Student Concepts of Gravity in Introductory Astronomy and Physics Courses

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Why study Gravity?

- Misconceptions are present!
- Lack of published research on students' concepts of gravity
- Results relevant to research on similar topics, such as Coulomb's Law
- Subject of interest in both physics and astronomy

Goals:

- To investigate students' thoughts about gravity
- To develop instructional materials which enable students to learn about gravity more effectively
- To quantitatively evaluate the effectiveness of the materials produced

Tools for Determining Students' Concepts of Gravity

Multiple Choice Diagnostic:

- 11 questions addressing several different aspects of gravitation (inverse square law, Newton's 3rd Law, force direction, universality, more)

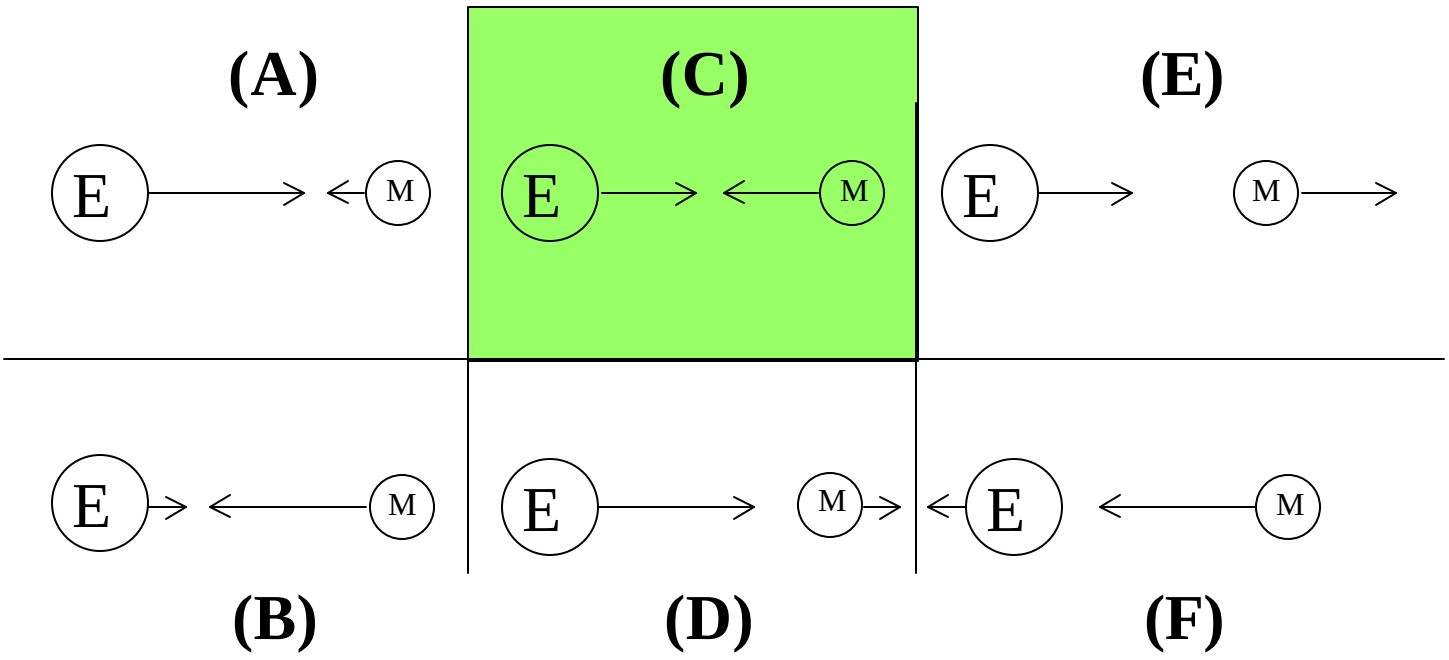
Free - Response Diagnostic:

- 10 free-response and drawing questions addressing similar aspects of gravitation. Students have the opportunity to explain their answers in their own words.

These diagnostics have been administered to over 2500 students in introductory physics and astronomy classes at Iowa State University and other colleges and universities since the Spring 1999 semester.

