

THE AWFUL TRUTH ABOUT ZERO-G

by

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July 2014

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## ABSTRACT

Zero-G is a concept that people think they know but usually misunderstand. To illustrate the effects that happen in free-fall, the proper term, NASA developed two different demonstration units based on drop towers it uses in microgravity research, and associated education materials. While highly valuable, their efficacy has never been tested to show that they lead to proper student understanding of gravity and free-fall rather than providing a classroom diversion. In preparation for employing the free-fall demonstrator in a museum, an informal education setting, I developed and tested an activity in which students are challenged to explain what is happening in free-fall and the apparent 0g of space, and lead them to discover that the "awful truth" that true 0g does not exist. The activity is targeted for grades 5–9, consistent with New Mexico education standards, but is applicable to a broad range of audiences. I describe common misperceptions, the apparatus used, and results of the activity with teachers and then with students in an after-school program.

## INTRODUCTION AND BACKGROUND

The City of Alamogordo in southern New Mexico has a population of 31,500 with connections to nearby Holloman Air Force Base and roots in the U.S. space program. It is also home to the New Mexico Museum of Space History, where I work. An important part of the Museum's audience is composed of middle school students on field trips or in summer camps. Our customers also come from Las Cruces, population 101,047, El Paso, Texas, population 672,538, and across the Southwest and the nation (City Data, 2012).

The museum does not have regular classes, making it difficult to tell whether activities actually work in developing a proper understanding of space principles such as zero-gravity, a concept that most people erroneously think they know from seeing astronauts floating in space. The expression indicates a belief that Earth's gravity stops at some point and that persons or objects in space are free of its influence. Among other misunderstandings are beliefs that gravity does not exist in space, or that the atmosphere or magnetism holds us on the ground (Appendix A). The National Aeronautics and Space Administration (NASA) provides a wide range of educational guides covering the subject. Most notable among these are drop tower demonstrators, using video recorders, where the behaviors of different devices can be observed during free-fall (Rogers & Wargo, 1998; NASA, 2003).

However, no one has studied whether these guides and devices help students understand gravity and free-fall, especially in the 45 to 60 minutes available to informal science education at the museum or in outreach events. This project was designed to determine whether such a drop tower demonstrator can be employed in an audience-participation manner that leads students to self-correct misperceptions about gravity and

the nature of what happens to people and objects in space. This led to my focus statement, Can a hands-on activity lead students to correct misperceptions of Zero-G, properly called free-fall, in an informal science education setting?

### CONCEPTUAL FRAMEWORK

A particular challenge in science education is changing preconceived notions (Zirbel, 2004). Specifically, as people grow up they *know* certain facts or truths about the universe and often retain misconceptions even after passing various science classes. Many people learn the answers to give in order to pass a course rather than actually understanding a scientific phenomenon (Morrow, 2003). People may even hold conflicting views — such as a flat Earth on which we live and a round one that astronauts see from space — without acknowledging the dichotomy (Danaia & McKinnon, 2008; Kalkan & Kiroglu, 2007). "Intuitive conceptions" develop from direct personal experience and become more deeply ingrained with age (Stepans, 2008).

Several papers report student misconceptions about gravity. Some students believe that gravity is absent in space (Pablico, 2010). Many students stated that Earth's gravity stops at the top of the atmosphere, or that astronauts float inside spacecraft because of 0g existing only in the spacecraft (Kavanaugh & Sneider, 2007). Other researchers have shown that activities must be structured so students do not build alternative models in which atmospheric pressure or magnetism holds us on Earth (Williamson & Willoughby, 2012; Shannon, 2012). But models must also show circular motion around spherical bodies produces free-fall, as in Newton's illustration that a cannon ball fired above the atmosphere could be placed in orbit (Agan & Sneider, 2004).

NASA further confuses the issue by referring to microgravity in the space research context because residual forces aboard spacecraft cause small accelerations equivalent to a millionth of Earth's gravity (Gurel & Acar, 2003). Even the term Zero-G is incorrect. In physics,  $G$  is the gravitational constant used in calculating the attraction between two bodies, while  $g$  is the local acceleration due to gravity. Acceleration due to gravity at the surface of Earth,  $9.8 \text{ m/s}^2$ , is expressed as 1g (Rogers, Vogt & Wargo, 1997).

What we perceive as 0g is given form in one of Einstein's thought experiments (Kavanaugh & Sneider, 2007). Consider a man sealed in an elevator and someone cuts the cables. For the few seconds that he is plummeting to his doom he cannot tell whether he is falling or gravity has been mysteriously turned off. The two effects are equivalent. This is what people see happening to astronauts in space. Astronauts and spacecraft fall around Earth together, so the effect is equivalent to zero-gravity and widely reported as "zero-g" or 0g (Rogers, Vogt & Wargo, 1997).

NASA has produced several microgravity guides for educators (Rogers, Vogt, & Wargo, 1997; Rogers & Wargo, 1998; Vogt & Wargo, 1992 & 1995). While these are rich in equations, illustrations, and demonstrations that show the effects of free-fall, they do not lead students to recognize the paradoxes of their own beliefs and then to reconstruct a correct understanding of free-fall. NASA developed two demonstrators based on the 2.2-second Drop Tower Facility at Glenn Research Center (Rogers & Wargo, 1998; NASA, 2003) as classroom aids. In either, simple devices such as opposing magnets on a hinged rod, a postage scale, and an oil-and-water flow toy are placed inside a drop package. A video camera links to a recorder so the effects of free-fall can be

played back and discussed. However, no study indicates whether the NASA apparatus or lessons have any effect on beliefs about 0g and free-fall.

Finally, my concern about science education is that it tends to produce trained space chimpanzees, my nod to the two chimps who preceded astronauts on Project Mercury missions. That is, students often learn which lever to pull to get the banana pellet without understanding the actual science. Science education often leaves students feeling helpless in the face of knowledge that must be memorized to pass a course and may even become attributed to magic for lack of true understanding (Stepans, 2008).

