The Posture of *Tyrannosaurus rex*: Why Do Student Views Lag Behind the Science?

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ABSTRACT

Today's students were born well after the dramatic scientific reinterpretations of theropod dinosaur stance and metabolism of the late 1960s and early 1970s. Yet, if asked to draw a picture of *Tyrannosaurus rex,* most of these students will likely draw an animal with an upright, tail-dragging posture, remarkably like the original 1905 description of this famous dinosaur. We documented this phenomenon by asking college ($n = 111$) and elementary to middle school students ($n = 143$) to draw pictures of *T. rex*. On each drawing, we measured the angle of the spine from a horizontal surface. An average angle of 50–60° was found in drawings from all ages, which is within about 5° of the 1905 posture at 57°. This is in striking contrast to images created by modern dinosaur scientists, which average between 0 and 10°. In an effort to explain this pattern, we measured *T. rex* images in a wide variety of popular books, most of them for children, published from the 1940s to today. Since 1970, a gradually increasing proportion has represented *T. rex* with a more horizontal back (lower tail angle). Thus, popular books, while slow to change, cannot entirely account for this pattern. The erect *T. rex* stance continues, however, to dominate other areas of popular experience, such as toys and cartoons, which most American children encounter early in life. We hypothesize that older-style images long embedded in pop culture could lead to cultural inertia, in which outdated scientific ideas are maintained in the public consciousness long after scientists have abandoned them. © *2013 National Association of Geoscience Teachers*. [DOI: 10.5408/11-259.1]

Key words: dinosaurs, paleoart, preconceptions, cultural inertia, reconstruction, draw-a-scientist

INTRODUCTION

Tyrannosaurus rex is without doubt the most famous species of dinosaur. It has starred in motion pictures almost since the beginning of the medium. It is the favorite dinosaur of many children; 5-year-olds regularly express an informed opinion on its habits. *T. rex* and *Escherichia coli* are probably the only organisms popularly known by their abbreviated Linnaean binomials.

Between its original description in 1905 and the early 1970s, most scientific and popular illustrations (including the very first one; Fig. 1A) of this dinosaur show it in a relatively erect posture, with its head held up and tail down, usually dragging on the ground (Fig. 1). The angle of the spine with the ground (the spinal angle) is greater than 50°. (The few notable exceptions include a painting by Charles R. Knight; Fig. 2). Beginning in the late 1960s, however, scientific opinion on the physiology and posture of theropod dinosaurs including *T. rex* began to change (e.g., Ostrom, 1969; Desmond, 1975; Bakker, 1986), and this dramatically affected the manner in which many artists portrayed them (e.g., Allmon and Ross, 2000; Paul, 2000, 2006; Debus and Debus, 2002; Allmon, 2006). These animals began to be interpreted by many dinosaur experts (and the artists who worked with or were influenced by them) as having been more agile and active, with the vertebral column oriented closer to the horizontal and the tail held well off the ground (Fig. 3). In this posture, the neck shows an S curve, with the head held farther back toward the hips (Horner and Lessem, 1993; Paul, 1988, 1998, 2005). This change in scientific opinion has been reflected in a massive outpouring of popular images of this horizontal posture (Fig. 3), including especially books and several highly popular feature films.

We authors collectively have more than 35 years of museum education experience and almost 60 years of experience teaching undergraduates in both majors and nonmajors classes. We have also served hundreds of K–12 teachers in professional development programs. Across these different learner populations, we have repeatedly noticed that, despite the wide availability of popular images of *T. rex* in the later, more dynamic posture, many students of all ages continued to conceive of *T. rex* in the old, tail-dragging posture. Effective instruction requires engaging learners' existing conceptions (e.g., Donovan and Bransford, 2005), and our anecdotal evidence indicated that drawing dinosaurs promised to offer a path to such engagement across a range of types of learners. In order to investigate the reality and origins of this anecdotal pattern, we therefore undertook a more formal survey of opinion to investigate how widespread such views are and why.

SCIENTIFIC VIEWS OF *T. REX* POSTURE

Before exploring popular conceptions of *T. rex*, it is important to understand the history and current status of scientific views. Specimens of *T. rex* were first collected by field parties from the American Museum of Natural History (AMNH) in 1900, and the species was described by the Museum's President, Henry Fairfield Osborn, in 1905. An almost-complete specimen of *T. rex* mounted in the Museum (AMNH specimen 5027) was the first ever put on

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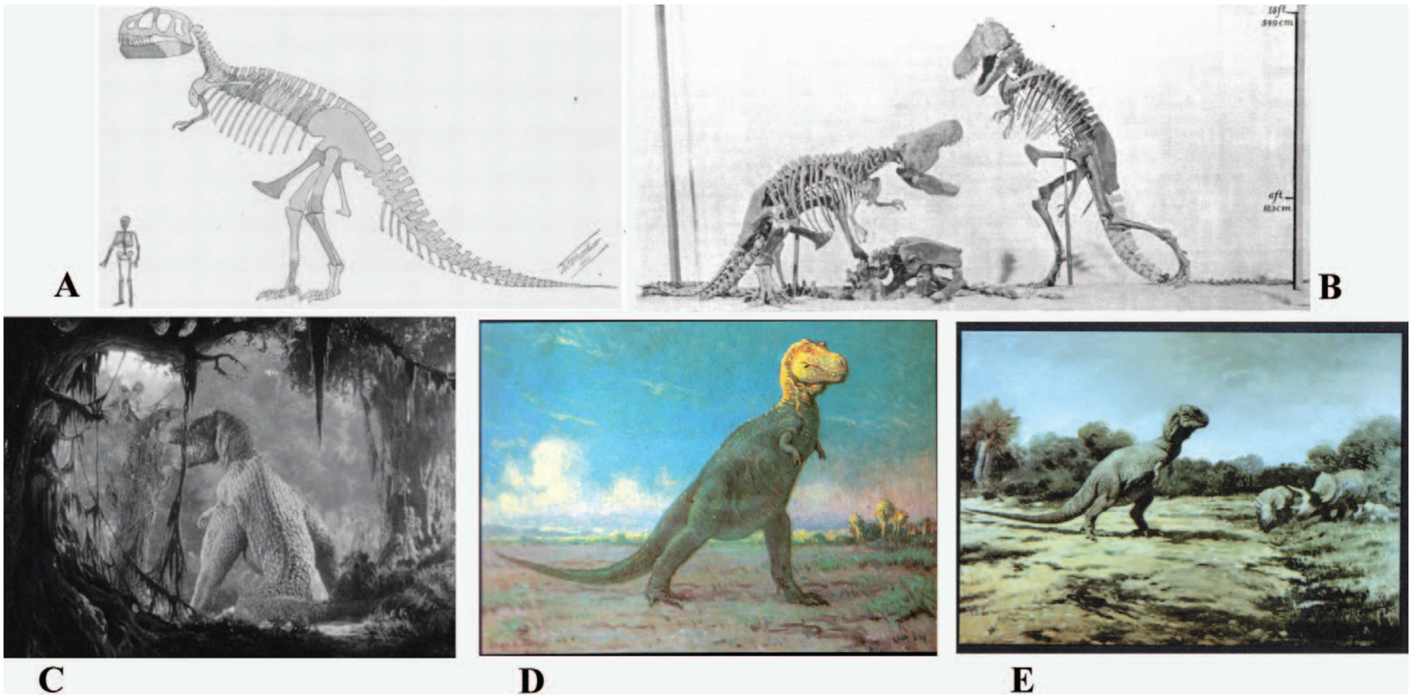

