TA Guide for

ASTR 311 Tutorial: Gravity

ver. 100907

Notes

Description

In this activity, students will investigate the quantities that determine the strength of the force of gravity between two objects, identifying what matters and how that quantity changes the force. So they can recognize and appreciate the inverse-square law of gravity, the students first play with an analogy: the amount of pain the cartoon character Fry feels when he looks are different sized light bulbs, from near and far and with open or squinting eyes. They do this through an "invention activity" (Schwartz and Martin, 2004) which are proven to increase students' understanding of the new concept (gravity) and their ability to transfer that knowledge to other situations. Student engagement and effort is known to increase when they must prepare to present their ideas to their peers, so student groups develop their ideas on whiteboards.

Learning Goals

After this tutorial, together with lecture materials, students should be able to

- compare, using Newton's Universal Law of Gravitation, how the gravitational force between two bodies changes as their mass changes and the distance between them changes.

Materials and Set-up — 10 minutes

The students will work together in groups of 3. The following materials are required:

- (1 per group) whiteboard
- (1 per group) a couple of whiteboard markers
- (1 per group) It is important not to give the students too much information too soon, or it will "short-circuit" the invention activity. So instead of giving students the full set of instructions, give them worksheets only when they are required. That means preparing the handouts in parts:
  - (1 per group) Part 1: pages 1 and 2 (double-sided)
  - (1 per group) Part 2: page 3
  - (1 per group) Part 3: pages 4 and 5 (double-sided)
  - (1 per student) Part 4: page 6
- set up overhead projector
- overhead transparencies of pages $1-4$ and the page with Fry, the rays and the gravity formula
- keep a fine-tipped dry erase marker for writing on the transparencies. (If you use dry erase instead of an overhead marker, you can erase them after the tutorial and re-use the overheads.)

Distribute the whiteboards with Pages 1 and 2 (held on with magnet?) around the room before the students enter. Put out as many whiteboard markers as there are: the more markers per group, the more students will participate. As they arrive, encourage them to work in groups. If they start reading and even working on Part 1, that's fine. Don't explain how to do the activity to each group individually, though. If they're not sure how to proceed, ask them to wait until the tutorial officially starts when you'll talk to the entire class. Not only does this save you having to explain the same thing many times, but it ensures you give the same instructions to all the students.

Part 0: Introduction and Motivation	2 minutes

It is **critical** that you don't short-circuit the creative task in Part 1 by telling the students this tutorial is about gravity. The word "gravity" was deliberately left off Pages 1 and 2. In fact, the less you say *at this stage* the better.

Part 1: Which is brighter?	10 minutes

In Part 1 of the tutorial, the students explore an analogy to gravity. They are presented with a series of contrasting cases. At first, only one parameter is changed at a time so they explicitly see the impact that parameter has. Later more than one parameter is changed so they can see what happens when the parameters are "mixed". The contrasting cases are chosen to there is a clear "winner" in Examples 1–4, but no clear "winner" in Example 5.

Briefly set up the situation. This is Fry. He's looking at different light bulbs (a big bright one, a small dim one and one in between). Sometimes his eyes are wide open, and sometimes he squints. Invite the students to consider the 2 cases (A and B) in each Example. They should pick the case that **hurts Fry's eyes more**. And if there is no way to tell for sure, they should chose "can't tell." Their group should also come up with an answer to the question at the bottom of Page 2.

When it seems like most groups are done, quickly go over their choices. Put up the overheads of Pages 1 and 2. For each Example, ask a student for **which** case *their group* chose and **why** they made that choice. (If you ask a student for the group's choice, rather than the student's individual choice, you reduce that students anxiety and increase the student's willingness to participate.) By discussing the choices for Example 5, you're also discussing the fake conversation between the 2 students. To answer that question with the class, you might ask,

> So, what about the two students? Is either one correct?

Student 2 is probably right but we a better way to analyze the pain, which motivates Part 2...

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Part 2: Measure the Pain — 15 minutes

To motivate this section, you might try something like this (while you or the other TA is handing out Part 2):

hand out Part 2

> To figure out which cases hurt more, we have to switch from **qualitative** - this one hurts more than that one - because it doesn't always give us an answer, to **quantitative** where we can say, "this one hurts 7 and this one hurts 12." To do that, your group is going to invent a procedure for calculating an **index** that measures Fry's pain.

Read aloud the four examples ("Litres per 100 kilometres,...") so the students have a good idea what we're looking for. Stress that

- the index is a number
- the same procedure has to work in every case
- the higher the index, the more pain he feels

Ask the students to work together on the whiteboard and tell them that you'll ask a couple of groups to share their ideas.

Over the next 10 minutes, wander around and interact with the students. Prompt them if they're stuck, but be careful not to give away the answers. For example, you might ask

> Let's look back at the Examples. In Example 1, does the pain change between A and B? Yes, it does. Why? What else changed? Your procedure should handle that.

When a group gets confident in their procedure, ask them to try it out on the cases to make sure it matches their choices in Part 1. Ask them what their index says about the "ambiguous" Example 5.

