they shake more vigorously or frequently.	Present data in a table or chart or drawing.	

Investigate: It's Alarming - Human Ears

Starter Question	Predicting	Conducting the Investigation	Sharing: Interpreting the data / results	
How easily can we determine direction to a sound source? Does the direction to a sound make a difference to how well we can determine where the sound is coming from?	Children should refer to their understanding. "It will be easier to tell the direction to a sound that is to one side or the other, rather than directly in front or behind, because our ears are on either side of our head."	Have one child in the centre of a circle of children. One person in the outer group should make a sound, can the child in the centre point directly to them? Children should consider how to make this fair test – the same volume sound, the same distance from the centre etc.	Are there differences between individuals? What happens if there is additional noise from the outer circle?	

Investigate: It's Alarming - Sound Meters

Starter Question	Predicting	Conducting the Investigation	Sharing: Interpreting the data / results	
How does distance from the sound source affect the loudness of a sound?	Children should make a simple prediction based on their background understanding or everyday experience.	Children should design a fair test. They should use a source of sound whose volume does not change.	Draw a graph to show how sound level changes with distance. What happens if there are other sources of sound?	

Take the Next Step

Applying Learning	Making Connections	Thoughtful Actions

What happens when two waves meet? Shake a slinky wave, allow it to reflect – what happens?

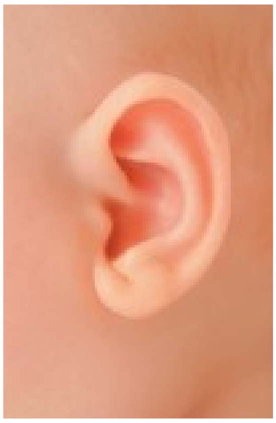
Gravitational waves are transverse waves but have a very small amplitude. See this video from Cardiff University that explains how tiny the waves are, and how their detection is made difficult by other sources of waves. https://youtu.be/Lcxt097G4Ps.

Design a Detector Grid that could be used to detect a hidden sound. How should children be arranged to be sure that they can correctly find where a sound comes from? Children might use direction to the sound, or the volume of the sound as their detection method. Children can explore different arrangements of detectors (in a line, in a grid, in a circle, randomly spread out) and find out which is best at detecting the source of a sound.

Reflection	Did I meet my learning objectives? What went well, what would I change? Are the children moving on with their science skills? What questions worked very well? What questions didn't work well? Ask the children would they change anything or do anything differently. Are there cross curriculum opportunities here? What further questions did students have?	

Strange Sounds

Preparation



CLASS LEVEL	FIRST – SIXTH CLASS
OBJ ECTIVE	Content strand and strand unit Energy & forces,Sound Through investigation the child should be enabled to learn that sound is a form of energy;understand and explore how different sounds may be made by making a variety of materials vibrate SESE:Science Curriculum page 63.In this activity children learn that vibrations produce sounds;observe the effects of these vibrations and then produce different sounds and vary the pitch and volume of these sounds
CURRICULUM LINKS	Skill development Investigating; experimenting; observing SESE:Science Living things – use all the senses to become aware of and explore environments Music Listening and responding – exploring sounds SPHE Myself/ knowing about my body/the ear
BACKGROUND	A session on sound (noting the sounds from the classroom,the school grounds; identifying recorded sounds from a CD,or from a number of different items in wrapped-up containers) would make a good lead-in to this activity.
MATERIALS/EQUIPMENT	(I) Seeing sound – Plastic bowl,Cling film,Rubber band,Uncooked rice,Light saucepan,Biscuittin,Large spoon,Scissors,Sticky tape (ii) Feeling sounds - A partner,Balloon (iii) Making weird sounds – Drinking straw,Strip of plastic,Balloon.
PREPARATION	Gather materials
BACKGROUND INFORMATION	Sound is caused by vibrations which travel through the air or other medium.Vibrations can be made by (i) blowing,(ii) banging or (iii) plucking a string. Sound cannottravel through a vacuum because there is nothing to pass on the vibrations.

