Teacher as Cognitive Archaeologist: A Study of Teaching Animation Principles to Business Students—The Five-Frame Walk Cycle

Nick V. Flor
Anderson School of Management
University of New Mexico
nickflor@unm.edu

ABSTRACT
Animation is a difficult skill that takes years to acquire expertise. Today’s information systems students need animation skills in order to develop modern graphical apps. I analyze the industry-standard principles and processes for 2-D animation, and derive a 5-frame 3-D animated walk cycle that students can learn in an hour.

Keywords: Cognitive Archaeology, Distributed Cognition, Animation, Design Science

INTRODUCTION
As instructors we are the prototypical scientists of the artificial (Simon, 1996). Generally, scientists of the "natural" use methods to study existing systems—physical or biological—and derive theories that explain them. In contrast, scientists of the artificial use methods to study "man-made" systems such as cultural or socio-technical systems and design artifacts that benefit them. The field of design science has emerged recently, which provides seven guidelines for producing artifacts that qualify as information systems research (Hevner, March, Park, & Ram, 2004): (1) design as artifact; (2) problem relevance; (3) design evaluation; (4) research contributions; (5) research rigor; (6) design as search process; and (7) communication of research.

Teachers are scientists of the artificial. They design and implement artifacts in the form of instructional materials (or "learning artifacts") that students interact with, and that empower the students with new abilities for interpreting the world or for acting in the world. Often, one finds that the teachers whom students consistently rank highly in teaching evaluations, are those that have developed innovative learning artifacts.

Unfortunately, despite the emergence of fields like design science, many of these learning artifacts never get published because they do not fit the zeitgeist of rigor for scientific publications, which typically demand an experimental framework surrounding the learning artifact consisting of a pre-test, post-test, experimental & control groups, along with statistics to show significant learning.

For many instructors who are focused on student learning first and publishing second, this kind of experimental setup for the purposes of demonstrating rigor is overkill. This is especially true when the learning artifact confers abilities on the students that they did not possess before, and where the students’ work shows clearly that they have learned. An example would be a learning artifact that taught business students how to model human figures in 3-D, a difficult skill
normally taught to fine-arts students. To the instructor it is apparent that he or she has created an effective learning artifact, otherwise the students would not be able to produce their works.

Publishing such learning artifacts, that have clear effectiveness, would be beneficial to both instructors and students alike. Their worthiness as research publications should be judged on qualities other than experimental rigor. In this paper I would like to argue for an approach to writing-up teaching research that approximates the stages that many instructors go through in designing learning artifacts, and that provides reviewers the data necessary to determine the artifact’s research quality. In this approach the instructor as “scientist of the artificial” writes up descriptions of (1) the need for the learning artifact; (2) the source materials used in designing the learning artifact; (3) the learning artifact itself; (4) how the artifact was tested, with results that demonstrate success; and (5) a discussion of the limitations of the artifact & future research.

I call this approach to designing and writing up learning artifacts “cognitive archaeology” (Wynn, 2002). It is a kind of representational analysis (Flor & Maglio, 2004), but instead of studying the dynamic movement and transformation of representations during a task’s performance, one analyzes largely static representations. Like an archaeologist the researcher first studies existing materials for doing an activity (stage 2). The researcher then formulates theories of the cognitive skills needed to perform the activity embodying those theories in an artifact (stage 3). Finally, the researcher tests these theories in a manner that other researchers can replicate.

I demonstrate the application of this approach to the design of instruction for a 3-D animated walk cycle targeted at business students, and end with a discussion of the limitations of the approach.

**STEP 1. WHY INFORMATION SYSTEMS STUDENTS NEED 3-D ANIMATION SKILLS**

Most undergraduate programs in management information systems consist of two tracks: a management track and a development track. Generally, the management track teaches students how to effectively use people, technologies, data, and work processes collectively information systems to support and to achieve operational goals. In contrast, the development track teaches students how to setup or develop the technologies used by information systems, e.g., how to setup an e-commerce web site, or to develop the software for a social media phone app. This paper addresses a challenge that instructors in the information-systems-development tracks must continually face.