#### METHODOLOGY

I named this activity The Awful Truth About Zero-G in order to engage participants with a promise of hidden knowledge about something they think they know. It follows the Conceptual Change Model (CCM) of Stepans (2008) in offering an approach for engaging students in re-discovery of gravity. Under CCM, students are asked to commit to a position or outcome, and then engage in activities that fully expose their belief and then confront it with conflicting or discrepant findings that should lead to an alternative position. Testing the new position leads to accommodation (acceptance) of the concept followed by extension to related phenomena. Because of the one-hour limit of a museum class, it is not possible to have students fully execute all the CCM steps. Rather, I have to lead them quickly to the answer. My idea was that students who re-create the discovery of gravity are more likely to take ownership of a corrected concept.

I start by asking students why astronauts float in space; because there is no gravity is a common answer. Then why doesn't space station zip away from Earth and never return? I ask. Students often rationalize various explanations. For example, there is a little

bit of gravity left, or Earth's magnetism holds it in orbit, or gravity holds space station but does not work inside the station. Following the CCM, these are the steps where the students commit to a position and expose or explain their beliefs, and then I force them to confront the contradictions they create. How can there be no gravity, but a little bit of gravity left? Why doesn't magnetism have similar effects on Earth? What would turn gravity off inside the station but not outside?

I then confide The Awful Truth, that there is no such thing as Zero-G, and show a three-minute video depicting astronauts under various conditions: aboard International Space Station, walking on the Moon, dropping a hammer and feather on the Moon, floating aboard the NASA low-g aircraft. It concludes with an equation using portraits: *Galileo + Newton + Einstein = astronaut Susan Still floating in space*. This is a discrepant equation (Figure 1). How can three old dead white men equal an attractive lady floating in space?



*Figure 1.* A discrepant equation—three old male scientists add up to an attractive woman floating in space—highlights the point that the discoveries of Galileo, Newton, and Einstein explain why people and objects float in space.

Next we quickly re-enact the discovery of gravity in order to introduce and accommodate a new concept under the CCM. Galileo rolled cannonballs down an incline to show they would accelerate to Earth equally. Students drop fishing weights to simulate his thought experiment about dropping cannonballs (Figure 2). Newton showed that all

bodies produce gravity, explained how Kepler's orbital laws work. I fire a Nerf ball to simulate a cannon putting a ball into orbit to demonstrate Newton's explanation that gravity and velocity combine to produce circular motion, i.e., orbits. I explain how all atoms produce gravity and that while gravity gets weaker with distance, it never reaches zero. The atoms in your bodies pull on the most distant stars in the universe, and they pull on you. I also explain that when the astronaut drops a feather on the Moon, the feather's gravity pulls the Moon up ever so slightly. Depending on the grade level, I go into the inverse square law, at the level of  $1/R^2$ , so they can see the math behind it, and understand that this is why gravity approaches but never reaches zero.

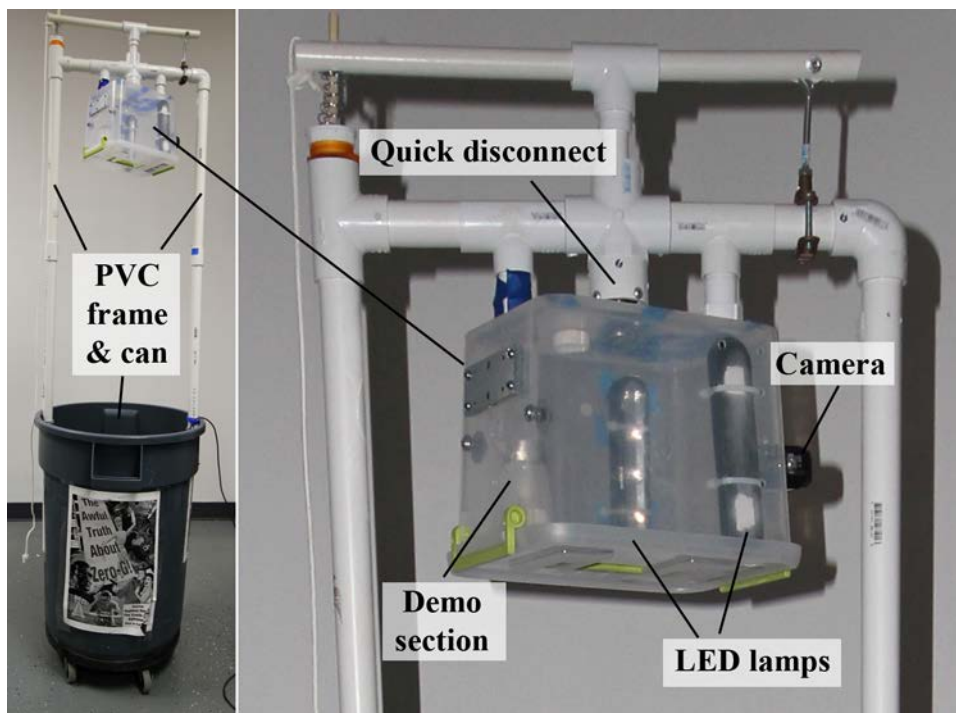


*Figure 2.* Student drops fishing weights to re-enact Galileo's thought experiment about dropping cannonballs from the Leaning Tower of Pisa. Faces are blurred for privacy.

Finally, Einstein postulated that a man falling in an elevator could not tell if gravity had been turned off. This is Einstein's Equivalence Principle. Students now operate the mini-drop tower, a device that provides 0.5-second of free-fall as a camera

system records events for frame-by-frame playback. This further engages the students and keeps them from being passive observers.

The mini-drop tower centers on plastic box with a sports video camera to record events at 60 frames/second (Figure 3). It is suspended from a PVC tubing frame by a garden hose quick-disconnect fitting that releases when a lever is pulled. The package drops 1.2 meter in 0.5 second into a large plastic trash can with foam padding at the bottom. Video is played back on a laptop through a projector. These demonstrations continue the Conceptual Change Model, transitioning from accommodating the concept to extending it through several illustrations of what happens in free-fall.



*Figure 3.* The mini-drop tower is mounted to a plastic trash can for demonstrations and easy storage and transport. The operator stands at left and pulls the string, depressing the lever at top right and releasing the hose disconnect.

The first and most important payload carried by the package is Hapless Harry, the Crash-Test Astronaut<sup>SM</sup>, a small artist's mannequin (Figure 4). He has a tiny nail in his

head to suspend him from a magnet outside the drop package. A feather is suspended in like manner. Students are asked to predict what will happen when the package drops, and a volunteer is brought up to release it. Harry and the feather float like an astronaut, thus connecting the activity to space and the astronauts seen in the opening video. This also requires a digression because I use a magnet to hold Harry and the feather in place. I explain that magnetism and gravity are unrelated and that there is no anti-gravity.



