Physics for Animation Artists

David Chai and Alejandro L. Garcia, San Jose State University, San Jose, CA

Animation has become enormously popular in feature films, television, and video games. Art departments and film schools at universities as well as animation programs at high schools have expanded in recent years to meet the growing demands for animation artists. Professional animators identify the technological facet as the most rapidly advancing (and now indispensable) component of their industry. Art students are keenly aware of these trends and understand that their future careers require them to have a broader exposure to science than in the past. Unfortunately, at present there is little overlap between art and science in the typical high school or college curriculum. This article describes our experience in bridging this gap at San Jose State University, with the hope that readers will find ideas that can be used in their own schools.

San Jose State is in the heart of Silicon Valley, located near many of the leading computer animation studios and video game production companies, such as DreamWorks, Pixar, Industrial Light & Magic, Electronic Arts, and Zynga. Our animation/illustration program is consistently ranked as one of the premier programs in the nation,[1] with more than 400 undergraduate majors. In spring 2008 we received a National Science Foundation CCLI grant[2] to develop physics curricular materials for art students studying animation. These materials have been used in various ways, including special lectures embedded within existing animation art courses and in a new upper-division general elective course, entitled "Physics of Animation," at San Jose State.

Physics lectures within an animation course

For the first three semesters of the NSF project, the authors team-taught Art 114, which is the first upper-division animation course at SJSU. Although there is no standard textbook, art students learn animation by completing a series of well-established exercises (often called "tests"). These exercises vary somewhat from school to school, but, in general, there are three basic categories of tests: Simple Drops, Basic Effects, and Character Animation (see Table I).

Students in Art 114 complete most of these animation tests in one semester.[3] In a typical high school animation class, students usually do three or four tests, with the bouncing ball and the walk cycle being the most commonly assigned exercises. Despite the popularity of computer animation, many animation courses (including Art 114) are still taught using traditional hand-drawn animation because drawing by hand not only trains the eye but is also an essential skill in many facets of the industry, such as storyboarding and visual development.[4] Regardless of the medium or technology used in creating animation, the challenge is not in drawing the individual images but rather in positioning the sequence of images to create the illusion of motion.

Table I. Common animation exercises (tests).

Category	Animation Tests	Physics Principles
Simple drops	Bouncing ball Brick falling off a ledge	1D Kinematics 3D Kinematics
Basic effects	Falling flour sack Drifting leaf Bouncing water balloon Swinging rope or tail	Inertia; Momentum Forces Vibrations; Fluids Pendulums
Character animation	Jumping human Walk cycle Character acting in a scene	Statics, action/reaction Rotational dynamics Biomechanics

Table II. Principles of animation.

Squash and stretch	Arcs
Anticipation	Secondary action
Staging	Timing
Straight ahead action and pose to pose	Exaggeration
Follow through and overlapping action	Solid drawing
Slow in and slow out	Appeal

Art 114 is a six-hour studio class, with students spending one or two weeks planning, drawing, and revising each animation test. We created a one-hour physics lecture to accompany each test; for example, for the bouncing ball we presented basic kinematics so that students understood the timing of accelerated motion. There were several obvious challenges. First, the vocabulary used by animation artists differs from standard physics terminology; for example, acceleration is called "slowing in/slowing out" or "easing in/easing out," while a trajectory is called the "path of action" (not to be confused with the "line of action"). The early Disney animators established the "Principles of Animation" (see Table II), which are still taught and followed to this day.[5,6] As often as possible we highlighted the connections between these principles and the physical laws of motion (e.g., how the principle of "follow through" is related to inertia and Newton's first law of forces).

Artists are visual learners and keen observers, so the lectures were more effective when combined with frequent in-class demonstrations. For example, we roll a wheel down an incline with notches spaced at 1, 3, 5, 7,… inches so the students can see and hear that this pattern of spacing occurs for accelerated motion. We call this the "Odd Rule" and students learn to recognize this spatial pattern for constant acceleration and to use it when they animate. For the jump and walk exercises, we found that biomechanics demonstrations using force plates were helpful.[7] Animators at all levels study motion using video reference, so it was natural to introduce them to using motion tracking software such as Tracker[8] and Logger Pro.[9] Furthermore, motion tracking is closely related to motion capture systems used in the animation industry, so students can relate the motion graphs obtained from video reference with the corresponding motion graphs used in computer animation, such as in AutoDesk Maya's graph editor.