Specifically, because new technologies are constantly emerging, information-systems-development (hereafter “IS-development”) instructors must continually learn and create instructional materials for these new technologies. The difficulty of creating instructional materials depends on whether the new technology is “evolutionary” or “revolutionary.”

An evolutionary technology is one that from a cognitive perspective derives from existing technologies. An example of an evolutionary technology is C#, a programming language derived from the C-programming language, which Microsoft developed and mandated as the foundation for building web and desktop apps in the early 2000s. Aside from being derived from
C, which most IS-development instructors know, C# has many features similar to the Java or the C++ programming languages, which most IS-development instructors also know. Thus, it is not too difficult to adapt existing instructional materials to use C#.

In contrast, with a revolutionary technology an IS-development instructor cannot merely adapt existing knowledge and instructional materials. He or she must acquire new knowledge and create new instructional materials. An example of a revolutionary technology is a smart phone. In order, to teach students how to develop software applications (apps) for today’s smart phones, an instructor must not only teach business programming, user-interface design, and graphics programming; he or she must also teach 3D modeling and animation.

The teaching of 3D modeling and animation is not just for developing games. Almost all modern computational devices— including phones, tablets, laptops, and desktop computers—contain advanced graphics processing units (GPUs) capable of displaying 3D models and animating those models in real time. Smart phones alone have achieved over a 50% market penetration in the United States in less than a decade (Dediu, 2012). Such devices, combined with their cellular and internet connectivity, provide inventors an opportunity to develop useful and innovative apps not only for entertainment, but for education and business as well. Even if one does not develop a game, users are beginning to expect interfaces with 3D models and animations.

However, to teach students to develop apps that contain 3D models and animations, an instructor must first learn 3-D modeling and animation, and then create instructional materials. The problem is that the ability to model and animate 3-D figures requires artistic skills, which are largely foreign to the typical IS-development instructor who has specialized in teaching databases, applications programming, and web development.

Of course an instructor can always bring in a guest lecturer who specializes in the new technology or require that students take modeling and animation courses. However, this tactic is not optimal for 3-D modeling and animation. Just as it became necessary for IS-development instructors to teach user-interface design when all devices were capable of presenting graphical user-interfaces, it will become necessary to teach 3-D modeling and animation since all modern computation devices will be capable of presenting them; and students will be put at a competitive disadvantage by not having the knowledge in a form that is integrated with other IS-development concepts like networks, databases, and business programming.

**STEP 2. 2-D ANIMATION AS THE BASIS FOR DESIGNING 3-D ANIMATIONS**

One of the most common 3-D animations is that of a character walking, also known as a walk cycle. To design instructional material for a 3-D walk cycle, which was targeted at business students, I used as source materials the most popular printed references on 2-D animation, which were also highly recommended by professional animators. While there are printed instructional references on 3-D walk cycles, there are two problems with these references. First, the walk cycles are targeted at artists designing characters for movies and so these walk cycles are too complex to implement for business students with no background in art or aesthetics. My business students are non-artists designing characters for mobile devices, where the characters need not be complex in appearance and movement. The second and more important reason is that the 3-D references all cited principles and processes in 2-D animation as the foundation for...
their 3-D instruction. I reasoned, therefore, that by discovering the fundamental principles and processes in 2-D animation, I could design a walk cycle—an artifact—that business students could learn in a short amount of time.

An Overview of the Fundamental Process of 2-D Animation

The standard for professional animation emerged from the efforts of animators at the Walt Disney Studios in the early half of the 20th century. According to Disney animation veterans Frank Thomas and Ollie Johnston (1995), animation is “that ability to make single drawings come alive” (p. 146). They add that “To bring a character to life, it is necessary to imbue each single extreme drawing of the figure with an attitude that reflects what he is feeling or thinking or trying to do.” Animation comes from animus which means life or to live. Making it move is not animation, but just the mechanics of it (Thomas & Johnston, 1995, pp. 146-147).