FIGURE 1: Reconstructed images of *T. rex* in the older, tail-dragging posture. (A) The original reconstruction of *T. rex*, drawn by W.D. Matthew. From Osborn (1905). (B) Model reconstruction of two *T. rex* skeletons in fighting poses. From Osborn (1913). (C) *T. rex* from the original 1933 motion picture *King Kong*. © 2012 Turner Entertainment; used by permission. (D) *T. rex* painting by Charles R. Knight (1946). Used by permission of the Natural History Museum of Los Angeles County. (E) *T. rex* painting by Charles R. Knight. Used by permission of the American Museum of Natural History.

public exhibit, and has had perhaps more influence on later perceptions of the posture of the species than any other. The specimen was mounted in 1915 by Barnum Brown, under the supervision of Osborn (Osborn, 1913; Brown, 1915; http://paleo.amnh.org/projects/t-rex/), and was the focus of very purposeful publicity by Osborn (Chambers, 2005). In addition to being seen by millions of visitors over almost a century, this mount has been figured in many textbooks and popular publications (e.g., Gregory, 1951; Colbert, 1961; Romer, 1966; Selsam, 1978), and been the subject of numerous artistic reconstructions, most famously by Charles R. Knight (Czerkas and Glut, 1982), which appeared in many popular books (e.g., Andrews, 1953; Geis, 1960). These views dominated both popular and scientific images of *T. rex* (as well as most other dinosaurs) for most of the 20th century (Allmon, 2006).

FIGURE 2: Charles R. Knight's famous painting "Tyrannosaurus Facing Triceratops" (ca. 1930), showing *T. rex* in both the traditional erect posture (background) and a more horizontal posture with tail off the ground (foreground). © 2012 The Field Museum, no. CK9T; used by permission.

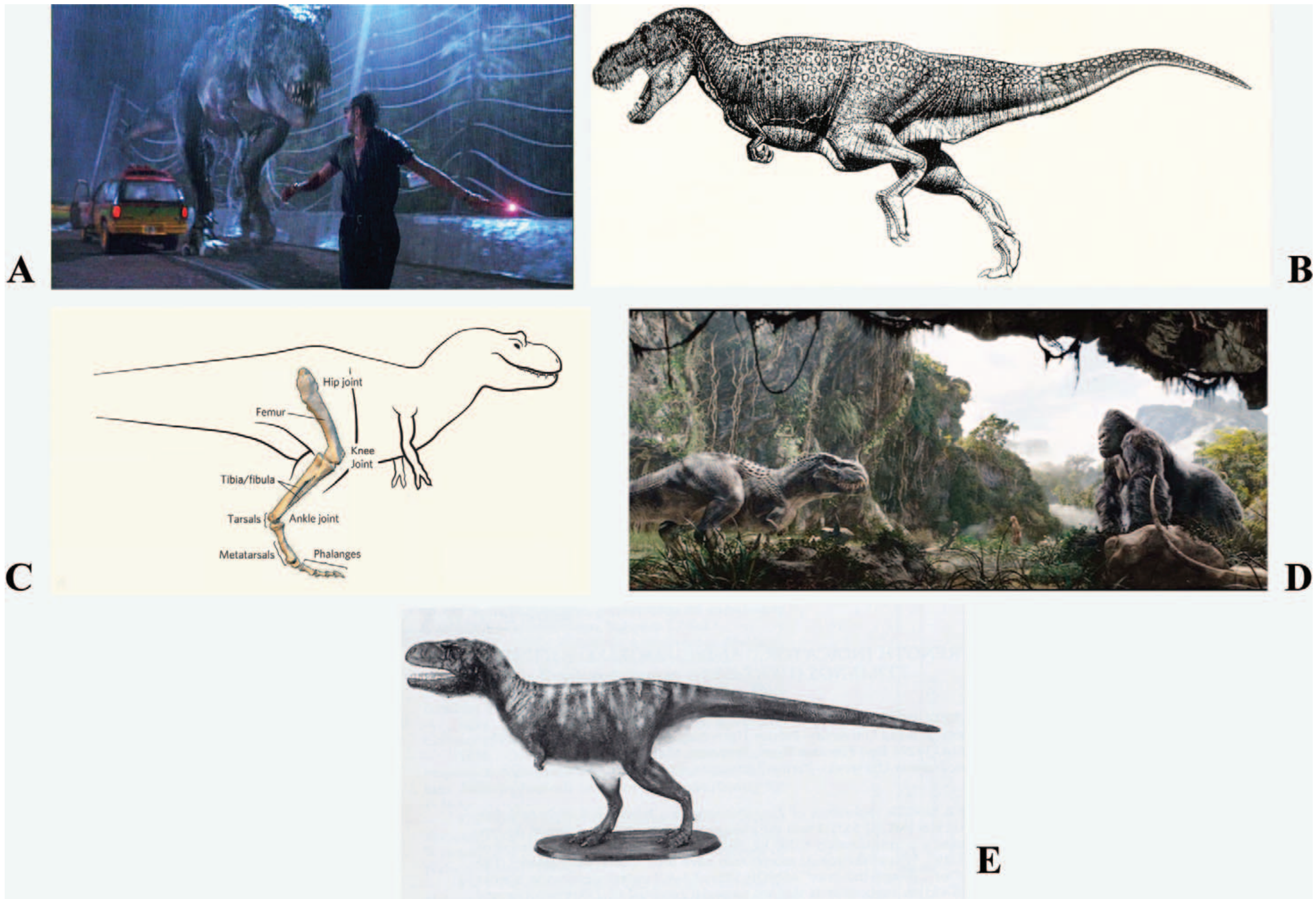

FIGURE 3: Reconstructed images of *T. rex* in the newer more horizontal posture. (A) *T. rex* as depicted in the first *Jurassic Park* film (1993). © 2012 Universal Studios; used by permission. (B) *T. rex* as depicted by artist Gregory Paul. From Paul (1988). © 2012 Gregory S. Paul; used by permission. (C) *T. rex* posture as sketched by Hutchinson and Gatesey (2006). © 2012 Nature Publishing Group; used by permission. (D) *T. rex* as depicted in the *King Kong* (2005). © 2012 Universal Studios; used by permission. (E) Reconstruction of *T. rex* by Matt Smith. From Farlow et al. (1995). Used by permission of the Society of Vertebrate Paleontology.