*Figure 4.* Hapless Harry and a feather ride Einstein's elevator. The last frame is darker because the package now is in the can.

After viewing the video showing Harry and the feather falling together, I move Harry and the drop package in a large circle and explain that astronauts and their spacecraft fall together in orbit around Earth, like Newton's imaginary mountaintop cannonball. Unlike the poor man in Einstein's elevator, they never hit bottom. Gravity and orbital velocity hold them in a continual state of free-fall or weightlessness. I also explain that they have experienced free-fall as children on playground swings – a fraction of a second of weightlessness at the top of the arc – and that this is the same as astronauts training on a low-g aircraft flying a roller-coaster trajectory.

The next demonstration is a discrepant event. I present a plastic jar half-filled with water and holding a ping-pong ball (Figure 5). After shaking to make it sink, which it cannot do, and discussing why it floats, I promise that I can make it sink without changing the apparatus. I do this by putting the jar into the package and free-fall, where capillary forces pull the ball under when buoyancy, a function of weight, disappears. From here I can move into discussions about fluid management and materials and combustion experiments on International Space Station. This, however, only works with a fluid that provides the correct contact wetting angle (R. Delombard, personal communication, 2014).



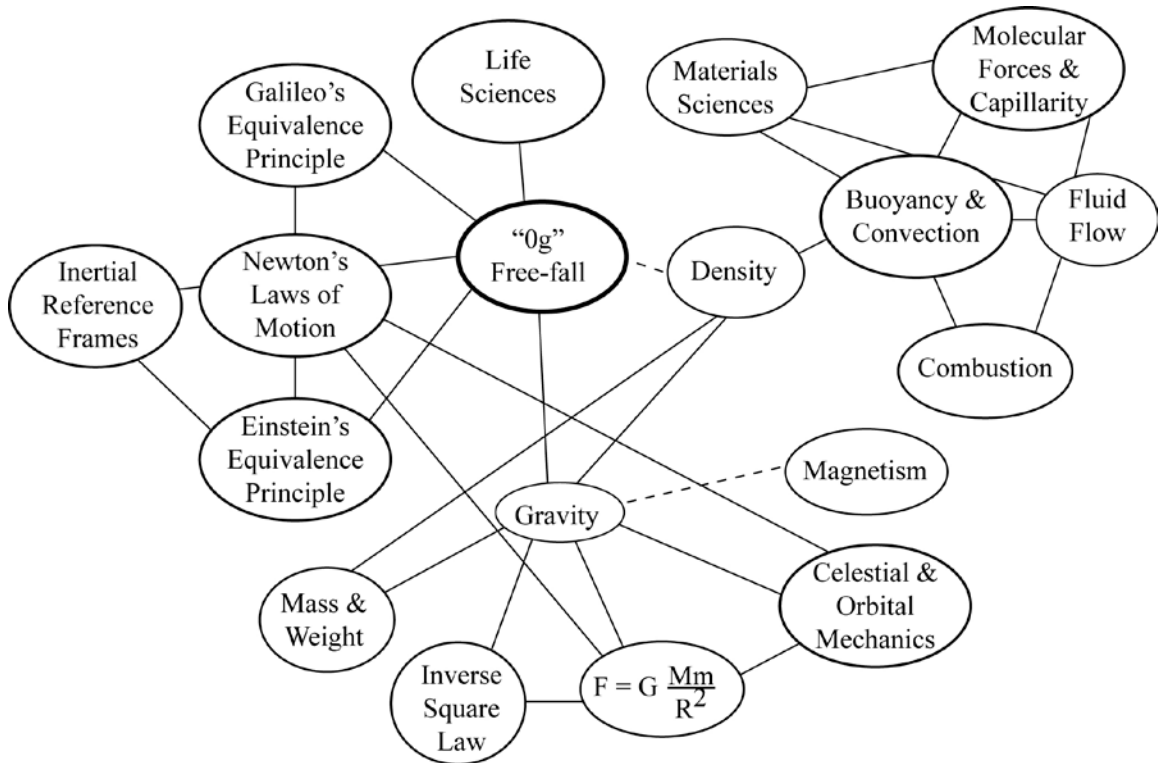
*Figure 5.* Detail views of a ping pong ball floating in water (left) and a candle flame (right) at T-1 second, T=0, and T+0.25 second of free-fall.

Additional demonstrations are provided, depending on the age level and time available. In each, students are asked to predict what will happen, then describe what they observe, and explain any discrepancy (Appendix B). Experiments include:

- Three magnets in a tube so the middle magnet is pushed to the center,
- A fishing weight on a spring to show how it becomes weightless,
- A plastic sphere half-filled with colored water to simulate a fuel tank,
- An oil-and-water flow toy where fluids stop dripping and climb the walls in free-fall,
- A tea candle to show how flames go to a nearly spherical shape, almost extinguishing, when convection is turned off.

Nominally the target audience is composed of students in grades 5–9, the range where the New Mexico Science Content Standards, Benchmarks, and Performance Standards (NMPED, 2003) mention gravity most often (excerpted in Appendix C). Under the Standards, fifth-grade students must be able to identify forces, including gravity, and understand that forces acting on an object will change its motion or direction. Sixth-grade students must know that gravity is universal and difficult to detect unless an object is massive. No mention is made for seventh grade. Eighth-grade students must know the four fundamental forces and that multiple forces acting together will have a net effect. Under Earth and Space Science, only the eighth-grade performance standards mention gravity as it acts on masses throughout the solar system. Ninth-grade students are required to know that gravity is universal and varies with distance. As discussions with state teachers revealed, teaching of gravity is uneven and often missing, and some teachers do not understand how gravity works. Thus, the activity is designed to engage all

grade levels since museum audiences often have mixed education levels. The activity is also designed to show how the concepts of gravity connect to other aspects of physics and to research aboard the International Space Station, or even coasting to Mars, rather than letting free-fall appear to be a standalone oddity in the universe (Figure 6).



*Figure 6.* Concept map shows how free-fall connects to several aspects of physics and chemistry. The dotted lines indicate that one phenomenon one does not cause the other.