Animation artists rarely need mathematical precision, yet the motion they create often needs to look realistic. Rather than having students use formulas, we developed basic guidelines, such as the "Odd Rule," that they can apply to their work. A related guideline is "Fourth Down at Half Time," which says that an object falls a quarter of the total distance from its apex when it has fallen for half of the time. Although it's tempting to introduce the students to the kinematic equations for their basic drop tests, for the more advanced animation tests the general guidelines are more useful. With these guidelines students can visually check their animation, whether it be a bouncing ball or a human jumping, to verify overall correctness (see Fig. 1). "Fourth Down at Half Time" is also used for the swinging motion of limbs (i.e., a pendulum that's a fourth the length swings in half the time). When numerical estimates are needed, the students use basic rules of thumb, such as that a ball bounce from arm's length and a full stride at walking speed each take about 24 frames (one second) for the cycle.[10]

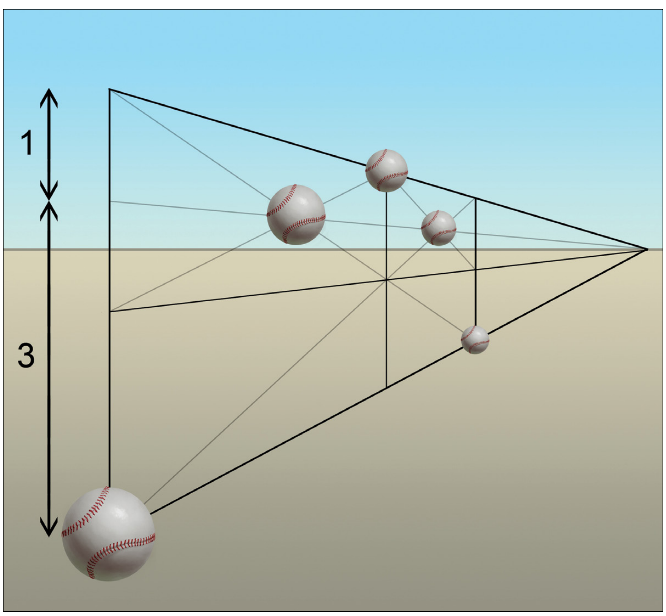

Fig. 1. Parabolic arc in perspective sketched using "Fourth Down at Half Time."

Physics of Animation general elective course

In Fall 2009, Physics of Animation was introduced as an upper-division general education elective in science at SJSU.[11] This new course, cross-listed as Art/Physics 123, has now been taught for two semesters and we expect to offer it on a regular basis since it is now a required course for art students majoring in animation/illustration. Art/Physics 123 most closely resembles our Physics of Music course (Music/Physics 166), which is also an upper-division GE elective.

With the creation of Art/Physics 123, we discontinued the physics lectures in Art 114 since students are expected to take Physics of Animation before or concurrent with their upper-division animation courses. The curriculum materials developed in Art 114 were incorporated into Art/Physics 123 but the stand-alone course covers many more topics in advanced effects animation (water waves, explosions, etc.). More importantly, Art/Physics 123 includes several lectures on lighting and optics, which are extremely important in modern animation film making (e.g., at DreamWorks Animation the lighting department is the largest unit in the studio).[12]

Bringing physics to your art students

If you are interested in bringing physics to animation students at your school, here is our advice: First, learn the basics of animation by reading an introductory text; for physicists we recommend *Animation: The Mechanics of Motion*[13] and *Timing for Animation*.[14] Tutorials found on our website, AnimationPhysics.com, are also helpful. Next, try your hand at animation, following the examples in those texts. If you like working on a computer, then try using Adobe Flash or Autodesk Maya; if you like to sketch, try DigiCel FlipBook.[15] For a hands-on approach try stop-motion animation, which is easily composed using digital video tools such as SAM Animation[16] or QuickTime Pro. The very simplest approach is to make a flipbook animation with a stack of cards (which can optionally be scanned and composed into a video).

Next, meet the animation teachers at your school to learn about their program. Most likely their students are working on animation exercises similar to those in Table I and are struggling with making the motion look believable. How you can help these students depends on your school. At San Jose State we now have an integrated program, but it all started with a single guest lecture on how to animate the bouncing ball. Over the past three years we have presented physics lectures to animation students in high schools and colleges around the San Francisco Bay Area, and the reception from their art teachers has been universally positive.