A general process has emerged for animating actions (see Blair, 1994; Tezuka Productions, 2003, p. 5; Thomas & Johnston, 1995, p. 241; White, 2009, pp. 5-8; Williams, 2001, p. 167). Like any human process, there are individual variations. For example, suppose an animator is asked to animate the action of a person sitting down and taking a sip of coffee. There are four steps in this process.

1. The animator starts off by drawing “keys.” These are two or more drawings of the character, which are sufficient to show a viewer what is happening. In our example, one key could be the character sitting in a chair, hands to the side, with the coffee cup on a table; the second key drawing could be the character with the rim of the cup against his or her mouth.

2. After drawing the keys, the animator then draws “extremes.” Extremes are drawings in between the keys that detail how the action is performed (Thomas & Johnston, 1995, p. 241); they often depict changes in contact between parts of the character’s body and other objects in the story environment (Williams, 2001, p. 64). In our coffee example, one extreme could be the character placing both hands on the table, followed by another extreme of the character grabbing the coffee cup. Note that keys are special kinds of extremes that are sufficient for a viewer to understand the action.

3. The animator then draws what is called either a “breakdown” or a “passing position.” These are drawings halfway in between the extremes. For example, if one extreme is the a hand grabbing a coffee cup, and the other extreme is the cup on the lips of character, then the breakdown or passing position is a drawing of the character hold the cup halfway in between the table and the lips.

4. Finally the animator draws as many character poses as needed in between the extremes and passing positions, in order to present an aesthetically pleasing movement. These drawings are known as “in-betweens.”

Figure 1 depicts another example of key and extreme drawings for the action of a person finding chalk on the floor and writing on a board. Not depicted are the passing positions or breakdowns, that go between the extremes and keys, and the in-betweens, which are all other drawings.
An Overview of the Twelve Fundamental Principles of 2-D Animation

The process described in the previous section indicates when to draw character poses, but it says little about how the characters should be depicted. Twelve principles have evolved to guide the form of the drawings (Thomas & Johnston, 1995, pp. 47-69): (1) Squash and stretch—distorting a picture while maintaining visual volume; (2) anticipation—preceding a major action like throwing a ball, with a wind-up drawing that primes the audience for the action; (3) staging—laying out the characters and other objects in a frame to present the attitudes and actions as explicitly as possible to the viewer; (4) straight ahead action and pose to pose—drawing unplanned versus planned poses; (5) follow through and overlapping action—drawing subtle movements after a character has completed a major movement that prevents the character from stopping entirely; (6) slow in and slow out—drawing in-betweens close to the extreme poses; (7) arcs—drawing figures that represent motion along curved paths, such as a swinging hand; (8) secondary action—drawing accompaniments that harmonize with the main animation without detracting from it; (9) timing—the number of drawings to make; (10) exaggeration—drawing a caricature of realism to make a scene more believable or convincing to the viewer; (11) solid drawing—drawing with weight, depth and balance and minimizing twins; (12) appeal—drawing visually pleasing characters for viewers that hold their visual attention.

While many of these principles are not defined in an operational manner, they serve as a valuable language for providing feedback to improve an animation.

A 2-D Animated Walk Cycle

With the fundamental processes and principles known, we can focus on a specific action—the 2-D walk cycle. It is such a primary action that almost all animation books cover it (Blair, 1994, p. 98; Tezuka Productions, 2003, pp. 28-30; Thomas & Johnston, 1995, pp. 346-347; White, 2009, pp. 65-69). Williams provides the most detailed account of the walk cycle (Williams, 2001, pp. 102-117). He describes two methods for animating a walk cycle. The first method (contact positions) starts with the both feet just contacting the ground, and the second method starts with the front foot down (down position). We will cover just the contact position method. There are 9 drawings: contact (extreme), down (in-between), passing position, up (in-between), contact (extreme), down, passing position, up, contact. Figure 2 depicts the first five drawings of the...
walk cycle. Between each of the nine drawings can be up to three more in-betweens depending on the desired timing and smoothness of the walk, for a maximum of 33 drawings.

Figure 2. Two extremes (contact), one passing position, and two in-betweens that constitute half of a walk-cycle (Williams, 2001, p. 108). See text for a description. There can be up to 33 drawings (frames) in a walk cycle.