In practice, the activity has been provided to groups ranging from third grade students to retired lifelong learners. Six distinct audiences were engaged in data collection. Cohort One comprised teachers attending the Scientifically Connected Communities conference sponsored by New Mexico State University in Las Cruces on March 9, 2013, selected to help fine tune the project before proceeding with students ( $N = 19$ ). Cohort Two had seventh and eighth-grade students from St. Francis of Assisi

School in Dulce, NM, on April 10, 2013 ( $N = 16$ ). Cohort Three had fourth-grade students from Sierra Elementary School in Las Cruces, NM, on April 26, 2013 ( $N = 26$ ). After a break for summer camps and some rework of the activity, I resumed surveys in the fall. Cohort Four had high-school Junior ROTC cadets from Stillwater, OK, on Sept. 6, 2013 ( $N = 38$ ). Cohort Five had fifth-grade students from Ramona Elementary School, El Paso, TX, on Dec. 11, 2013 ( $N = 54$ ). Cohort Six was a fourth-grade after-school science club at North Elementary School, Alamogordo, NM, on Feb. 25, 2014 ( $N = 9$ ).

In addition, I used informal observations throughout 2013–14 from groups that did not take surveys for data. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained (Appendix D). No demographic information other than grade level data was collected.

At the start and finish of presentations used for data, students fill The Awful Truth About Zero-G Inquiry to gauge their understanding of gravity and its effects as outlined in the Triangulation Matrix in Table 1.

Table 1  
*Data triangulation matrix*

	Intake Inquiry	Activity Questions	Exit Inquiry
Perceptions of 0g, free-fall	x	x	
Real-time adjustments to activities		x	x
Adjusted view of 0g, free-fall		x	x

Questions are based on misperceptions about gravity as posted on NASA's Amazing Space web site and the American Institute of Physics list of Children's Misconceptions of Science (Appendix A), and my observations in giving lectures and

teaching astronomy classes. The original Inquiry consists of ten true/false questions about the nature of gravity and a single multiple-choice question with five choices on what causes gravity (Appendix E). The first eight, later just five, true/false questions let the student select from common misperceptions about gravity, including it stops at the top of the atmosphere or does not exist in space, or bodies stay in orbit because of magnetism. The correct choice for each is False. The last two, which are True, are that falling is when nothing stops gravity from pulling you down, and that gravity decreases with distance but is always present. The multiple-choice question offers five possible sources for gravity. Only the third, matter, is correct. The exit version of the Inquiry adds a fill-in-the-blank question, What is the Awful Truth About Zero-G? During the summer I deleted three true/false questions and one multiple-choice option, as noted in Appendix E, as potentially confusing.

Activity questions were less rigid than the written survey since I often adapted in real-time (Appendix B). I would start with asking students what happens when astronauts are floating in space. When students reply that there is no gravity, I ask why space station does not fly away from Earth. Students then rationalize answers such as there is a little gravity, or it is magnetism, or other effects. I turn these around and show how they have painted themselves into a corner, then explain that there is no such thing as 0g.

I stop the video at different times and ask them why lunar dust falls if there is no gravity in space, whether the hammer or feather will hit the lunar surface first when dropped, and why people appear to float in space when they are on the NASA low-g aircraft. During the thought experiment enactments, I ask students to predict which weights will hit the ground first and what might affect their arrival (uneven release, air

resistance), what will happen to Hapless Harry and the feather when released into free-fall, and what will happen during the fluid and candle experiments. After each run, I explain what has happened so they see how gravity acts evenly on all bodies, thus cancelling its net effect so what is happening is Einstein's equivalence of 0g. These activities are related to experiments aboard space station, thus showing the relevance of the science.

### DATA ANALYSIS

In depicting my data I use a combination of data table and bar chart. The data table shows percentages that correctly answer the true/false questions, pre- and post-activity, and then lists the change in percentages answering correctly. The table next lists the number of responses on the multiple-choice question, and then tabulates the net change in correct or incorrect answers. This is not a percentage because students could select any combination of answers, or all, or none. Bar charts depict loss as a bar extending to the left, and improvement to the right. This provides a quick way to compare changes. A grey background bar is added to guide the reader in scanning from left to right.

Cohort One, Teachers, was given a different survey to determine if teachers thought the activity appropriate for their students. Cohorts Two and Three received the original Inquiry survey. Cohorts Four through Six received a shorter Inquiry, as noted in Appendix E, to reduce confusion.

#### Cohort One: Teachers

I first demonstrated the drop tower at the annual Scientifically Connected Communities (SC<sup>2</sup>) conference held March 9, 2013, for teachers by New Mexico State

University (NMSU) in Las Cruces ( $N = 19$ ). I wanted opinions from teachers who are with students all week long and understand their perceptions. I did not invite teachers to assist, as I do in the class version, so I could allow more time for discussion. Of these, eleven attendees cover grades 4–12. One each teaches grades 4, 4–8, 5, and 5–12. Three teach grade 6, and four teach grade 7 or 7–8.

The activity was well received. All teachers attending my session filled out the NMSU evaluation form and 74% filled out my evaluation form (Appendix F). The NMSU evaluation asked attendees to "rate the overall impact this session will have on your teaching practice" on a scale of 1–5. The average rating was 4.58. My form asked whether "This activity is appropriate for my class level" on a scale of 0–4. Adjusting the scale to NMSU's 1–5 also produced an average of 4.58.

Suggestions for the length of the activity ranged from 20 to 90 minutes. The latter was an outlier, with 45 to 60 minutes suggested by 29% of respondents. The mode was 30 minutes, mentioned by 43%, and the average was 39 minutes. These point towards a nominal museum class length of 60 minutes, which typically will be 50 minutes given time to get students seated and then out in time for the next part of their museum visit.

The open request for comments produced answers indicating that I should modify the survey. One respondent asked, "Are you talking about the gravitational constant  $G$ ?" The project title deliberately uses  $G$ , the constant, rather than  $g$ , local acceleration due to gravity; this is a common mistake. The same respondent also questioned whether some gravity being left assumes that distance has not gone to infinity. Again, this is a detail that the students will discover in the activity. Finally, one respondent indicated that the

questions may be at too high a level for her fourth grade students: "I'm happy if they know that 'gravity pulls in' " and keeps planets in orbit and things falling to Earth.

