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# Getting a Feel for Gravity

Exploring space requires first of all that we get our spacecraft off the ground, at least into Earth orbit. Then, if we want to explore any other bodies in our solar system, we have to get our spacecraft out of Earth orbit and somehow propel it to its intended target. Unless we have unlimited fuel and unlimited time, we must take into consideration the gravitational forces exerted by the sun, the planets, and any other large bodies we may approach. And, of course, even if we could build a spacecraft big enough to hold all the fuel necessary to ignore gravity, it would probably be too heavy to get off the ground!

So rather than fight gravity, space mission planners use gravity to serve their own purposes. Trajectories to distant targets are planned to take advantage of the gravitational pull of other bodies along the way. For example, the Voyager 2 spacecraft, in exploring the outer planets, used the tremendous gravitational force of massive Jupiter to slingshot itself to Saturn, then used Saturn for an additional kick out to Uranus, and so on. NASA's first New Millennium Program mission, Deep Space 1, is the first spacecraft to use solar electric (ion) energy as its primary means of propulsion. The ion engine exerts no more force than a single sheet of paper resting on your hand. But, over time, and with a trajectory planned to take advantage of the gravitational pull of the sun and Earth's orbital motion, Deep Space 1 will be able to accelerate to speeds faster than spacecraft that use conventional chemical propulsion, and will do so on a lot less fuel.

In this activity, students use their own bodies to create a model of the solar system and the forces the sun and planets exert on each other and on passing objects such as spacecraft. The verbal description by the teacher of what is being represented, along with the non-verbal kinesthetic and visual experience, can leave students with a life-long instinctive feel for one of the most basic of physical concepts.

In the first part of the activity, the students model giving a spacecraft a planetary gravity assist. In the second part, the students first get a feel for the idea of "projecting" gravitational force using mime. They then create a model of motions and interacting forces among the Sun, the Earth, the Deep Space 1 spacecraft, and its target asteroid.

## Borrowing Energy from a Planet

We can speed up a spacecraft by slowing down a planet! Because of the difference in mass between the two objects, the planet will scarcely miss the minute amount of energy lost, but to the spacecraft, the extra boost can mean the difference between reaching its destination in a reasonable time or getting there long after everyone who launched it is dead!

Three-person Model:

1. Two partners, representing a two-body gravitational system, face each other, reaching with outstretched arms to grab hands. They lean back to create tension, and one partner (the smaller) "orbits" the other, at a fairly rapid—yet controllable—pace.

2. A third partner, the "spacecraft," approaches the orbiting "planet." The spacecraft "borrows" energy by grabbing onto the planet's shoulder, thereby acquiring the energy needed to create acceleration.

3. As the spacecraft makes "gravitational" contact, the two-person system should feel a real energy transfer as momentary drag. The spacecraft should feel a boost of acceleration that causes it to speed up and change direction.

Four-or-more-person Model Using a Rope:

*Photo: Courtesy of Robert M. Brown*

1. Instead of grabbing hands, students use a rope to represent the gravitational force. Two or three partners holding on to one end of the rope represent the larger object (the Sun) and one partner holding on to the other end represent the smaller object (the planet). Keeping the rope taut, the planet "orbits" the sun at a fairly rapid—but controllable—pace.

2. The fourth (or fifth) partner becomes the spacecraft. As the spacecraft approaches the planet, matching speeds, the spacecraft grabs on to the planet (grabbing hands or locking arms). Some of the energy of the two-body gravitational system is transferred to the spacecraft, accelerating it. At the same time, the two-body system slows down just slightly.

3. When the spacecraft lets go, "it" can feel the acceleration and it flies off in a new direction, moving faster. This acceleration is the energy transfer of the gravity assist.

## Creating a Force Field

In this part of the activity, students model gravitational forces reaching out into space, experiencing kinesthetically the abstract and difficult physical concept of a *field*.

*Photo: Courtesy of Jennifer Schaupeter*

1. Each student finds a partner. The partners stand facing each other, arms outstretched and palms together. Pushing gently, first one, then the other exerts the force, giving and taking, back and forth. They gradually push harder, adding energy to the force. (picture 2)

2. The partners back away from each other a bit, leaving a few inches between their hands as they continue to push and be pushed, give and take. Now, instead of using direct force, the partners are modeling a force *field*, like a gravitational field. If they concentrate and put their whole bodies into the movement, it will feel more realistic to them. (Picture 3)

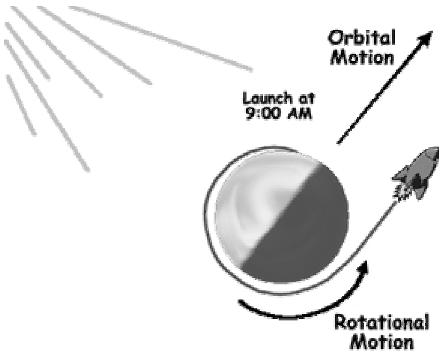
3. The students experiment with modeling the force field from a greater distance, tuning into each other and paying attention to details of the other's movements to create the effect.