The older, tail-dragging posture of *T. rex* (in general) and the AMNH mount (in particular) were first criticized explicitly by Newman (1970), who noted that "the stance of the mounted specimen in New York has been accepted uncritically, and there have been no significant departures from this classic pose" (p. 119). Newman studied the stance of *Tyrannosaurus* during the mounting of a skeleton at the Natural History Museum, London, and compared his findings with the AMNH specimen. He pointed out that there was good evidence that at least part of the thoracic region of the vertebral column was rigid, and that the skull on the AMNH specimen was oriented so that articulation between the occipital condyle of the skull and atlas vertebra would have been difficult or impossible. "If the dorsal region is oriented horizontally," he wrote, "the 'swan neck' would permit the skull to be carried horizontally, and the flexible nature of the neck would also enable the animal to maneuver its head and reach the ground, an important factor when feeding" (p. 120). Newman did not, however, jump immediately to the extreme horizontal and agile pose; he concluded that *T. rex*'s gait "was an ungainly waddling rather than the formerly postulated majestic striding" (p. 123).

Newman's paper catalyzed the evolution of paleontological thinking about the posture and behavior of *T. rex,* contributing to the "dinosaur renaissance" of the 1970s and 1980s (Bakker, 1975, 1986; Desmond, 1975; Thomas and Olson, 1980; Lucas, 2007). By the mid-1980s, the majority of dinosaur paleontologists were convinced that many dinosaurs, and probably most theropods, were much more dynamic and active than previously thought. *T. rex* in particular was regularly reconstructed in books authored by paleontologists in a highly active and agile posture, with the vertebral column close to horizontal and able to move very quickly, perhaps even run, after its prey (e.g., Bakker, 1986).

By the 1990s, however, a new wave of paleontological research focused on various aspects of *T. rex*'s biology, including its posture and locomotion, resulting in revision of some of the most extreme interpretations of the renaissance period. For example, although Paul (1988, 1998, 2005) reconstructed *T. rex* in a hyperactive, very bird-like pose, with vertebral column almost ramrod straight and horizontal, with knees flexed, and the first *Jurassic Park* film (1993) featured a scene in which a *T. rex* almost outran a Jeep in fourth gear (ca. 72 kmph [45 mph]), more recent studies—

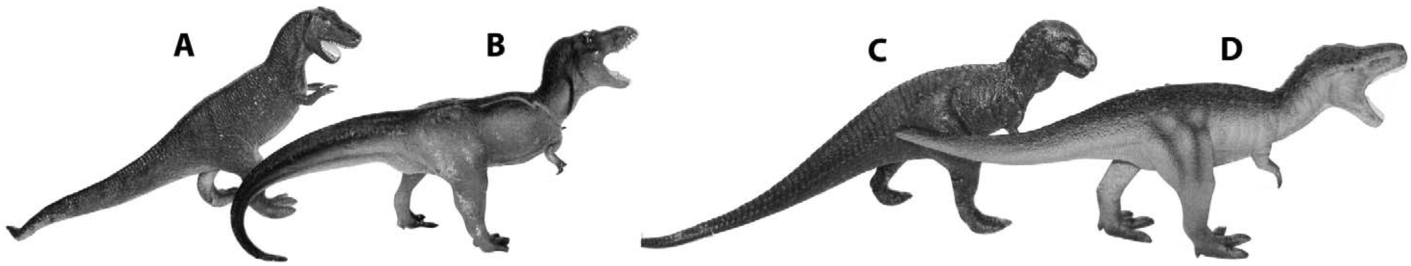

FIGURE 4: Old and new versions of *T. rex* from lines of realistic plastic figurines produced for two major natural history museums. (A, B) Produced for the Carnegie Museum of Natural History by Safari, Ltd., (A) 1988, (B) 1998. (C, D) Produced for the Natural History Museum, London, (C) 1977 by Invicta Plastics, (D) ca. 2006 by Toy Way. Collection of the Paleontological Research Institution.

while certainly not arguing for the older, tail-dragging pose—have emphasized the difficulties of reconstructing ancient behavior with precision, and several have reached more conservative conclusions about *T. rex* posture and speed. Farlow et al. (1995), for example, argued that a fall while running at high speeds would be lethal for an animal as large as *T. rex* (6,000 kg [13,200 lb]). They suggested that *T. rex* was "unlikely to have been as fast or maneuverable a runner" as the fastest living running animals, such as the ostrich, and they estimated that its top speed was probably no more than 50–55 kmph (30–35 mph), similar to the sprint speed of the modern African elephant. Farlow et al. (1995) introduced a new life restoration (by coauthor Matt Smith; Fig. 3E) that, while perhaps not as lithe and limber as those of Bakker (1986, 1987) or Paul (1988), is still very far from the tail dragger of old. Smith's restoration is cited by *T. rex* specialist Jack Horner as "the way I think *T. rex* really looked" (Horner and Lessem, 1993, p. 97).

The conclusions of Farlow et al. are supported by an ongoing series of studies by John Hutchinson and colleagues, who analyzed the biomechanics of *T. rex* in detail by using computer simulations. Hutchinson emphasizes that it is a misleading oversimplification to dichotomize the limb posture of *T. rex* as either columnar, meaning anything that is basically vertical like an elephant's, or flexed, meaning anything else. "Somewhere along the way, people have lost sight of the fact that a limb posture is a point on a continuum" (Hutchinson, 2007). Hutchinson and colleagues argue that more upright postures are more plausible than completely horizontal ones, and that *T. rex* was not an exceptionally fast runner, probably not exceeding 40 kmph (25 mph) (Hutchinson et al., 2002, 2005). Hutchinson and Gatesey (2006) published a simple figure (Fig. 3C) that Hutchinson (2007) suggests is "a little more flexed than is likely, but pretty close" to what he thinks *T. rex*'s posture most probably was. Not everyone agrees with these revisions. Other authors continue to maintain that *T. rex* displayed a very bird-like, flexed-leg stance and could run at speeds approaching 60 kmph (40 mph) or more (e.g., Christensen, 1998; Paul, 1998, 2005).

In the larger context, however, these are small disagreements. Compared to pre-1970 restorations of *T. rex,* all of these recent interpretations agree on the essential aspects of its posture. Although researchers disagree about details, such as the exact angle of the vertebral column, the flexure of the legs while standing and walking, and the maximum speeds at which the animal could move, *T. rex* is seen today by paleontologists as having been active and alert, with a tail-off-the-ground posture that allowed it to move and pursue its prey with considerable agility.