#### Cohort Two: Middle-School Students

Cohort Two had seventh- and eight-grade students from St. Francis School in Lumberton, New Mexico ( $N = 16$ ). As described by their teachers the students have difficult family backgrounds and thus were less likely to open up and become engaged in classroom activities in an unfamiliar setting. After the video I asked the students what was happening with the people experiencing apparent 0g. Answers included no gravity or zero-gravity. When asked why the space station was orbiting Earth, they replied that it was because of a gravitational orbit or magnetism. By contrast, astronauts stay on the Moon because of spacesuits or heavy boots, or "a little bit of gravity on the Moon ... but not much."

Percentage of Cohort Two students answering correctly ( $N = 16$ ,  $N = 15$ )

	Pre	Post	Change	< Worse   Better >
1. ... ends at the top of atmosphere	50	60	10	
2. Zero-G means you are not moving	75	60	-15	
3. ... no gravity in space	31	73	42	
4. ... but there is inside a spaceship	94	73	-21	
5. Satellites orbit of magnetism	31	30	-1	
6. Planets orbit because of its magnetism	31	20	-11	
7. When you fall, gravity is turned off	75	60	-15	
8. Falling is when nothing stops you	50	73	23	
9. Gravity decreases with distance	69	73	4	

Multiple-choice question (check all that apply) [number of responses shown]

Gravity is produced by	Pre	Post	Change	< Worse   Better >
<input type="radio"/> Magnetism	8	6	2	
<input type="radio"/> Only big bodies	0	1	-1	
<input type="radio"/> Everything	5	7	2	
<input type="radio"/> The atmosphere	3	0	2	
<input type="radio"/> Rotating a spacecraft	1	1	0	

*Figure 7.* Changes in survey responses by Cohort Two, composed of seventh- and eighth-grade students. One student skipped the post-activity survey.

In the elevator with the mannequin and feather experiment, one student predicted that the feather would shoot to the top of the container while the mannequin fell while others predicted that the two would fall at the same rate or both stay near the top. They wanted to take turns pulling the release and were excited watching the video of what happens inside.

The survey showed a slight improvement in student perceptions. No student answered the entire survey correctly. There was a 10% improvement answering false that gravity stops at the top of the atmosphere (1). For (2), there was a 15% decline answering

false that Zero-G means you are not moving. For (3), correct scores nearly doubled, by 86%, that it is false that there is no gravity in space. Oddly, for (4) the scores dropped 21% that there is no gravity in space but there is inside a spaceship. Questions (5) and (6), stating that magnetism keeps objects in Earth or solar orbit, had small declines. A 15% decline occurred on (7), stating the gravity is turned off when you fall. The last two questions showed slight improvements. Question (8) rose 23% that falling happens when nothing gets in your way, and (9) rose 38% that gravity gets weaker with distance but always has something left. Although the multiple-choice question let students check all items that apply, the totals indicate that they picked just one item. Answers improved slightly for magnetism, everything, and the atmosphere as causes of gravity, and declined slightly for only big bodies.

Only 31% of the cohort answered the open question, *What is the Awful Truth About Zero-G?*, added at the end of the exit survey, probably because I inadvertently placed it at the end of the multiple choice list. Each gave correct answers, though. The most correct were that “it’s all about free fall” and “that there is no space that has 0g.” And in the discussions during the activities, one student stated, “You can’t turn off gravity because there’s no switch.”

The mixed results indicate that the students still were not resolving internal conflicts about whether gravity actually disappears or goes to zero. The perception that magnetism causes gravity is strongly rooted as noted by the unchanging responses to questions (5) and (6), and the modest improvement in the number who incorrectly chose gravity. In a brief interview after the activity, the teachers said they felt I did a good job and gave the students a good visualization of a difficult physics concept. While I

perceived silence among them, the teacher said, "It's the best I've seen them being attentive." He also suggested that the activity needs a better "wow factor" to help hook the students.

### Cohort Three: Fourth Grade Students

Cohort Three was composed of fourth-grade students ( $N = 26$ ) from Sierra Elementary School in Las Cruces, NM. An important difference in this presentation is that I included Newton's three laws of motion and law of universal gravitation. No props were added.

The activity produced modest increases in correct perceptions of gravity. Most striking were improvements of 23% rise for gravity ending at the top of the atmosphere (1) and 38% for no gravity in space (3). Paradoxically, there was a 10% improvement in the belief that magnetism holds satellites in orbit (5) and a 4% decline in the belief that it holds planets in orbit (6). The last two questions, about falling (8) and gravity and distance (9), both showed 12% improvement. Most disappointing is a marked increase in the multiple-choice question showing the perception that magnetism causes gravity, from 11% to 18%. This occurred despite me specifically telling students that magnetism and gravity are unrelated.

On the post-test survey, 73% answered the extra question, 65% correctly. Answers included the typical "There's no such thing as zero-G," "It doesn't exist," and "... they made it up." Two odd identical misperceptions were "that the zero-G does not have atmosphere." While the written answers are encouraging, they cannot be taken as definitive. The students may have been repeating the answer given at the beginning, and building off each other's verbal responses.

Percentage of Cohort Three students answering correctly ( $N = 26$ )

	Pre	Post	Change	< Worse   Better >
1. ... ends at the top of atmosphere	12	46	23	
2. Zero-G means you are not moving	81	77	-4	
3. ... no gravity in space	35	73	38	
4. ... but there is inside a spaceship	58	58	0	
5. Satellites orbit because of magnetism	23	35	10	
6. Planets orbit because of its magnetism	46	42	-4	
7. When you fall, gravity is turned off	92	69	-23	
8. Falling is when nothing stops you	65	77	12	
9. Gravity decreases with distance	42	54	12	

Multiple-choice question (check all that apply) [number of responses shown]

Gravity is produced by				< Worse   Better >
<input type="radio"/> Magnetism	11	18	-7	
<input type="radio"/> Only big bodies	2	2	0	
<input type="radio"/> Everything	7	7	0	
<input type="radio"/> The atmosphere	15	10	-5	
<input type="radio"/> Rotating a spacecraft	3	5	2	