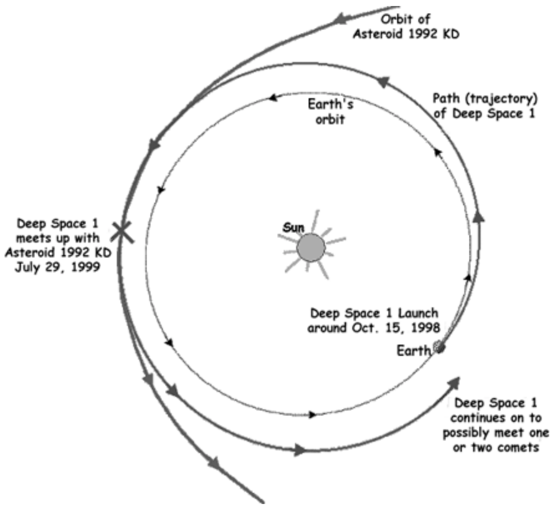
4. Now, instead of an invisible force of pushing, ask the students to think of an invisible force of *pulling* toward oneself, as if exerting energy of an active *attraction*, in waves of accelerating force. The partner with extended arms draws back, as if to pull the arms of the distant partner. Emphasize the movement of drawing in the arms and hands, then relaxing briefly to extend again, to draw in with another "wave" of gravity. (picture 4)

## Ion Driving to "Higher" Orbit

Spacecraft trajectories usually take advantage of Earth's orbital motion around the sun and leave Earth orbit heading in the same direction around the sun as Earth is already traveling (counterclockwise, looking "down" on the solar system). The final rocket boost pushes it out ahead of Earth and may give it enough of a kick to change its orbit around the sun slightly from that of Earth's. No longer traveling with Earth, the spacecraft coasts on its own orbital path defined by the initial thrust relative to the gravity of the Sun. With most spacecraft, no additional thrust is applied, except for minor attitude control or course correction maneuvers. This technique is called a Hohmann Transfer, essentially transferring the spacecraft from Earth's orbit around the sun to an orbital path that includes both Earth and the target body. If the spacecraft's target—an asteroid in the case of Deep Space 1— is orbiting farther from the Sun than the Hohmann Transfer can accomplish, additional propulsive maneuvers are required to overcome the Sun's gravitational pull and boost the spacecraft into a more distant orbit so that it can eventually meet up with its target. Deep Space 1 at this point must activate its ion drive engine, aiming its gentle thrust against the force of the Sun's gravity to transfer to a new orbital path.

This part of the activity models Deep Space 1's launch, final rocket boost out of Earth orbit, activation of its ion engine, orbital transfer maneuver, and asteroid rendezvous, as influenced by the gravitational fields of Earth and the Sun.





1. Seven or eight students represent the Sun by standing in a central circle, facing outward, with hands mime-projecting an invisible gravitational force field. Students work together to create a series of wave motions that represent the attractive force of gravity.

2. Three or four students form a circle, facing outward, to represent planet Earth, standing at some distance from the Sun, with hands mime-projecting an invisible gravitational field around the planet. As the Earth group moves around the Sun group, they all mime-project the balanced tension between the gravitational attraction between the two bodies and the force of centripetal acceleration that keeps Earth in its orbit and prevents it from spiraling in toward the Sun.

3. One student represents the asteroid that Deep Space 1 will encounter. The "asteroid " moves through an eccentric elliptical orbit coming in just beyond Earth's orbit. You may want to ask several students, one at a time, to play asteroids or comets, using the mime force-field-at-a-distance technique to orbit around the Sun, transferring the "gravitational" kinesthetic connection to the Sun along the way.

4. One student represents Deep Space 1, and demonstrates the effect of the powerful thrust needed to escape Earth's gravity at launch to reach an orbit around Earth.

5. When the Deep Space 1 student is positioned just right (moving in the same direction the Earth group is orbiting the Sun group), he or she, in slow motion, demonstrates the thrust of the final rocket stage that sends the spacecraft into its own orbit around the Sun.

6. With the Sun group, the Earth group, and the Deep Space 1 individual all working together, Deep Space 1 demonstrates this temporary cruise in its own orbit around the Sun, then, as the ion engine starts up, slight acceleration that pushes it into a new orbit a bit farther from the Sun.

7. As Deep Space 1 approaches the point in its orbit opposite the launch point, the asteroid approaches in its orbit to meet up with Deep Space 1. The "encounter" occurs (with Deep Space 1 "taking pictures" and making other measurements of the asteroid) and then the asteroid and the spacecraft continue on their separate orbits.

   In actuality, the asteroid's orbit is considerably inclined to the ecliptic—the plane in which most of the planets orbit the Sun—so a third dimension (or fourth, if we count time) is involved to further complicate the navigational problem.