T. REX POSTURE IN POPULAR CULTURE

The changes in the scientific views of *T. rex* and other dinosaurs during the 1970s and 1980s quickly became manifest in numerous artistic reconstructions by a new generation of dinosaur artists, including John Gurche, Gregory Paul, Mark Hallett (see, e.g., Crumley, 2000; Debus and Debus, 2002). Appearance of these new images, furthermore, coincided with a number of other cultural currents that substantially increased their distribution to and impact on the general public, including technological advances in computer graphics (e.g., Brilliant, 2002), the increased commercialization of fossils (e.g., Marston, 1997; Simpson, 2000; Long, 2002), and debates about collecting fossils on public lands (Secretary of the Interior, 2000). As a result of all of these developments, dinosaurs in general and *T. rex* in particular achieved more public attention than Osborn could ever have dreamed of (e.g., Gould, 1989, 1993; Sanz, 2002).

Movies played a major role in this popularization. *T. rex* had been featured in movies since the early 20th century, most notably the silent films *The Lost World* (1925) and *King Kong* (1933) (see, e.g., Glut, 1980; Fig. 1C). Advances in computer technology, however, now allowed the new dynamic interpretations of dinosaurs to be visualized on the screen with unprecedented realism. As a result, *T. rex* was able to reach an animated apotheosis of action in a series of blockbuster motion pictures including *Jurassic Park* (1993) and *King Kong* (2005). The number of people who have seen the three *Jurassic Park* films alone is suggested by their worldwide gross ticket sales (as of 2006) of more than $2 billion (www.the-numbers.com/movies/series/JurassicPark.php). All of these recent films show *T. rex* with an almost completely horizontal spinal angle (Fig. 3).

The change in scientific views of dinosaur posture was also reflected in at least some dinosaur toys. Realistic plastic dinosaur figurines became widespread in the 1950s and 1960s (Cain and Fredericks, 1999; Tanner, 2000), and as late as the 1980s, most lines generally reflected the tail-dragger posture. In the 1990s, however, at least two higher-end lines of these figurines began to produce revised versions that reflected the more horizontal posture (Fig. 4).

Many major natural history museums in the U.S. also responded to the change in scientific views of dinosaurs with new mounts of *T. rex* skeletons, all in more or less dynamic, active, non–tail-dragging postures (e.g., Royal Tyrell Muse-

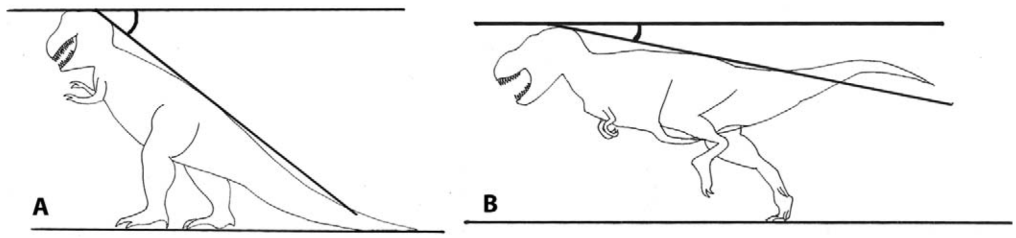

FIGURE 5: Outline sketches of the two extreme reconstructed postures of *T. rex*, showing how spinal angle was measured.

um of Paleontology, Drumheller, Alberta, in 1985; Academy of Natural Sciences, Philadelphia, PA, in 1986; Denver Museum of Nature and Science in 1987; Museum of the Rockies, Bozeman, MT, in 1993; University of California Museum of Paleontology, Berkeley, CA, in 1995). Even the venerable AMNH mount came down in 1992, reappearing in the new posture in the completely new dinosaur halls in 1994 (see Dingus, 1996). Cumulatively, these museums are visited by millions of people annually.

Finally, against this scientific, artistic, and technological backdrop played out the protracted legal and financial saga of the most complete *T. rex* skeleton ever found (nicknamed Sue) in the courts and media (Fiffer, 2000). The story culminated in the purchase of the specimen by Chicago's Field Museum for $8.3 million, provided largely by corporate giants McDonalds and Disney. Sue was prepared, studied, and mounted as a centerpiece exhibit in the Field Museum, again with intense media attention. She also became a new feature attraction at Florida's Disney World. In these venues, the more dynamic interpretation of *T. rex* has also been seen by millions.

PUBLIC CONCEPTIONS OF *T. REX* POSTURE

Methods

We assessed public conceptions of the posture of *T. rex* by surveying undergraduate students at Ithaca College and precollege (grades 1–12) student and family visitors to the Museum of the Earth at the Paleontological Research Institution (PRI), both located in Ithaca, New York, asking them simply to "draw a *T. rex*," before the students had any discussions with PRI educators about dinosaur posture or the purpose of the activity.

Participants were chosen out of convenience, that is, to obtain data from students of a broad set of ages, data were collected during an interval of time when participants were already engaged in dinosaur-related educational programming. Clearly, an audience of undergraduate students taking a nonmajors' geology class and children who visit a natural history museum is a nonrandom sample, and the study is non-experimental. The study did not involve testing instructional methods, but its findings are suggestive of common existing conceptions and how to unearth them. Engaging learners' understandings is essential to effective instruction (Donovan and Bransford, 2005). Because all drawings evaluated were done before instruction in both the museum and in the classroom settings, it is possible that a post-instructional data set would yield very different results.

After making the drawings, participants were told that we would like to keep their pictures toward collecting data for a study. To anonymize the data, during the data collection process all student names and identifying information were removed from drawings by a research assistant with no personal connection to the subjects.

We quantified the posture in the drawings by measuring the spinal angle, the angle of the vertebral column with the horizontal (Fig. 5). Specifically, the angle was measured between a line from the top of the neck (the anterior cervical vertebrae) through the hip (approximately the sacrum) and a horizontal line along the ground (generally the base of the paper). One individual made all the measurements, for internal consistency in approach. Relatively erect postures have high spinal angle values (Osborn's 1905 illustration [Fig. 1A] = 57°; 1933 version of *King Kong* [Fig. 1C] = 49°); relatively horizontal postures have low values (Smith's 2003 reconstruction [Fig. 3E] = 15°; 2005 version of *King Kong* [Fig. 3D] = 0°). Examples of student drawings are shown in Fig. 6.