Multiple choice questions:

Multiple choice Q8: Which of the following diagrams most closely represents the gravitational forces that the earth and the moon exert ***on each other***? (Note: The mass of the earth is about 80 times that of the moon)



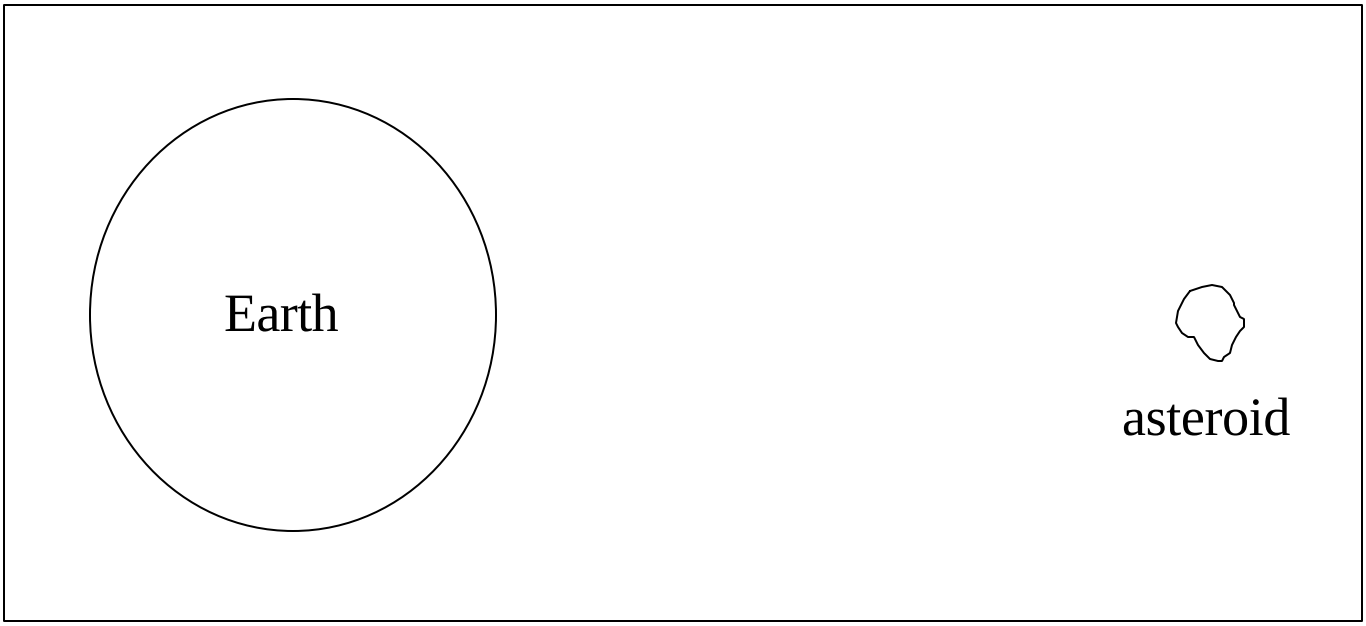
Multiple choice questions:

Multiple choice Q8: Which of the following diagrams most closely represents the gravitational forces that the earth and the moon exert ***on each other***? (Note: The mass of the earth is about 80 times that of the moon)

	Phys111	Phys112		
Response	Spring '00 (N = 289)	Fall 1998 (N = 79)	Fall 1999 (N = 96)	Spring '00 (N = 119)
A	59%	38%	47%	32%
B	24%	53%	45%	29%
C (correct)	8%	6%	6%	36%
D	2%	0%	0%	1%
E	2%	1%	0%	1%
F	4%	0%	2%	1%
No response	0%	1%	0%	0%

Student thinking: Objects of unequal masses exert unequal forces on one another!

Free-response questions:



Free Response Q2: Refer to the picture above. The magnitude of the force exerted ***by*** the asteroid ***on*** the Earth is [circle one]:

a) *larger than* the magnitude of the force exerted ***by*** the Earth ***on*** the asteroid

b) *the same as* the magnitude of the force exerted ***by*** the Earth ***on*** the asteroid

c) *smaller than* the magnitude of the force exerted ***by*** the Earth ***on*** the asteroid

d) *zero*. (the asteroid exerts *no* force on the Earth)

Explain the reasoning for your choice.