**STEP 3. THE LEARNING ARTIFACT: THE FIVE-FRAME WALK CYCLE**

There are two challenges in designing instruction for a 3-D animated walk cycle targeted at business students. First, business students generally have no drawing or modeling skills. Thus creating a figure to animate is problematic. I solved this problem by using the cognitive archaeology method to develop instructional material for modeling 3-D manikins or robots, similar in form to the 2-d figures depicted in the previous section (see Figure 11 for examples; Flor, 2012). Second, business students do not have the character drawing experience or the modeling experience necessary for depict body parts in the various angles needed for a walk cycle. For example, one cannot simply tell a business student to model a character with arms and legs swung wide apart; more precise directions are necessary for a consistent pose. Finally, the character animation module was part of a larger class on developing 3-D virtual worlds and I had only an hour to teach them how to animate a walk cycle that was sufficient for prototyping virtual world applications—having them model all 33 frames of a walk cycle was not an option.

These constraints combined with my understanding of the 2-D animation process, led me to design a walk cycle where the students only had to generate five frames—three extremes and two passing positions—and where the joint positions were specified precisely. In all, there were 24 frames in the walk cycle, but the computer automatically generated the 19 in-betweens. Students could create customized variations of the walk cycle by modify the values of joint positions subject to rules of symmetry, which I outlined for them. Students were lectured on the 12 principles of animation, should they want to improve the aesthetics of their character’s walk at a later date, but the principles were not central to the five-frame walk cycle. The following sections describe the five-frame walk cycle.

**Preparatory Steps**

Before the students could begin to animate the five-frame walk cycle, they needed to pose their 3-D characters (manikins) in a starting position consisting of the figure fully erect, with both arms down at the side
First Extreme (at Time Position 1)

Given the starting pose, students were told to rotate the following joints: (a) right shoulder, -25 degrees; (b) right hip, -10 degrees; (c) right knee, -45 degrees; (d) left shoulder, 25 degrees; left hip, 10 degrees. If students wanted a bigger or smaller angle for the shoulder or hip joints, they could experiment with different values subject to the constraint that corresponding joints had the same magnitude & opposite signs. I called this a symmetry constraint. So, for example, a student could try a 30 degree angle on the right shoulder, but it had to be matched by -30 degree angle on the left shoulder. Finally, students could vary the rotation angle for the right knee. Figure 4 depicts the first extreme.

Second Extreme (at Time Position 12)

At time position 12 students were told to rotate the following joints: (a) right shoulder, 25 degrees; (b) right hip, 10 degrees; (c) right knee, 0 degrees; (d) left shoulder, -25 degrees; left hip,
-10 degrees; (e) left knee: 45 degrees. Note that these are the same values as the first extreme, except the sides of the body are swapped. Figure 5 depicts the second extreme.

**Third Extreme (at Time Position 24)**

The 3-D modeling and animation software allows users to easily copy all joint positions at a given time position. For the third extreme, the students were told to copy and paste the joint positions from time position 1 into time position 24, which denoted the last frame of the walk cycle. Figure 6 depicts the third extreme.

**First Passing Position (First Breakdown at Time Position 6)**

With the extremes in place, the computer could automatically generate all the in-betweens poses. These in-between poses were simple linear interpolations of the joint values for the extremes, resulting in frames where the feet were underground. This happened between the first and second, as well as the second and third extremes. To solve this problem the students were told to go to
the passing position, or to the position where both legs were nearly vertical, and to lift the figure so that the feet were not underground. Figure 7 depicts the first passing position.

![Figure 7. First Passing Position (First Breakdown). See text for explanation.](image1)

**Second Passing Position (at Time Position 17)**

Similar to the first passing position, the computer generated frames where the feet were under ground in this instance between the second and third extremes. The students were told to go to the second passing position, or to the position where both legs were nearly vertical, and to lift the figure so that the feet were not underground.