Participants were not asked why they had drawn their *T. rex* in the way they had; we assume that most participants had been exposed over their lifetimes to many images of *T. rex* and similar theropods that would have influenced their conception of what a *T. rex* looks like. Instead, we surveyed the sources of the sorts of images to which participants would likely have been exposed. We assessed potential

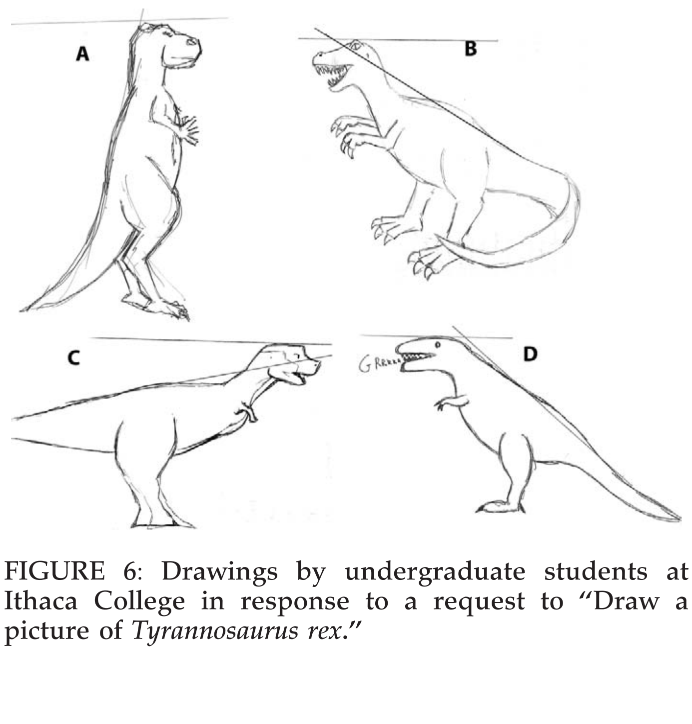

FIGURE 6: Drawings by undergraduate students at Ithaca College in response to a request to "Draw a picture of *Tyrannosaurus rex*."

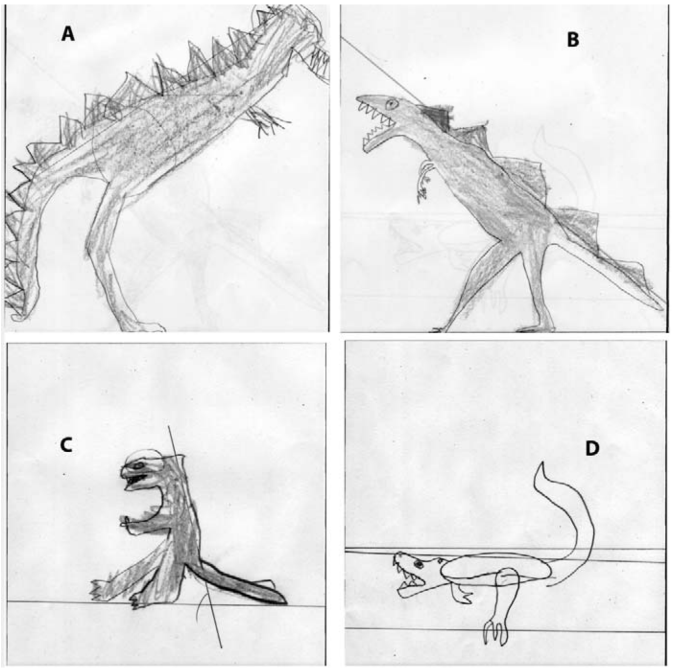

FIGURE 7: Drawings by precollege students visiting the Museum of the Earth in response to a request to "Draw a picture of *Tyrannosaurus rex*."

sources of public views on *T. rex* posture by surveying popular books, films, and other material culture items (e.g., toys), measuring the posture of *T. rex* images with the same method used on the student drawings. While other anatomical traits such as tail and head position are relevant to posture, spinal angle most simply captures the postural change we sought to document.

College Students

The students in Ross's History of Life class at Ithaca College undertook the activity as a pre-assessment of dinosaur knowledge just before beginning a month-long unit on dinosaurs. The students in this class are almost all nonscience majors, with few if any previous college-level science courses. (Any postassessment changes to the students' perceptions of *T. rex* posture are not analyzed here.) Students were surveyed in spring 2005 and spring 2006, resulting in a total of 111 measured drawings (Fig. 6). Gender was not recorded, but the classes were roughly evenly split between males and females.

Precollege Students

Between 2005 and 2007, precollege students who were making class visits to the Museum of the Earth to participate in dinosaur education programs were surveyed. The activity was used as a pre-assessment and mechanism for discussing with students the nature of science (tailored to age level). In total, 205 drawings were measured (Fig. 7); of these, 143 drawings came from school groups, and 62 from children visiting with caregivers. The students who made these drawings ranged in age from 5 to 15, with over 91% between 7 and 13. Gender was not recorded, but students visiting with school classes and children visiting with families are typically close to evenly split between males and females. The groups came from schools representing a variety of geographic and socioeconomic backgrounds (urban to rural, 14–43% reduced or free lunch); school demographic data is presented in Table I.

Popular Books

The posture of *T. rex* was measured on 126 images taken from 92 popular books on dinosaurs, published between 1941 and 2005 (see the Appendix) (Fig. 8). Criteria for including an image in the data set included that: (1) the image had to have appeared in a book published in English, primarily about dinosaurs, mainly for a nonscientific, general audience; and (2) the image had to be clearly identified in the book as *Tyrannosaurus*. Within these criteria, we were not selective; we measured every image from every book we could easily locate.

Other Popular Images

The posture was measured of a total of 56 *T. rex* in toys, games, puzzles, household items (e.g., cookie cutters), clothing, models, comics, and motion pictures dating from 1930 to 2008 (Fig. 9). All objects or images had to be clearly identified as *Tyrannosaurus,* and their date of creation had to be known to within 5 years. The toys were in the authors' personal collections or the collection of PRI's Education Department, or images were taken from retail sites on the Internet. Film images were taken from the Internet or books (e.g., Glut, 1980). Other items came mostly from images taken from the Internet.

Analysis

All data were binned and plotted at 10° intervals. Median posture angles were computed for the college students and precollege students as a group (Fig. 10). We used median angles rather than mean for this and other comparisons, because we were seeking to document drawings of typical participants, those in the middle of the respective distributions they represent; averages in contrast might be greatly influenced by outlier values of a few unusual drawings. Precollege data were also plotted against age (Fig. 11). For book data, a linear regression was fit through the post-1970 data, and to minimize the impact of outlying values in irregularly distributed data, the median angle was computed for each year of publication for which we have data ($n = 0$–10) and a linear regression was performed on these medians (Fig. 12). For other popular images (non-book items), we did not have precise age data for many objects, so data were binned into three intervals: pre-1970, the 1970s (the transitional decade in scientific interpretation), and post-1970s, and computed medians for each of these time intervals (Fig. 13). For comparison, the book data were binned in the same way (Fig. 14). The year 1970 was chosen as a transition, because it came immediately after the publication of Ostrom's description of *Deinonychus* (1969), and just before its influential interpretation by Bakker (1975). To compare the statistical significance of differences between distributions of spinal angle data, two nonparametric tests were used, the Mann–Whitney U (MW) test to compare the position (approximately speaking, the median) of distributions, and the Kolmogorov–Smirnov (KS) test to take also into account differences in distribution shape.