The truth is, we are **not expecting them to get the "right" answer** here. In the past, almost every group comes up with the pain proportional to the size of the bulb and Fry's eyes, and inverse with distance but not inverse square. That's okay, this invention is meant to begin to alert them to what's important and what's not. Research shows that when students reach the end of this task, they are eager and anxious to learn the right answer. And when they hear it, it has much more meaning because they've invested their time and energy in the problem.

Since you've had a chance to see what most groups are doing, you should be able to pick one or two groups with interesting procedures. Ask those groups to briefly share their ideas. Don't just pick a group that got it right (if any group did). If a group had a really ingenious or imaginative idea, ask them to share.

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Part 3: Gravity	10 minutes

hand out Part 3

The students are now "prepared to learn" (Schwartz, 2004) so present them with the "right" answer. Put up the Universal Gravitation overhead and briefly describe why each variable is there and how it changes the pain. You don't want to tell anyone that what they did was wrong, so you might say,

> Your formulas are good. They let you predict which case hurts more. Let me show you what an astronomer would probably do...

So that everyone can follow, even if they can't hear or are momentarily distracted, write the variables and generate the formula for pain $P = (B\,E)/d^2$ on the overhead as you describe these variables and their effects:

size of light bulb The bigger the bulb B, the more light it emits and the bigger the pain, P.

size of Fry's eye The bigger the opening in Fry's eye E, the more light is allowed in and the bigger the pain, P

distance The bigger the distance to the lightbulb d, the **smaller** the pain, P. Student will likely not see, though, why this is an inverse-square relationship. The diagram gives a geometric interpretation of how many photons hit Fry's eye. You might try something like this:

> Imagine the light rays that come off the light bulb. They pass through a "window" at distance 1. What happens to all those light rays at twice the distance? The rays spread out 2 times wider and 2 times higher. You need a window **4 times bigger** to "catch" all those rays so each original window catches only **one quarter** as many rays as before. The pain in Fry's eye is 4 times less that it was before. At 3 times the distance, the rays spread over an area 9 times bigger and the pain is 9 times less. [Stress the pattern:] the distance is 2 times bigger, the pain is 4 times smaller; 3 times farther, 9 times less pain. This is called an inverse-square law.

Notice that all the calculations here and below are done through proportionality and the results are always relative to a standard case. The students never need to calculate the actual force of gravity using the gravitational constant.

It turns out many students do not see the connection between the amount of pain (Part 1 and 2) and the force of gravity (Part 3). By the end of the activity, they feel they've done two different tasks, one about the brightness of lights and one about gravity. We need to help them see the connection.

Now tell them that force of gravity follows exactly the same pattern. The force between two masses m_1 and m_2 separated by distance r has this form (refer to overhead). The force between them

- is directly proportional to the masses: for example, if m_1 or m_2 doubles, then F doubles
- is inversely proportional to the square of the distance: for example, if r increases by a factor of 3, F decreases by a factor of $3^2 = 9$

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Emphasize again the link between pain and gravity by stressing that gravity follows the same relationship to mass and distance that Fry's pain follows with the size of the light bulb, his eyes and distance.

Ask the students to look at Part 3. Do the first case together so you can model how to express the answer in terms of the original force.

> In this first example, one of the masses gets 3 times bigger. Will the force be bigger or smaller, compared to the original force? Bigger, good. How much bigger? Right, force depends directly on the mass, so the new force will be 3 times bigger, or $3F$.

For each remaining case, they should

first decide if the force in the new situation is bigger or smaller than the original (or choose "can't tell" if there is no way to tell for sure).

second compute the new force, compared to the original F, by following the relationships

When they've had a chance to go through the 5 other cases, quickly run over the answers on the overhead. Pay special attention to the cases where the distance gets smaller and the force gets bigger: some might struggle to remember what to do with a fraction in the denominator.

Ask them to continue on Page 5 where they encounter real astronomical objects. While they're working on these problems, wander around and help individual groups as needed. The answers will always be in terms of the original force, F.

Part 4: Questions	10 minutes

As groups finish Part 3, hand each student a question sheet, Part 4. They can continue to work together but we need each student to hand in their own paper.

hand out Part 4 they finish Part 3

Question 1 and **Question 2** reinforce how to use the formula for gravity, particularly the inverse square.

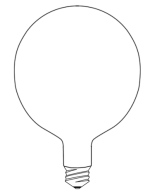
Question 3 gives us a way to check that they actually did the activity. Students are sometimes shocked by how little (or much) they'd weigh on the various bodies. We ask for the weight of a fictional student, by the way, so as not to force students to reveal how much they weigh. Many people are uncomfortable doing that, and they shouldn't lose marks for not giving personal information.