Strange Sounds

Activity

SETTING THE SCENE	Brainstorm on sound – what is it? What would the world be like without sound? How would people communicate with each other? Discuss speech as one of the forms of communication. What other forms are there?
Prompt QUESTIONS	What are vibrations? Why do you need air or some other substance for sound to travel? How are sounds made? Can you always hear sounds? Can you see sound? TRY AND SEE
DEVELOPMENT OF ACTIVITY	Ask the children to put their fingers on the outside of their throat when they are talking – do they feel anything? Ask the children to tap the desk and listen; then to tap the desk again, this time listening with their ear touching the desk. Do they notice any difference? Does sound travel better through the air or through the desk?
SAFETY	Care with cutting the straws.
ACTIVITY	(i) Seeing sound: Cut the piece of cling film so that it is bigger than the top of the bowl. Stretch the cling film over the top of the bowl and secure it with the rubber band. Tape the cling film down to keep it stretched. This is your 'drum'. Sprinkle a few grains of rice on top of the 'drum'. Hold the saucepan near the 'drum' and hit it sharply with the spoon. What do you notice? (ii) Feeling sound: Blow up the balloon and hold it against your ear. Ask your partner to press their lips against the balloon and speak; then swap around. What do you notice? (iii) Making weird sounds: a. Hold a strip of plastic tightly between your thumbs and the heel of your hands and blow hard across the strip. b. Press one end of the straw flat; cut the sides to form a point, put the pointed end of the straw in your mouth and blow hard. c. Blow up a balloon and hold the neck to stop the air escaping. Grip the neck of the balloon and stretch it vertically and horizontally. What happens as the air escapes?

Strange Sounds

Review

R EVI EW	Whathave you found outaboutsound? (i) Seeing sound Does the loudness of the sound affect the way the rice dances? Does the distance between the saucepan and the ‘drum’affectthe way the rice dances? (ii) Feeling sound Is there any difference in what you feel when your partner speaks loudly and softly? (iii) Making weird sounds Try differentlengths of straw.Does this make any difference to the sound produced?
ASSESSMENT	The children could be asked to make a sound tape. They could make their sounds and explain them on tape or video-tape.
FOLLOW-UP ACTIVITIES	How could you use what you have learnt about sound to investigate a musical instrument? What vibrates when playing a drum? What vibrates when playing a guitar or a flute? Design and make a musical instrument. How can you vary the sound produced by your instrument? Why does this affect the sound? Can you make strange sounds? The children could be asked: - What else would you like to find out? - How would you find it out? This would encourage them to design their own investigation.

How Good are the Ears of LIGO Compared to Our Ears?

Preparation: Teacher hides sources of a short, sharp sound around the classroom in advance – ideally something that the teacher can set off without the children knowing the location of the sound source. If you don't have a remote speaker or an alarm clock, then arrange in advance for one child to clap their hands or knock on their desk while the rest of the class has their eyes closed.

Prompt: Sound one of the hidden alarms – can the children identify the location of the sound source without moving around? Could they design a detector grid (of children) that would be able to tell where a sound comes from?

Ask the children if they can recall a thunderstorm. Is it easier to tell where the sound of thunder is coming from or is it easier to tell if the thunder is close or further away? Explain that we are now able to detect waves coming from very far away in space as part of LIGO, but we can't always tell exactly where they came from. We are going to use our ears as if they are the detectors of LIGO.

Wonder/Explore: Explain how we mostly determine the direction to a sound from the time delay between hearing a sound at one ear to hearing the same sound at the other ear. This works because our ears are on opposite sides of our heads and the speed of sound is fast, but not as fast as light. Demonstrate how volume of a sound decreases with distance and for most people this is how we judge if a sound source is near or far. This can be fully explored as part of the investigation cycle as It's Alarming! – Sound Meters.

Investigation: It's Alarming - Human Ears

Children should first investigate "How easily can we determine direction to a sound source?"