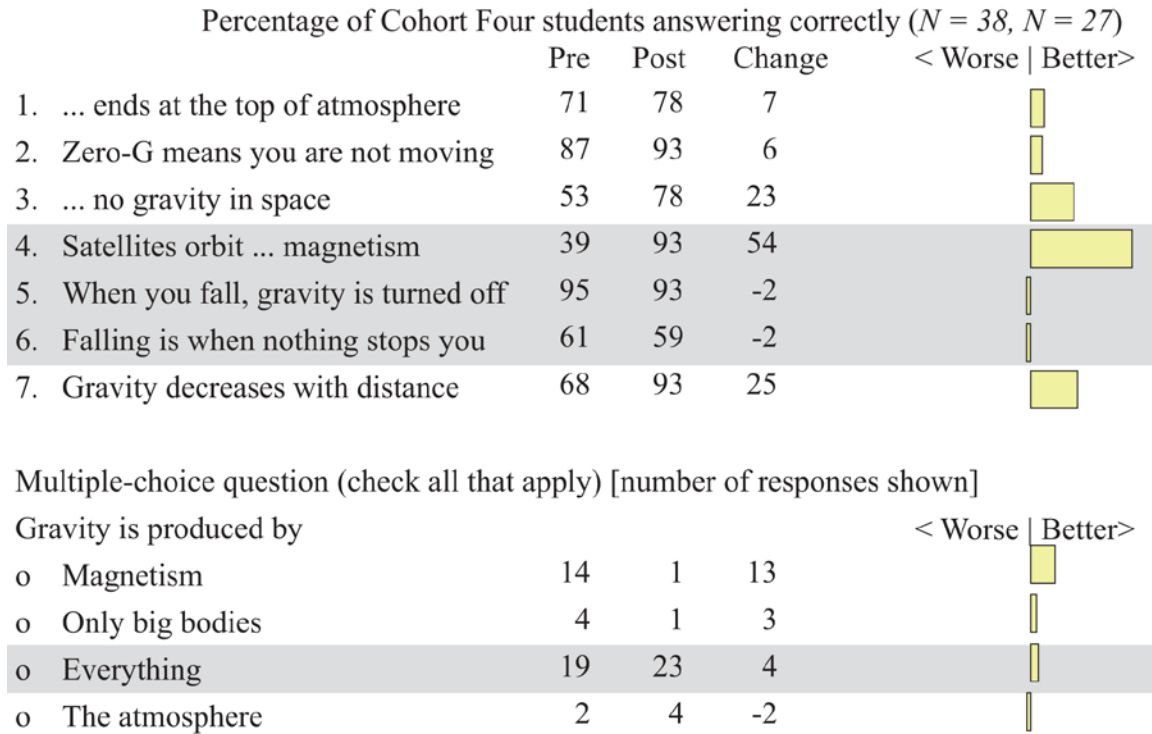
Figure 8. Changes in survey responses by Cohort Three, a fourth-grade class.

#### Cohort Four: ROTC Students

Cohort Four consisted of the JROTC students from Oklahoma ( $N = 38$ ). Eleven skipped the post-activity inquiry, a 29% loss of the cohort. Assuming that the missing group is random, the inquiries showed significant before/after changes. Three questions (1, 2, 5) had high initial scores and showed slight improvements (1, 2) or, paradoxically, a slight decline (5). No gravity in space (3), improved 23%. Satellites stay in orbit because of magnetism (4), improved 54%, with an exit score 93%. Gravity persists even as it gets weaker (7), improved 25%.

Answers to the essay question at the end were 85% correct, with 15% left blank. Answers ranged from "There is no such thing" and "... everything produces gravity..." to "There is no such thing as Zero-G. There will always be at least a small amount of gravity." One even wrote "...we only use the term metaphorically. However, we can use the terms weightlessness and free-fall." Oddly, on the questions this student also checked that there is no gravity in space and that magnetism and everything cause gravity.

A total of 44% (12 students) scored 100% on the post-activity inquiry, and another 22% (six students) missed only one question, Falling is when nothing stops gravity from pulling you down (6). On the pre-activity inquiry, only 5% (two responses) were perfect. The large number makes it highly unlikely that several students copied from one who happened to get everything right. I attribute at least part of the result to the student group being older and more attuned to aerospace issues since they are in earliest training to become Air Force officers. In addition, their instructors often spoke up to link my talk and their class lessons.



*Figure 9.* Changes in survey responses by Cohort Four, a class of Air Force JROTC students in grades 11 and 12.

### Cohort 5: Fifth-Grade Students

Cohort Five consisted of fifth-grade students from Ramona Elementary School in El Paso, TX ( $N = 54$ ). The general results were highly mixed. Significant declines in correct answers occurred on gravity ends at the top of the atmosphere (1), down 19%, and there is no gravity in space (3), down 44%. Three questions had significant improvements, 0g means you are not moving (2), up 66%, gravity turns off when you fall (5), up 66%, and gravity gets weaker but never reaches zero (7), up 33%. The multiple-choice questions showed good results. "Everything produces gravity" declined from 37% to 32% correct. But there were improvements in attributing it to magnetism, down from 37% to 14%. Answers about big bodies and air pressure also improved.