Results

Students

The survey results (Figs. 10 and 11) show that the students in the sample produce an image mimicking pre-1970s images (i.e., high spinal angle) of *T. rex* posture. The median spinal angle of drawings of precollege students (median $= 46°$, $n = 205$) was slightly lower than college students (median $= 54°$, $n = 111$) and there was a statistically significant difference between the position (MW $P = 0.006$) and shape (KW $P = 0.009$) of the two distributions. Most drawings in both groups, however, were well within the range of the older, tail-dragging poses (63% of precollege were $\geq 40°$, as were 72% of college). Among precollege students for which we have age data (143 of 205), there was substantial variation within all age groups, with no obvious trend: among 5–9 year olds, median $= 44.5°$ ($n = 54$), and among 10–15 year olds, median $= 45°$ ($n = 89$); there was no statistically significant difference between these two groups (MW $P = 0.488$, KS $P = 0.294$) (Fig. 11). There was, however, a relatively higher frequency (though still low) of very low back angles ($< 20°$) among 5–9 year olds (20%) than among 10–15 year olds (10%) or college students (4%).

Books

Before the 1970s, spinal angles of illustrations in popular books were mostly $> 40°$ (Figs. 12 and 14), and there was a modest statistically significant difference between books from the 1970s ($N = 20$) and pre-1970s ($N = 13$) (MW $P = 0.089$, KS $P = 0.042$). Beginning in the late 1970s, however, median spinal angles of these illustrations began to decline fairly steadily, though substantial variation among illustrations remained through the 1970s and 1980s. Since 1980, 58% of the book images measured were less than 30°, and since 1990, 67%; in contrast, since 1980, only 22% have been $\geq 40°$ and since 1990, only 13%. There is a strong statistically significant difference between books from the 1970s ($N = 20$) and those afterward ($N = 95$): MW $P < 0.001$, KS $P < 0.001$), and a linear regression through the highly variable data since 1970 shows a decline of about 20 degrees per decade over the entire interval ($R = 0.430$, $P < 0.001$); Fig. 12 shows a plot through the median data for each year ($R = 0.738$, $P < 0.001$).

Pop Culture Images

In contrast to books, other popular images (such as toys and films) show relatively little change since the 1950s (Fig. 13). The median angle of the items measured from before 1970 was 46° ($N = 8$), that for the 1970s was 44° ($N = 8$), and that for 1980 onward was 41° ($N = 46$). There is no statistically significant difference between the objects before 1970 and the 1970s (MW $P = 0.600$, KS $P = 0.929$), and while there could have been some change since then, in fact there is no statistically significant difference between objects from the 1970s and before ($N = 16$) and since then (MW $P = 0.489$, KS $P = 0.574$). Old-style, tail-dragging forms are still dominant; even after the 1970s only 30% of the measured items have had a stance less than 30°, and 52% have an angle $\geq 40°$.

DISCUSSION

We have been surprised—and the data confirmed our initial observations—that typical contemporary students

TABLE I: Demographic data of participating school groups.[1]

School district	School	Grade	n	American Indian, Alaskan, Asian, or Pacific Islander (%)	Black (not Hispanic) (%)[1]	Hispanic (%)[1]	White (not Hispanic) (%)[1]	Eligible for free lunch (%)[1]
Margaret Central School District	Margaretville Elementary School	1st	21	1.3	1.3	11.2	86.1	37.0
Owego-Apalachin Central City School District	Owego Elementary School	2nd	37	0.9	4.9	1.1	93.1	40.4
Ithaca City School District	South Hill Elementary School	4th-5th	15	4.4	14.0	4.7	77.0	14.0
Elmira City School District	Ernie Davis Middle School	7th	70	2.4	23.3	3.0	71.3	43.3
Ithaca College Biology Department	History of Life (nonmajors course)	College	111	4.7	3.5	4.7	87.1	N/A

[1]Demographic data are for the respective schools and college, not from the specific classes attending the Museum of the Earth. K–12 data are from 2004-05 New York State School and District Report Cards, available at: http://www.p12.nysed.gov/repcrd2005/; college data from http://www.cappex.com/colleges/Ithaca-College-191968.