This can be explored by having one student in the centre of a circle of children. The central student should try to determine direction to a sound made by another student. They might point to where they think the sound is coming from. Children should be encouraged to ask their own questions about the activity, such as:

- How closely can they determine the direction to a sound source? For older children: Can they describe this in terms of an angle from a reference direction?
- Is there an orientation of the listener's ears/head for which it is harder or easier to determine the direction of the sound source? (What happens if one ear is covered?)
- Does it matter if the person in the middle moves their head around?
- Does adding additional noise from other sources affect the central student? or What happens if all the children are making noise at the same time?
- Are there differences between individuals?

Teachers should be aware of those children with hearing loss and adapt accordingly.

Investigation: It’s Alarming! - Sound Meters

Children could then investigate: “How does distance from the sound source affect the loudness of a sound?”

Preparation:

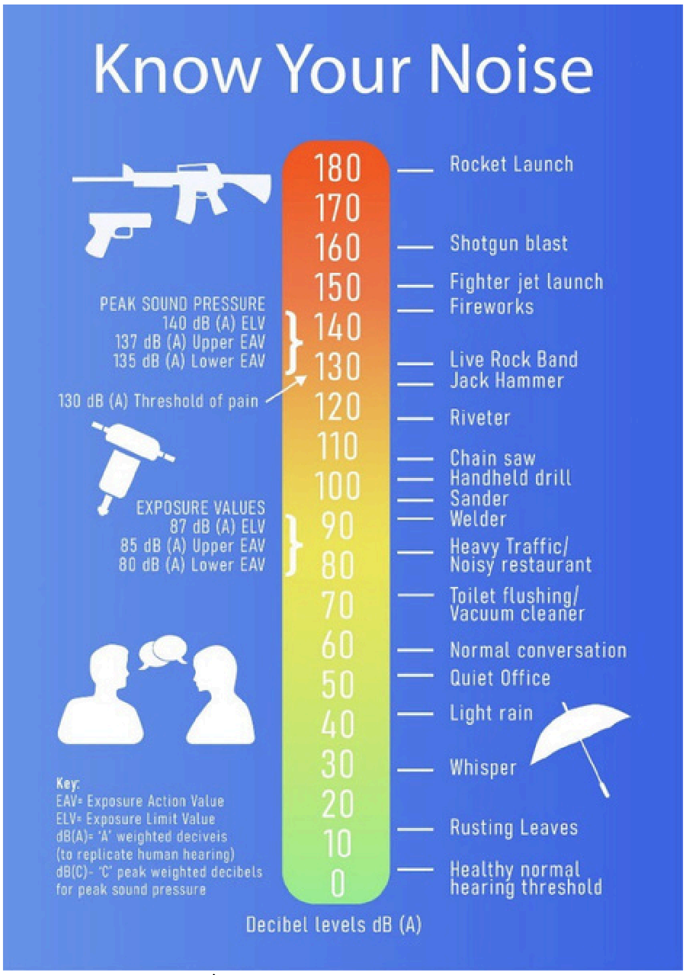
Oscilloscope from XYZ-Apps is a free app for smart phones that displays a waveform of a sound. It can be used to explore the amplitude of a wave – but does not have a capture screen or recording function.

Sound Meter from Splend Apps measures sound levels in dB. It records min, avg and max sound levels and displays sound level vs time.

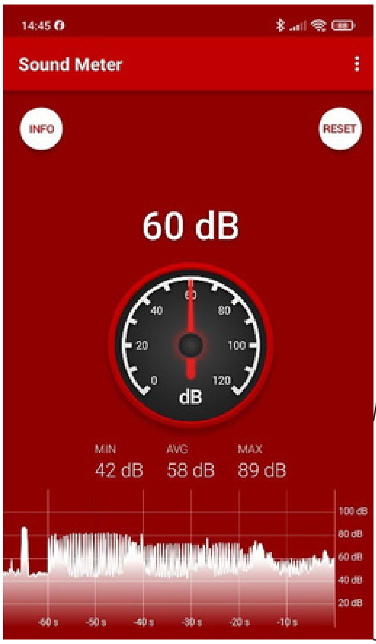
Loudness of a sound is measured in decibels. A sound will be 6dB quieter for each doubling of distance from the sound source.