Selected results (*Iowa State*):

Free Response Q2:

	Fall '99		Su'99
	U-CP1	U-CP2	U-CP1
N=	547	414	41
LARGER THAN:	3%	1%	2%
SAME AS:	15%	38%	12%
SMALLER THAN:	74%	59%	76%
ZERO:	7%	1%	7%

LARGER objects exert MORE force on SMALLER objects than SMALLER objects exert on LARGER objects....even after instruction (!)

Free response questions:

Free Response Q8:

Imagine that you are standing on the surface of the moon holding a pen in one hand.

A) If you let go of the pen, what happens to the pen? Why?

	Fall '99			
	U-Astro	U-AP1	U-CP1	U-CP2
N=	103	302	534	414
DROPS	33%	42%	66%	75%
FLOATS	36%	34%	19%	12%
FLOATS AWAY	26%	22%	12%	11%
Other/No answer	5%	2%	3%	1%

Of the astronomy students answering incorrectly, **51%** explicitly stated that there was no gravity in space or on the moon.

Free response questions:

Free Response Question 9b:

Imagine that you are in the Space Shuttle orbiting the earth.

i) [circle one] Does the Earth exert a gravitational force on the Shuttle? **YES** **NO**

ii) [circle one] Does the Earth exert a gravitational force on you? **YES** **NO**

	Fall '99 U-AP1	Su'99 U-CP1
N=	302	41
i) % CORRECT	75%	93%
ii) % CORRECT	49%	58%

Intervention by worksheet instruction:

•Goal: achieve more effective instruction on gravitational concepts by creating an alternative to standard recitation.

•Uses printed worksheets in a collaborative small-group environment.

•Similar in style to tutorials produced by the Physics Education Group at the University of Washington.

•Preliminary use at Hawkeye Community College (Astronomy) and Iowa State (Physics 111 and 221), wider testing at Iowa State in Fall 1999 (Physics 111 and 221)

•With slight adjustments, the worksheets can be used in introductory astronomy courses as well as both algebra-based and calculus-based physics courses.

Worksheet instruction: Does it work?

Most students say the worksheets were useful and worth the time spent - but that doesn't necessarily mean they learned from it!

We would like to quantitatively demonstrate whether or not the worksheet instruction was effective.

Asking relevant **final exam questions** in the introductory physics classes is one way to test this.

Two multiple choice questions were written for the final exams for Physics 111 and 221, the algebra-based and calculus-based first-semester physics courses at Iowa State, subject to the lecturer's approval

Final Exam questions -
F99 Physics 111/221 Results

The rings of the planet Saturn are composed of millions of chunks of icy debris. Consider a chunk of ice in one of Saturn's rings. The magnitude of the gravitational force exerted by the chunk of ice on Saturn is:

A) **greater than** the gravitational force exerted by Saturn on the chunk of ice.

B) **the same magnitude as** the gravitational force exerted by Saturn on the chunk of ice.

C) **nonzero, and less than** the gravitational force exerted by Saturn on the chunk of ice.

D) **zero**.

E) Not enough information is given to answer this question.

Saturn's rings	N=		% correct
Alg. Phys I	211	Traditional	41%
	72	Worksheet	71%
Calc. Phys. I	383	Traditional	61%
	116	Worksheet	87%

Final Exam questions -
F99 Physics 111 Results

Algebra-based Physics I

Two lead spheres of mass M are separated by a distance r; they are isolated in space with no other masses nearby. the magnitude of the gravitational force experienced by each mass is F. Now one of the masses is doubled, the other is tripled, and they are pushed farther apart to a separation of 3r. Then, the magnitude of the gravitational force on the larger mass is:

A) F
B) 2F
C) F/2
D) 2F/3
E) 3F/2

Lead Spheres	N=		% correct
Alg. Phys I	211	Traditional	51%
	72	Worksheet	54%

Final Exam questions -
F99 Physics 221 Results

Calculus-based Physics I

Two lead spheres of mass M are separated by a distance r; they are isolated in space with no other masses nearby. the magnitude of the gravitational force experienced by each mass is F. Now one of the masses is doubled, and they are pushed farther apart to a separation of 2r. Then, the magnitudes of the gravitational forces experienced by the masses are:

A) equal, and are equal to F
B) equal, and are larger than F
C) equal, and are smaller than F
D) not equal, but one of them is larger than F
E) not equal, and neither of them is larger than F

Lead Spheres	N=		% correct
Calc. Phys. I	383	Traditional	45%
	116	Worksheet	70%

Summary:

•Misconceptions are present in each of the courses surveyed. Students' misconceptions and their reasoning for these misconceptions are often similar for students in different classes (astronomy, algebra-based physics, and calculus-based physics)

•Worksheets are valuable in both algebra-based and calculus-based classes, though differences between the classes must not be overlooked.

•There is room for improvement in instruction over standard recitation, and worksheet instruction appears to be a step in the right direction.

•Instruction for one class is not necessarily sufficient for another.

Final Exam questions -
F99 Physics 221 Results

Physics 221

A) equal, and are equal to F
B) equal, and are larger than F
C) equal, and are smaller than F

We can compare just the students answering "equal" to see if there is still a difference in performance on the ratio aspect of the question without interference from the Newton's Third Law part of the problem.

When comparing just the students answering "equal," we see that **77%** of these worksheet students answer correctly, while only **63%** of these non-worksheet students answer correctly.

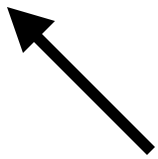
Don’t use the following slides (not enough space)

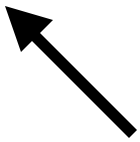
Final Exam questions -
F99 Physics 221 Results

Physics 221

Two lead spheres of mass M are separated by a distance r; they are isolated in space with no other masses nearby. the magnitude of the gravitational force experienced by each mass is F. Now one of the masses is doubled, and they are pushed farther apart to a separation of 2r. Then, the magnitudes of the gravitational forces experienced by the masses are:

A) equal, and are equal to F
B) equal, and are larger than F
C) equal, and are smaller than F
D) not equal, but one of them is larger than F
E) not equal, and neither of them is larger than F

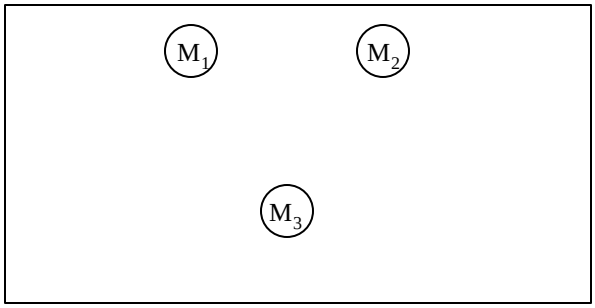




Mixing Newton's Third Law and ratios?

Concepts: Direction and Superposition

Free Response Question 6:



In the above diagram, three large moons are arranged so that they make an equilateral triangle. All three are the same size and have the same mass. Moons M_1 and M_2 are fixed in position and ***can not move.*** Moon M_3 is initially at rest, but is free to move.

Will moon M_3 move? [circle one] **YES** **NO**

If yes, draw an arrow to indicate the direction that M_3 will move, and explain the reason for your answer. If no, explain why M_3 does not move.

	Fall '99 U-AP1	Su'99 U-CP1
N=	**302**	**41**
i) % CORRECT	**51%**	**63%**

Multiple choice questions:

Multiple choice Q1:

The mass of the sun is about 3 x 10^5 times the mass of the earth. How does the magnitude of the gravitational force exerted by the sun on the earth compare with the magnitude of the gravitational force exerted by the earth on the sun? The force exerted by the sun on the earth is:

A. About 9 x 10^{10} times larger

B. About 3 x 10^5 times larger

C. Exactly the same

D. About 3 x 10^5 times smaller

E. About 9 x 10^{10} times smaller

Multiple choice questions:

Multiple Choice Q1 Results:

Students in various settings/backgrounds/courses have the same misconception:

	Phys111	Phys112		
Response	Spring'00 (N = 289)	Fall '98 (N = 79)	Fall '99 (N = 96)	Spring '00 (N = 119)
A	11%	13%	10%	11%
B	64%	68%	73%	45%
C (correct)	17%	14%	10%	41%
D	7%	5%	6%	3%
E	0%	0%	0%	0%
No Response	1%	0%	0%	0%

Student thinking: Objects of unequal masses exert unequal forces on one another!