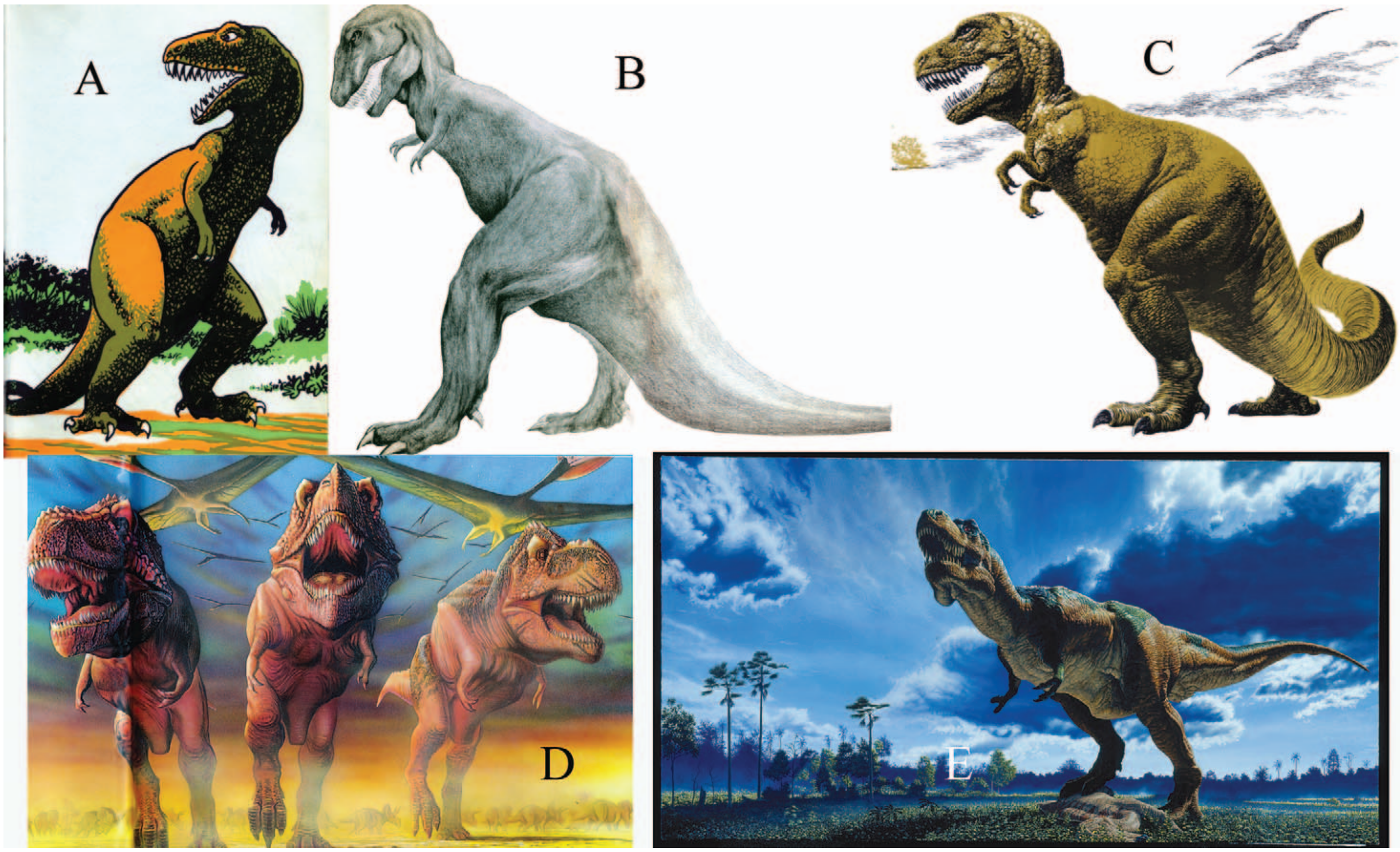

FIGURE 8: Representative images of *T. rex* from popular books. (A) From Frost (1956). Used by permission of Maxton Publishers, Inc. (B) From Geis (1960). Used by permission of Grosset and Dunlap, A Division of Penguin Young Readers Group, A member of Penguin Group (USA). (C) From Ravielli (1963). © 2012 Anthony P. Ravielli. Used by permission of the Ravielli family. (C, D) From Rey (2001). © 2012 Luis V. Rey. Used by permission. (E) Painting of *T. rex* based on Sue, by John Gurche (2000). © 2012 The Field Museum. Used by permission.

produced firmly pre-1970s images of *T. rex* posture, despite having all been born well after 1980, when the change in *T. rex* stance had become common in dinosaur reconstructions. Despite hugely popular films such as *Jurassic Park,* and updated museum exhibits visited by millions of people, most of today's students see the world's most popular dinosaur largely the way Henry Fairfield Osborn did a century ago. Several decades after theropod stance was reinterpreted a small percentage of precollege students draw *T. rex* with a low spinal angle, more than in the college group, but to the degree that this might be a change in public perception, it is remarkably slow in coming. At least in this respect, it is almost as though the dinosaur renaissance never happened. What can account for this pattern?

We originally hypothesized that outdated illustrations in popular books (not all of which are created with input from dinosaur scientists) might be responsible, but our results suggest that this cannot be the complete explanation. Images in popular books have shown increasingly modern postures over the past three decades (Figs. 12 and 14). While perhaps a bit slow to catch up to the science, popular books today mostly mirror current paleontological views of *T. rex* posture. Newer motion pictures likewise have shown and even embrace new interpretations of *T. rex* posture and behavior.

Other popular images (other than films), however, are a different story. The older, erect, tail-dragging stance for *T. rex* continues to dominate other areas of popular experience, such as toys, clothing, and cartoons (Fig. 9). The spinal angles shown by these images have remained essentially unchanged since the 1960s. It might be argued that, at least for free-standing toys, it is structurally necessary to have the tail close to the ground so that the figure can have a tripod stance for support, and so this might produce a bias toward the older posture. This cannot, however, be the entire explanation for our results, since the higher spinal angles are also present in numerous two-dimensional popular images as well. Perhaps the most popular of all popular versions of *T. rex* is Barney, the purple Public Television Service dinosaur who first appeared in 1987 and became the center of a far-reaching media and merchandising juggernaut (see, e.g., www.answers.com/topic/barney-tv-dinosaur). Barney clearly stands in the old-fashioned, erect posture (i.e., a spinal angle of ca. 90°), although his tail is usually off the ground (as tail length is too short to be to scale) (Fig. 9B).

The data presented in Figs. 12–14 are only for images labeled "*T. rex*" or "*Tyrannosaurus*." There exists in popular culture a vast array of more generic theropod dinosaur images that are not explicitly labeled with a particular genus or species name, and these images are

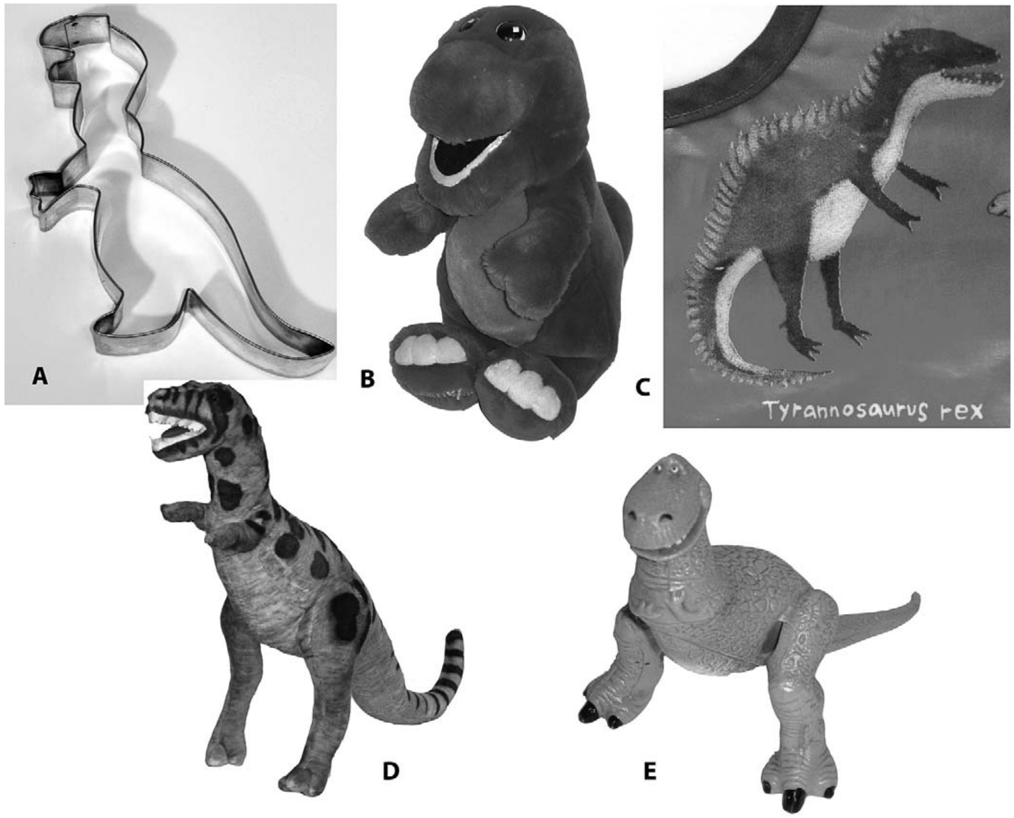

FIGURE 9: Representative contemporary toys and other merchandise featuring reconstructions of *T. rex* in the older, tail-dragging posture. (A) Common cookie cutter, ca. 1995. (B) Plush Barney puppet by Dakin, 1992. (C) Plastic baby bib by Crocodile Creek, ca. 2005. (D) Plush *Tyrannosaurus rex* by Melissa and Doug, ca. 2005. (E) *Toy Story*'s Rex figurine by Hasbro, ca. 1995. All items in the collection of the Paleontological Research Institution.