Investigate:

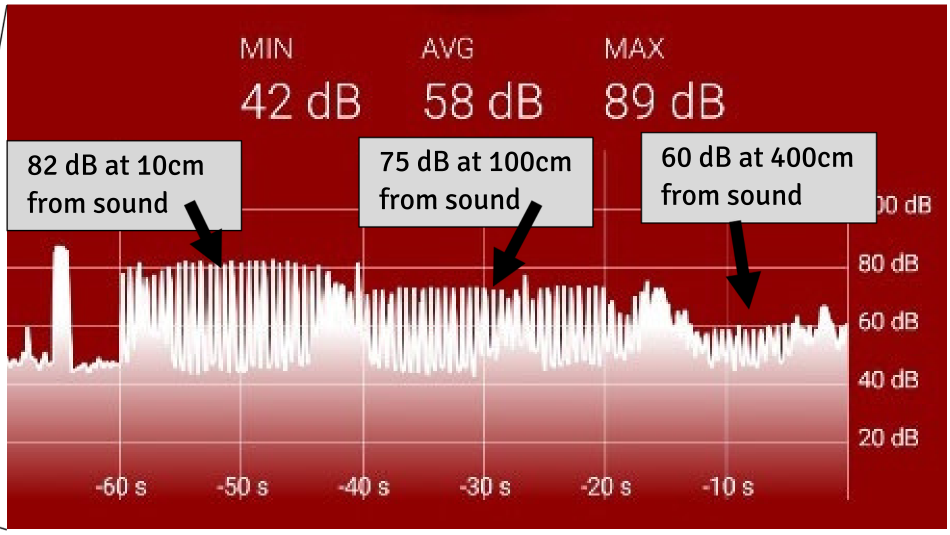
Children should work out how to answer the starter question by carrying out a fair test.



Children should use sound meters with a given source of sound (a metronome is a good choice, if you don’t have one to hand, use this https://youtu.be/gSmf7W3DUjs).



Their result can be plotted as a graph or drawn up in a table of distance vs loudness in dB. A graph will be clearer since the relationship isn’t linear.



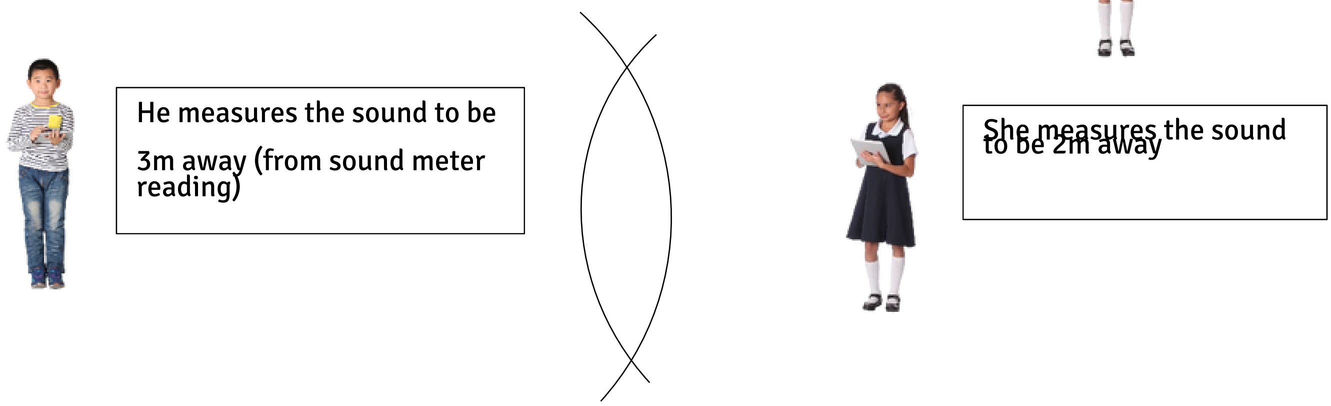
What happens if there are other sources of noise?

BCO The Space For Science
Ireland esero
Taighde Éireann Research Ireland

Take the Next Step:

Design the best arrangement of detectors to find the source of an unknown sound, using either direction (human ears) or volume (sound meters).

