Introductory Astrophysics Teaching Manual

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1 Observational Astrophysics

1. **Engage**
   - Learning objectives: Today we are going to learn about how scientists discover and study planets outside our solar system.
   - Key words: exoplanet, flux, period, transit depth, folding
   - Knowledge Outcomes:
     - How scientists observe exoplanets
     - What exoplanet data looks like
     - How scientists use plots to
     - How exoplanet size can be estimated from flux data
   - Skill Outcomes:
     - Use a jupyter notebook to run python code
     - Make value estimates by looking at plots
2. **Prior Learning**
   - Check knowledge about our own solar system
     - Number of planets
     - Different planet sizes and compositions
     - Planets orbit the Sun
   - Discussion of telescopes and space observatories as background for "usual" way of observing space objects
3. **Intro New Knowledge**
   - Define **exoplanets** and discuss categories of them in relation to the planets in our solar system
   - Differentiate what are "usual" observation methods with how exoplanets typically observed - **transit method** (call back to introduction)
   - *Physical Demo 1*: transits - hold a ball and spin in a circle?
4. **Build New Content**
   - **Question:** Given the transit method demo, what do you expect a graph of the total light from a system to look like? (Keep using physical demo to get students engaged)
   - Details of transit method **- period, transit depth**
   - Emphasize what the signal looks like (graphic and call back to physical demo 1)
5. **Apply Learning**
   - "Students have the opportunity to apply what they have learnt to new situations."
   - *Investigation:* Students will explore and attempt to answer a series of questions.
     (a) How can we estimate the period of a transit?
     (b) How can we estimate the transit depth of the exoplanet?
     (c) Physical demo 2: folding - baking paper?
     (d) What happens to the folded light curve when you use your estimate of the period versus when you use the known period of the exoplanet?
     (e) What type of exoplanet would you classify this as?

2 Theoretical Astrophysics

1. **Engage**
   - Learning objectives: Today we are going to learn about how scientists discover and study mysterious objects called black holes.
   - Key words: binary black hole, gravitational waves, strain, amplitude
   - Knowledge Outcomes:
     - Understand how scientists observe black holes (it is different that observing EM sources)
     - Signals carry information about their sources
     - Fitting theoretical signal templates to real data gives scientific insight
   - Skill Outcomes:
     - Use a jupyter notebook to run python code
     - Change input values to match fit with data
2. **Prior Learning**
   - Check knowledge about stellar life cycle - what happens to stars when they die?
   - **Question:** What do you know about black holes?
3. **Intro New Knowledge**
   - Define **black holes** and how they can be in binary systems
   - Discuss how space is like a fabric called "spacetime" - really heavy objects distort spacetime in a measurable way, called **gravitational waves**
   - *Video:* LIGO detecting gravitational waves
   - LIGO is measuring a quantity called **strain**
4. **Build New Content**
   - **Question:** What do you think we can learn from the signals?
   - Shapes of signals tell us information about the sources
   - Discuss theoretical signal waveforms and real data
   - Mass and distance and their effects on **amplitude** - emphasize this relationship
5. **Apply Learning**
   - "Students have the opportunity to apply what they have learnt to new situations."
   - *Investigation:* Students will explore and attempt to answer a series of questions.
     (a) What does the signal look like when the black holes have similar or the same mass?
     (b) What happens if you make the masses really large?
     (c) What happens if you make the masses really different from each other?
     (d) What happens if you make the distance large (i.e. far away)?

3 Astronomical Instrumentation

1. **Engage**
   - Learning objectives: Today we are going to learn about how scientists take and analyze images to study objects in space.
   - Key words: photovoltaic effect, image effects, stars, galaxies
   - Knowledge Outcomes:
     - General idea of how detectors convert observed photons into a digital signal
     - Understanding that image cleaning is required to produce images shown in media
   - Skill Outcomes:
     - Identifying morphological differences between stars and galaxies in a real JWST image
     - Differentiating between observations vs. artifacts in images
2. **Prior Learning**
   - Check misconceptions about astronomy images displayed in media. Do students think images come out perfectly when taken? Allude to image cleaning without explicitly mentioning it.
   - Ask the students if they know how digital cameras create images
3. **Intro New Knowledge**
   - Recap: everything in the Universe is made of atoms, and atoms contain electrons
   - Some special materials can help us use these electrons to convert light into a digital signal
   - *Whiteboard demo*: draw a star inscribed into a 3x3 pixel grid, then a 10x10 pixel grid to introduce concept of resolution. Relate to Figure 12 in lab manual
4. **Build New Content**
   - **Question:** How do we expect the brightness of something to correlate to how many electrons it knocks loose in the detector?
   - More electrons = brighter pixels, more pixels = better resolution, therefore we can get a really nice image with a larger detector!
5. **Apply Learning**
   - "Students have the opportunity to apply what they have learnt to new situations."
   - *Investigation:* Students will explore and attempt to answer a series of questions.
     (a) How many of your objects are galaxies and how many are stars? How can you tell?
     (b) What could help you better differentiate between the two types of objects?
     (c) Before you apply the image effects, take a second to think about what each of them might do to the image.
     (d) After having gone through each effect, what can you say about what they do to the image? How many of your initial guesses were right?
     (e) **CLOSEOUT CHALLENGE QUESTION**: How would you remove some of these effects from your images? Can they all be removed? Cost considerations, time considerations, etc.