But how do art students feel about learning physics? We did anonymous surveys, based on the Colorado Learning Attitudes about Science Survey,[17] of animation/illustration majors at San Jose State and of students taking animation at Santa Clara High School. Nearly two-thirds of the high school students *disagreed* with the statement, "The subject of physics has little relation to what I experience in the real world" and that increased to 96% for graduating college seniors. For both groups, about 85% of these art students agreed with the statement, "Nearly everyone is capable of understanding physics if they work at it." One student from Art/Physics 123 wrote, "I love how the class puts a rationalization to the physical world. It gives me extra ways to understand things when I animate. Allowing me to make things more convincing or by informing myself. I can make decisions on how I want something to look."

The Laws of Cartoon Motion

When physicists think of "animation," the first thought that comes to mind is often the image of Wile E. Coyote running off a cliff and not falling until he looks down. This memorable scene and other common distortions are humorously outlined in "The Laws of Cartoon Motion."[18] So what's the point of teaching physics to animators if they blatantly violate the laws of motion on a regular basis?

Animators learn to draw realistic people and animals, with correct proportion and perspective, even though it's expected that they will distort these features. Real coyotes don't stand on two legs, yet Chuck Jones made sure that Wile E. Coyote's musculature and facial features created a "suspension of disbelief" that drew us into the story.[19] The study of anatomy is a well-established element of an artist's education and we believe the same principle applies to the study of physics. It is essential for animators to understand the principles of mechanics, optics, and other facets of the real world even if their animated worlds sometimes distort the laws of physics. As Disney animator Art Babbitt said, "Animation follows the laws of physics—unless it is funnier otherwise."

References

1. J. Kornblum, "Wanted by top studios: Future animators," *USA Today* (Aug. 8, 2005).
2. "Physics of Animation: Master Classes in Physics for Visual Artists," NSF CCLI Award #0737123.
3. Examples of animation tests by SJSU students may be found at: animationphysics.pbworks.com/Animation-Exercises.
4. The animation/illustration curriculum at SJSU also includes a number of computer animation courses and students complete a similar set of animation tests in those courses.
5. O. Johnston and F. Thomas, *The Illusion of Life: Disney Animation* (Disney Editions, 1995).
6. J. Lasseter, "Principles of traditional animation applied to 3D computer animation," *Computer Graphics* **21:4**, 35–44, (July 1987), (SIGGRAPH 87).
7. R. Cross, "Standing, walking, running, and jumping on a force plate," *Am. J. Phys.* **67**, 304–309 (April 1999).
8. www.cabrillo.edu/~dbrown/tracker/.
9. www.vernier.com/soft/lp.html.
10. Animators usually work with frame rate of 24 fps (frames per second), as in film, instead of 30 fps, as in video.
11. artphysics123.pbworks.com/.
12. M. Murphy, "This Way There Be Dragons," *New York Times* (May 25, 2010).
13. C. Webster, *Animation: The Mechanics of Motion* (Focal Press (2005).
14. H. Whitaker and J. Halas, *Timing for Animation* (Focal Press, 2009).
15. www.digicelinc.com/.
16. www.samanimation.com/.
17. W. Adams, K. Perkins, N. Podolefsky, M. Dubson, N. Finkelstein, and C. Wieman, "New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey," *Phys. Rev. ST Phys. Educ. Res.* **2,** 010101 (2006).
18. "O'Donnell's Laws of Cartoon Motion," *Esquire* (June 1980), reprinted in *IEEE Institute* **18**, 12 (Oct. 1994); remarque.org/~doug/cartoon-physics.html.
19. C. Jones and Chuck Amuck: *The Life and Times of an Animated Cartoonist* (Farrar, Straus and Giroux, 1999).

Assistant Professor **David Chai** *is an instructor of animation at San Jose State University and an independent animation director. He has worked on a variety of projects ranging from educational software, animation for television and video, commercial advertising, to independent films.*

Alejandro Garcia *is a professor in the Department of Physics and Astronomy at San Jose State and is the author of the textbook,* Numerical Methods for Physics. *He is currently on leave, working in the Center for Computational Sciences and Engineering at Lawrence Berkeley National Lab and in the Department for Artistic Development at Dreamworks Animation SKG.*
algarcia@ algarcia.org