Children should then apply their understand of the best way to arrange the detectors (the children) to correctly locate the alarm sound. They might suggest a grid of children/sound meters, or a line or some other distribution within the room. Require children to stay in one spot and not move around when they hear the noise. Children should then test their arrangement to see how accurately they can detect the location of the sound source. Children might predict and test how different arrangement of detectors works. For example, a line of children might work if the sound source is located perpendicular to the line, but not if the sound source is placed parallel to the end of the line of children. Children might explore the minimum number of detectors needed for Human Ears or for Sound Meters to determine the location of the sound source. Can two children always accurately find the location of a sound?



The sound will be at either of the places where the two circles intersect. Without knowing the direction, two detectors cannot determine where the sound actually came from. The same is true of the LIGO gravitational wave detectors.

“How good are the ears of LIGO compared to our ears?”

Tell the children that “One of the Gravitational Waves detected by LIGO/VIRGO had its location narrowed down because it wasn’t clearly detected by one of the ground-based detectors. This was because the source of the wave approached the detector at a 45-degree angle to the arms.”

Have the children found that humans have a similar spot where it is difficult to distinguish the location of a sound source?

How would they modify their design if they had fewer detectors? Is there a minimum number of detectors needed? This directly compares to LIGO where more detectors mean better detections.

BCO The Space For Science   Ireland esero   Taighde Éireann Research Ireland

Curious Minds/ESERO

SPECIAL EDUCATION SUPPORT SERVICE
building on ability

Framework for Inquiry - Promoting Inclusion

When planning science activities for students with Special Educational Needs (SEN), a number of issues need to be considered. Careful planning for inclusion using the framework for inquiry should aim to engage students in science with real purpose. Potential areas of difficulty are identified below along with suggested strategies. This list is not exhaustive, further strategies are available in the Guidelines for Teachers of Students with General Learning Disabilities (NCCA, 2007).

ENGAGE

POTENTIAL AREA OF DIFFICULTY	STRATEGIES
Delayed language development/poor vocabulary/concepts	• Teach the language of science demonstrating meaning and/or using visual aids (material, property, strong, weak, textured, dimpled, absorbent, force, gravity). • Have the student demonstrate scientific phenomena, for example gravity —using 'give me, show me, make me,' as much as possible. • Assist the student in expressing ideas through scaffolding, verbalising a demonstration, modelling . • Use outdoor play to develop concepts.

I NVESTIGATE

POTENTIAL AREA OF DIFFICULTY	STRATEGIES
Fear of failure/poor self-esteem/fear of taking risks	• Model the speculation of a range of answers/ideas. • Repeat and record suggestions from the students and refer back to them.
Understanding Time and Chronology	• Practice recording the passing of time, establish classroom routines that draw the students' attention to the measurement of time. • Teach and practice the language of time.
Fine/Gross Motor Difficulties	• Allow time to practice handling new equipment. • Allow additional time for drawing diagrams, making models etc. • Give students the option to explain work orally or in another format.
Short Term Memory	• Provide the student with visual clues/symbols which can be used to remind him/her of various stages of the investigation.

TAKE THE NEXT STEP

POTENTIAL AREA OF DIFFICULTY	STRATEGIES
Developing Ideas	• Keep ideas as simple as possible, use visuals as a reminder of earlier ideas. • Discuss ideas with the whole group. • Repeat and record suggestions from students and refer back to them. • Encourage work in small group and in pairs.
Communicating Ideas	• Ask students to describe observations verbally or nonverbally using an increasing vocabulary. • Display findings from investigations; sing, do drawings or take pictures. • Use ICT: simple written or word-processed accounts taking photographs, making video recordings of an investigation.

REFLECTION

- Did I take into account the individual learning needs of my students with SEN? What differentiation strategies worked well?
- Did I ensure that the lesson content was clear and that the materials used were appropriate?
- Was I aware of the pace at which students worked and the physical effort required?
- Are there cross curriculum opportunities here?
- Are the students moving on with their skills? Did the students enjoy the activity?

More strategies, resources and support available atwww.sess.ie

curious minds Discover STEM
Taighde Éireann Research Ireland
Ireland esero