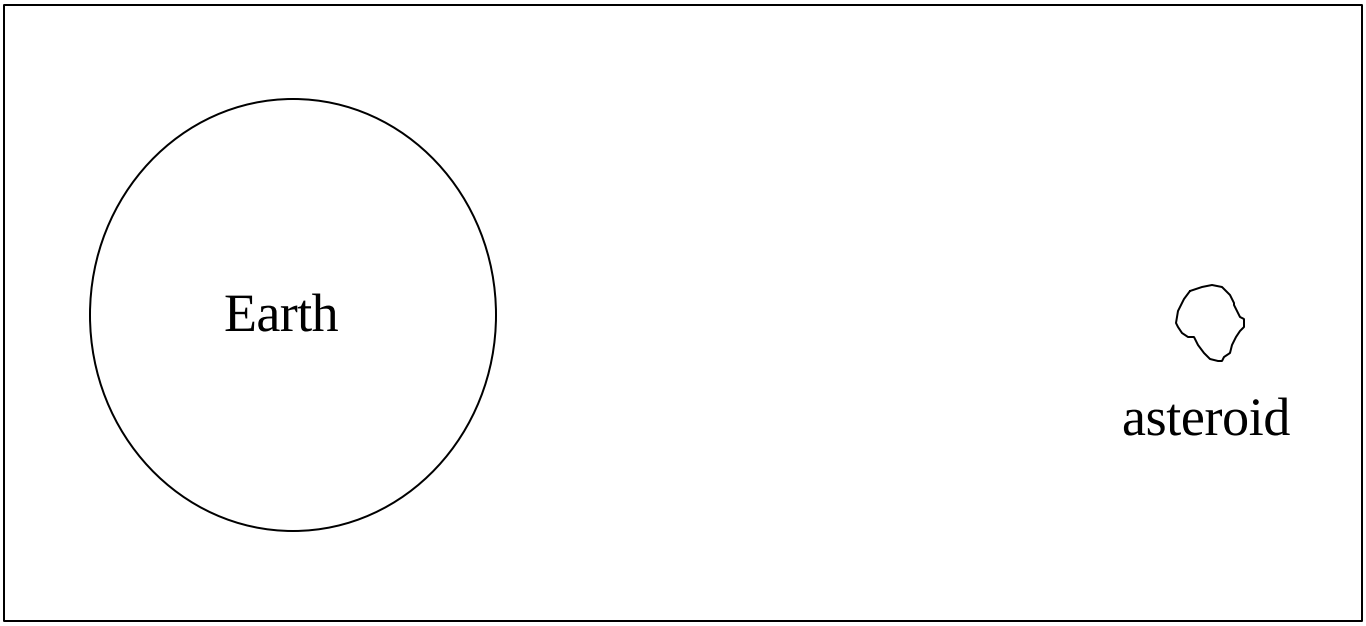
Multiple choice questions:

Multiple choice Q8: Which of the following diagrams most closely represents the gravitational forces that the earth and the moon exert ***on each other***? (Note: The mass of the earth is about 80 times that of the moon)

Response	ISU Phys222 Spring 2000 (N = 240)
A	26%
B	32%
C (correct)	38%
D	3%
E	0%
F	1%
No response	0%

Student thinking: Objects of unequal masses exert unequal forces on one another!