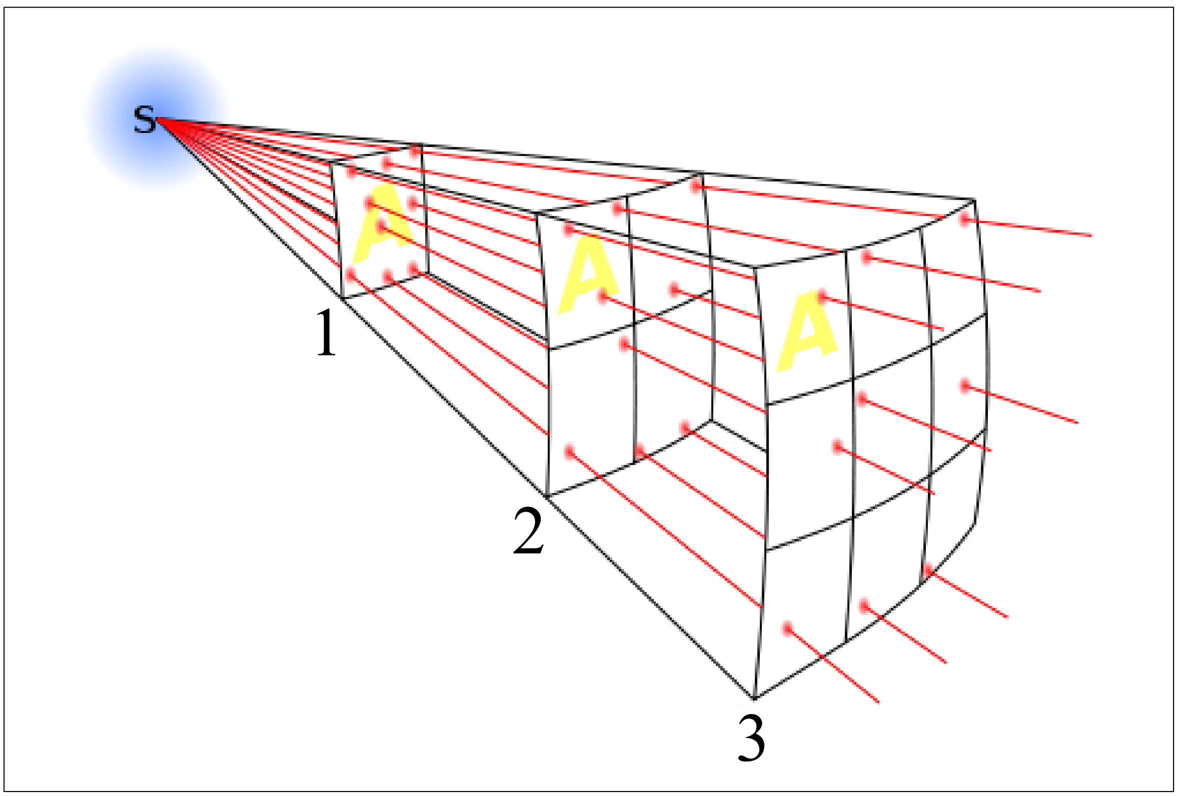
Question 4 purposely hints that there are, in fact, places where there is no gravity. That's false (we do not expect them to know about Lagrange points) so we're asking the students to disagree with the statement. This should force them to think a little more carefully and provide a stronger argument.

Clean up

Collect the whiteboards. Try to make sure each has a magnet. Collect dry erase markers back in the basket. Return everything to the storage room.

Erase the overhead transparencies and collect them together so they're ready for the next section of the tutorial.

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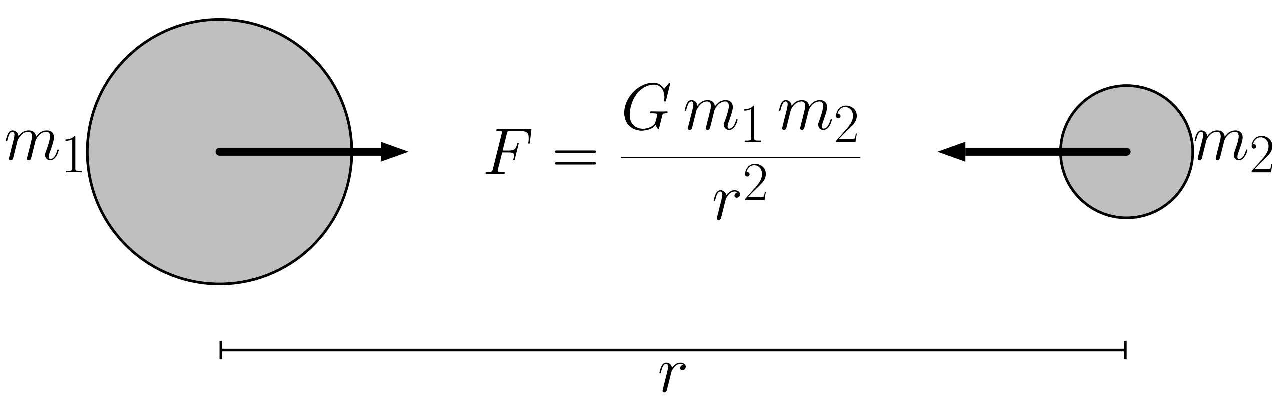
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$F = \frac{G\, m_1\, m_2}{r^2}$
m_2
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