![Figure 8. The Second Passing Position (Second Breakdown). See text for explanation.](image2)

Figure 9 depicts all five frames of the walk cycle in order.
STEP 4. THE TEST OF THE ARTIFACT AND RESULTS

Participants

Forty-three students participated in this study. The students came from a course offered in the Fall of 2010: MGMT 330 — Fundamentals of Virtual Business Programming. None of the students had any experience with animation prior to taking the course, which was a required course for junior and senior level students majoring in management of information systems.

Apparatus

For hardware, students used their personal laptops or desktop computers to run the 3-D modeling software. The software used was Maya 2010, which the students downloaded for free from the Autodesk.com website as part of Autodesk’s free software program for students and faculty. All 43 students reported successfully loading Maya onto their personal computers. The University’s online instructional system, WebCT, held a link to YouTube tutorial videos made by the instructor on the topic of modeling and animating 3D characters and this video was made available to all students.

Procedure

Students were given a lecture one week on how to model a 3-D character followed the next week by a lecture on rigging and animating a walk cycle for the manikin based on the five-frame walk cycle described earlier. I referred to the 3-D character as a “robot avatar” instead of a “manikin” since students are more familiar with the former. They were then given an assignment where they had a week both to create a personalized robot avatar and to animate a walk cycle for the robot avatar (see Figure 10 for the written instructions).

The students received the five-frame walk cycle lecture through YouTube videos that were embedded in the University’s online instructional delivery system, WebCT. The total time for the video lectures was approximately one hour.
Based on the Professor's Robot as taught in class:

1. Model a robot body in Maya (filename: body.mb).
2. Model a robot head in Maya (filename: head.mb).
3. Model a robot hand in Maya (filename: hand.mb).
5. Personalize your robot body parts.
6. Merge all the body parts to yield a robot avatar.
7. Animate a walk cycle for your robot avatar (filename: robot.mb).

Results

Of the 43 students, 33 turned in a walking robot, while 10 students did not turn in the assignment. Of the 10 students that did not turn in a robot, 7 did not turn in any assignments at all during the semester. Of the 33 students that turned in a walking robot, 3 did not save their files properly and only turned in a walking skeleton. However, when their work was checked in person, they indeed modeled and animated the robot correctly. If you remove the 7 students that did not show up to class, then 91.6% of the students successfully followed the procedure for modeling and animating the robot.
DISCUSSION AND CONCLUSION (STEP 5)

There are two main benefits of the five-frame walk cycle. First, it is learnable by non-artists in a short amount of time. Specifically, my information-systems-development students with no art experience and no 3-D animation experience prior to the course were able to view an hour-long instructional video on the five-frame walk cycle, and then model and animate a walking robot in under a week. The second benefit is that once learned, it enables students to add both 3-D user-controlled character (avatars) and computer-controlled (non-player) characters to their 3-D virtual worlds where the creation of prototype 3-D virtual worlds was the larger goal of my course.

The main limitation of the five-frame walk cycle is visually apparent. The five-frame walk cycle is a mechanical walk cycle that is not as aesthetically pleasing to viewers as a longer-frame walk cycle that incorporates the 12-principles of animation. However, students can always go back at a later time and add more frames or tweak the animations and the models to incorporate the 12-principles of animation. And it should be emphasized that the primary goal of the course was to give students the skills necessary to discover and prototype useful applications of 3-D virtual worlds not to create entertainment media. The fact that the walk cycle is not as aesthetically pleasing as a movie walk cycle does not prevent the development of prototypes.

I believe most instructors at some point in designing their teaching materials have engaged in this kind of cognitive archaeology where they analyze representational materials from a domain outside their area of expertise, then create learning artifacts for their domain based on the principles and processes discovered, and finally test these artifacts in the classroom, revising the artifacts based on various kinds of student feedback.

While some may not view this method as being on the same level of rigor as more established methods, successful application results in the development of a novel artifact that benefits a learning system, and also results in a rich-enough description of the artifact so that others can replicate and improve upon it. In the current case, the five-frame walk cycle enables students to develop avatars and computer-controlled characters as part of prototype 3-D virtual worlds something they could not do before. And the dissemination of knowledge about beneficial artifacts ought to be what we strive for in a science of the artificial.

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