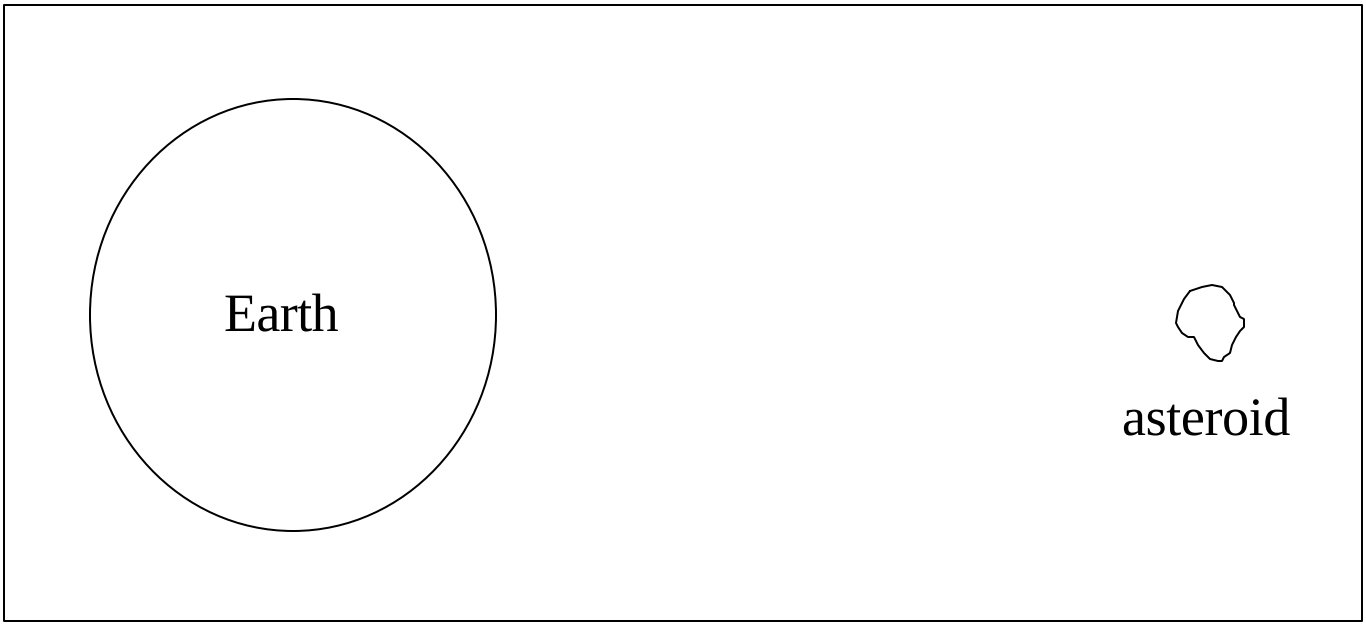
Free-response questions:



Free Response Q2: Refer to the picture above. State whether the magnitude of the force exerted by the Earth on the asteroid is **larger than, smaller than, or the same as** the magnitude of the force exerted by the asteroid on the Earth. Explain the reasoning for your choice.

Selected results (Hawkeye CC):

Free Response Q2:



Same as:	**10%**
Smaller than:	**5%**
Larger than:	**86%**

76% of all students explicitly reasoned that because the Earth was larger or more massive, it exerted a greater force on the asteroid.

LARGER objects exert MORE force on SMALLER objects than SMALLER objects exert on LARGER objects.

Selected results (*Northern Iowa*, *Iowa State*):

Free Response Q2:

	U-AP1	U-AP1	U-AP2	U-CP1
N=	15	48	21	41
LARGER THAN:	0%	2%	5%	2%
SAME AS:	0%	13%	19%	12%
SMALLER THAN:	80%	63%	67%	76%
ZERO:	20%	23%	5%	7%

LARGER objects exert MORE force on SMALLER objects than SMALLER objects exert on LARGER objects....even after instruction (!)

Free response questions:

Free Response Q8:

Imagine that you are standing on the surface of the moon holding a pen in one hand.

A) If you let go of the pen, what happens to the pen? Why?

	CC-Ast	U-AP1	U-AP1	U-AP2	U-CP1
N=	21	15	48	21	41
DROPS	45%	67%	40%	38%	68%
FLOATS	31%	13%	31%	38%	10%
FLOATS AWAY	24%	20%	29%	14%	15%