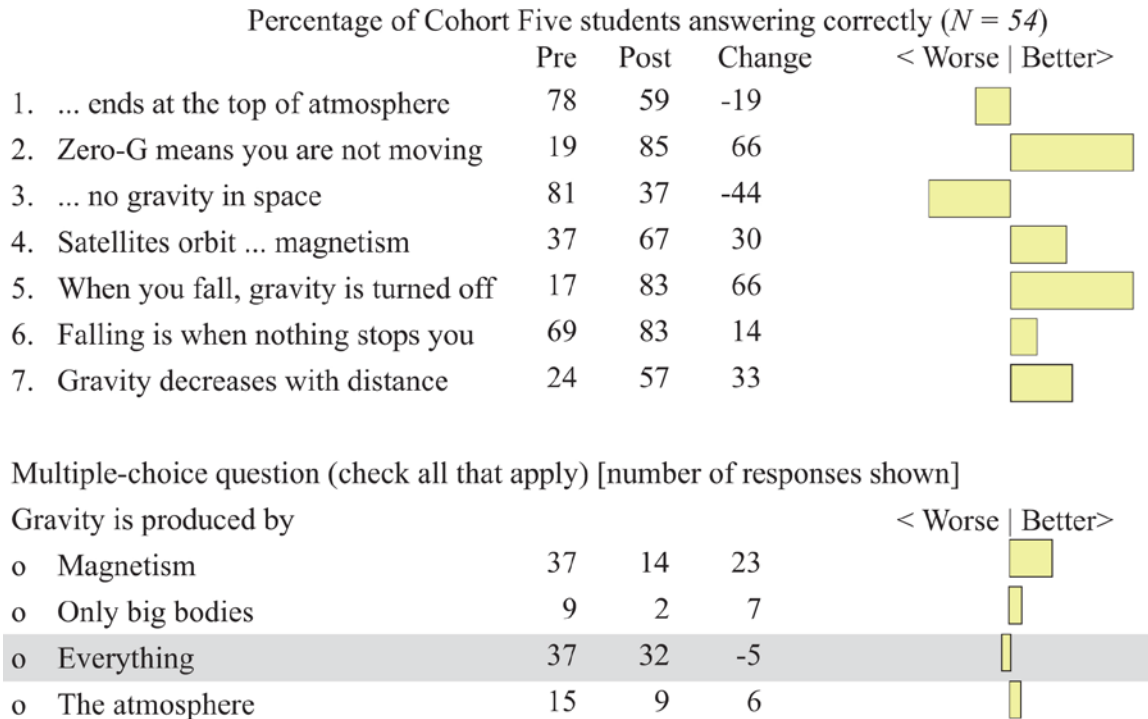


Figure 10. Changes in survey responses by Cohort Five, a fifth-grade class.

Only 57% of students answered the short-answer question, all but three correctly. Answers were along the lines of "It does not exist" and "There is no such thing." Two students incorrectly stated, "There is no gravity," and one stated, "ZeroG is when there is no Gravity." While statistics indicate modest impact on student beliefs, 11 inquiries stand out. Ten, or 19%, were perfect, though three did not complete the short answer, and an eleventh was perfect but stated, "There's no gravity. (No such thing)."

#### Cohort Six: Science Club

Cohort Six involved fourth grade students in an after-school STEM program ( $N = 9$ ). In this case the post-test survey was given a week after the class. Students showed marked improvements in understanding that gravity does not stop at the top of the atmosphere (1), 33%, the Zero-G means you are not moving (2), 28%, that there is

gravity in space (3), 34%, and that some gravity is left even though it gets weaker (7), 33%. The magnetism results are conflicting. The satellites orbit because of magnetism (7) dropped 11%, while the number selecting magnetism as a cause of gravity dropped from five to two. The multiple-choice answers showed modest improvements. No one attributed gravity only to big bodies, while "everything" went from none to two. Air pressure stayed constant at four votes each time. This may be due to not discussing air pressure as false during the class. All students replied correctly in some form on the short-answer question, ranging from "There is none" to "the Awful Truth About Zero-G is there is no such thing." A nearly perfect score was made by 11% on the post-activity inquiry, missing only by checking "air around us" on the multiple-choice question.

Percentage of Cohort Six students answering correctly ( $N = 9$ )

	Pre	Post	Change	< Worse   Better >
1. ... ends at the top of atmosphere	44	67	33	
2. Zero-G means you are not moving	78	100	28	
3. ... no gravity in space	33	67	34	
4. Satellites orbit ... magnetism	33	22	-11	
5. When you fall, gravity is turned off	100	67	-33	
6. Falling is when nothing stops you	100	89	-11	
7. Gravity decreases with distance	44	67	33	

Multiple-choice question (check all that apply) [number of responses shown]

Gravity is produced by	Pre	Post	Change	< Worse   Better >
<input type="radio"/> Magnetism	5	2	3	
<input type="radio"/> Only big bodies	0	0	0	
<input type="radio"/> Everything	0	2	2	
<input type="radio"/> The atmosphere	4	4	0	

Figure 11. Changes in survey responses by Cohort Six, a small after-school science club.

## INTERPRETATION AND CONCLUSIONS

Can a hands-on activity lead students to correct misperceptions of Zero-G — which properly is called free-fall — in an informal science education setting? Initial results indicate that it helps students develop correct understandings about 0g or at least set the framework so that they view space phenomena differently and will eventually understand better. The shifts from misperception to correct perception on various aspects of gravity for the most part are modest, and at times misperceptions rose after the presentation. Magnetism and air pressure retain a strong hold on student perceptions.

The trend showing more students writing that there is no such thing as 0g in the final question indicates that my approach is correct. Many students got perfect or near-perfect scores on the post-activity inquiry after the summer break when I had fine-tuned my presentations. These include 44% in Cohort Four, 19% in Cohort Five, and 11% in Cohort Six. A single instance might be written off to several students copying from the one classmate they know is a genius, but I observed no such huddles. The high 44% value for Cohort Four may be the product of an older, self-selected group already interested in space. Even if the missing students had responded incorrectly, 32% of the class would have a perfect score. The 19% value for Ramona Elementary School's fifth graders and 11% for the STEM science club are indicative of a successful program.

Involving the students in the activity is important. Teachers have commented that they were impressed that I provided more than a standard lecture. Students have been eager to volunteer, even just to pull the release. Confounding factors must be recognized and eliminated early. Even though some aspect of the procedure may be mechanically efficient or simple, it cannot be used if there is a chance that the audience may perceive it

as a part of the physics that is being explained. Magnets were an easy way to attach and release the drop package, but had mechanical problems. Ultimately I was concerned that the audience might perceive the magnets as playing a role in gravity, so I switched to the hose disconnect. I also added a short discussion of the four fundamental forces to explain that gravity and magnetism are not related. Cohorts Four, Five, and Six, which range from twelfth down to fourth grade, had significantly better scores with regard to magnetism.

Finally, anecdotal evidence supports this approach. Virtually every teacher who has brought a class to us for The Awful Truth has been enthusiastic about the presentation and felt that it added value to what they are teaching students. In presentations where the groups were too large and quick to conduct the Inquiry, such as school assemblies, I have obtained a voice vote at the end of the class. I ask, "What is the awful truth about zero-g?" More than half the students routinely answer, "There's no such thing." Next I ask, "What is really happening?" About a quarter to a half of the students correctly answer, "Free-fall" or "weightlessness." The problem is not solved, but clearly this is the right approach and can be more successful with refinements of questions in the Inquiry tool and the presentation.

#### VALUE

I have long worried that classroom science education is somewhat like training space chimpanzees: students learn which lever to pull to get the banana pellet, but leave internalizing a different belief system. I believe that engaging them in rediscovering the principles behind gravity leads them to take internal ownership of the concept, and thus hold a correct understanding about gravity. This conforms well to Stepan's Conceptual

Change Model in which students are challenged to examine their own beliefs and then adopt a correct one. It might also be described as constructive confrontation.

Traditionally teachers, including me, would confront students with, "What you know is wrong, I am right. Accept it and let's do the next item." This can lead to natural resistance "because my dad told me this, it's what I've always know, and you're The Man." The constructive confrontation of the CCM has students confront themselves by making them defend a position and realize, "This doesn't work. What does?" A museum, though, cannot fully implement the Stepan's model because of time constraints.

This is the approach I have been developing as a science educator. In my first incarnation as a science educator, in the mid-1980s, I simply assembled slides of information and presented facts. Now, I give students several viewpoints with a common focus and led them to change their concept. Starting with a discrepant event – what they see is different from what they think is happening – appeals to everyone's desire to know something hidden or unusual. By engaging them in a rediscovery process I encourage internal ownership of the concept of gravity. Showing how 0g equivalent is a design challenge for engineers and research opportunity for scientists gives relevance, and offers the students the possibility of taking part in future discoveries as scientists. I also avoid saying, "No, you're wrong" directly so I do not discourage students, although "no" sometimes is the only answer. But neither do I allow incorrect understandings. I encourage with "You're almost there," or "How about B instead of A?"

Finally, in a sense my own work is an example of the CCM at work. I discovered it late in my project, after I had reinvented many of its components. As a result, I now am an eager adherent and will apply it in more rigorous fashion to future education activities.

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APPENDICES

APPENDIX A  
MISPERCEPTIONS ABOUT GRAVITY

Misperceptions about gravity from NASA's Amazing Space web site (<http://amazing-space.stsci.edu/eds/tools/type/myths.php>) and the American Institute of Physics (<http://amasci.com/miscon/opphys.html>).

1. Magnetism causes gravity.
2. Gravity exists only on Earth.
3. Weight and mass are the same.
4. Gravity is selective; it acts differently or not at all on some matter.
5. Gravity increases with height.
6. Gravity requires a medium to act through.
7. Gravity cannot exist without air.

APPENDIX B  
OPEN-ENDED DISCUSSION QUESTIONS

Students were asked to predict what would happen to each of the demonstration units during free-fall and then engaged in short discussions about what did happen.

1. Fishing weights: This one precedes the drop tower. Which weight will fall faster or slower? Why? Why did they fall at the same rate?
2. Hapless Harry (mannequin) and a feather: What will happen when the package is released? Why? If this was in elevator with a human inside, could he or she tell whether he was falling or if gravity was turned off?
3. Liquid motion timer (clear plastic box with colored oils dripping past each other): What is happening inside? What will happen in free-fall? Why or why not?
4. Ping pong ball in a jar: After shaking and the ball stays afloat, I proclaim that I can make it sink. How? This happens when the container goes into free-fall and buoyancy disappears but capillary forces pull the ball downward.
5. Candle flame: I hold a lit match in the light path of the projector to make a shadowgraph showing the hot exhaust rising. What will happen when the candle goes into free-fall? Why?

APPENDIX C  
NEW MEXICO SCIENCE CONTENT STANDARDS, BENCHMARKS,  
AND PERFORMANCE STANDARDS (EXCERPTS)

## Strand II: Content of Science

Standard I (Physical Science): Understand the structure and properties of matter, the characteristics of energy, and the interactions between matter and energy.

5-8 Benchmark III: Describe and explain forces that produce motion in objects.

### Performance Standards

#### Grade 5

3. Identify forces in nature (e.g., gravity, magnetism, electricity, friction).
4. Understand that when a force (e.g., gravity, friction) acts on an object, the object speeds up, slows down, or goes in a different direction.

#### Grade 6

1. Know that every object exerts gravitational force on every other object dependent on the masses and distance of separation (e.g., motions of celestial objects, tides).
2. Know that gravitational force is hard to detect unless one of the objects (e.g., Earth) has a lot of mass.

#### Grade 8

1. Know that there are fundamental forces in nature (e.g., gravity, electromagnetic forces, nuclear forces).
3. Analyze the separate forces acting on an object at rest or in motion (e.g., gravity, elastic forces, friction), including how multiple forces reinforce or cancel one another to result in a net force that acts on an object.

APPENDIX D  
INSTITUTIONAL REVIEW BOARD PERMISSION



**INSTITUTIONAL REVIEW BOARD**  
**For the Protection of Human Subjects**  
**FWA 00000165**

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**MEMORANDUM**

**TO:** David Dooling and John Graves  
**FROM:** Mark Quinn, Chair *Mark Quinn cy*  
**DATE:** November 30, 2012  
**RE:** "The Awful Truth about Zero-G" [DD113012-EX]

The above research, described in your submission of November 30, 2012, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.
- (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
- (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
- (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
- (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

APPENDIX E

THE AWFUL TRUTH ABOUT ZERO-G INQUIRY

## True/false questions

1. Gravity ends at the top of Earth's atmosphere
2. Zero-G means you are not moving
3. There is no gravity in space
4. \*There's no gravity in space, but there is inside a spaceship
5. Satellites stay in orbit around Earth because of magnetism
6. \*Planets stay in orbit around the Sun because of its magnetism
7. When you fall, gravity is turned off
8. \*The force of gravity is constant across the universe
9. Falling is when nothing stops gravity from pulling you down
10. Gravity decreases with distance, but there's always a small pull left

## Multiple-choice question

Gravity is produced by

- Magnetism
- Only big bodies
- Matter itself
- The atmosphere
- \*Rotating a spacecraft

The Awful Truth About Zero-G is (fill in blank; post-activity only).

\* These options were deleted to reduce possible confusion in the shorter inquiries.

APPENDIX F  
TEACHER SURVEY

SURVEY FORM FOR TEACHERS AT THE SC<sup>2</sup> CONFERENCE

I teach \_\_\_\_ grade.

This activity is appropriate for my class level. (0 = strongly disagree; 4 = strongly agree)

0      1      2      3      4

Which part is best and why?

Which part is worst and why?

Which part is too complex and why?

The appropriate duration would be \_\_\_\_\_ minutes.