even more frequently in the older posture. Even casual examination of many everyday products bearing unnamed dinosaur images reveals a common pattern: the great majority of images fall into three general morphological categories: long-necked sauropod, bipedal theropod, and horned ceratopsian (Fig. 15). (These are, probably not coincidentally, the three most common dinosaurs listed by the college students we have surveyed when asked to ''list as many dinosaur names as you know'': *T. rex* is first, followed by *Brontosaurus/Apatosaurus*, followed by *Triceratops*.) These images have a number of features in common. First, they are more generalized and less detailed. Second, they are in many respects neotenic (or, more accurately, paedomorphic); that is, they are more cartoonish and juvenilized in their morphology, in features such as their generally large heads and eyes, short limbs, and chubby body shape (see, e.g., Gould, 1979; Figs. 9 and 15). In the case of the theropod image morphotype, these features tend to be more readily accommodated in a form with high spinal angle, with the animal squatting on its haunches.

Despite the widespread presence of modern images of *T. rex* in films and recent books, not all American children read dinosaur books, watch *Jurassic Park,* or visit natural history museums. We suggest that many more people encounter dinosaurs in more everyday settings: on their pajamas, chicken nuggets, and stuffed animals, for example. These cute paedomorphic images are especially common in products for very young children. From a child's earliest years, he/she might therefore learn to associate such forms with the word *dinosaur*. Thus, it could be these images that ultimately have a greater influence on their perception of what dinosaurs looked like than the more accurate reconstructions children see later.

Once conceptions form, they tend to be tightly held, and with dinosaur media for young children being populated by tail draggers the dominance of this kind of image makes more sense. While the drawings could make it look like the participants do not know much about *T. rex* posture, it is also interesting to note that it does look like almost everyone knows something about this creature that lived a long, long time ago. Most students apparently know that the *T. rex* had bigger hind legs than forelegs; and that they had big, sharp teeth and a long tail. In other words, *everyone* (in the sample) *knows something about dinosaurs, and* T. rex *in particular*. In a society often characterized as scientifically illiterate, it is remarkable that a large portion of the population has any conception of the basic morphology of creatures that walked the Earth millions of years ago. In this context, the observation that they do not hold the current scientific conception of theropod posture, might seem inconsequential; it does, however, suggest how certain kinds of scientific information wend their way to the general population. Specifically, it points to the importance of understanding and engaging learners' preexisting conceptions for teaching for scientifically accurate and durable understandings.

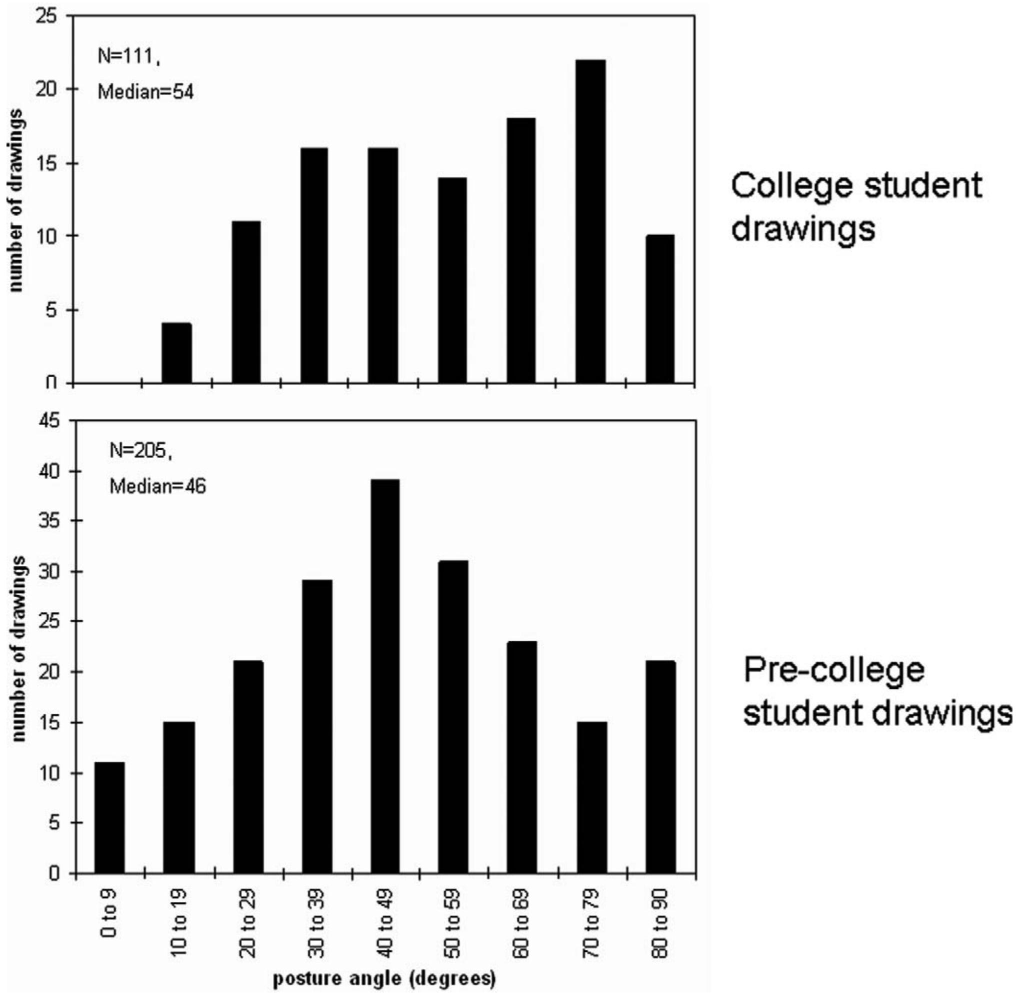

FIGURE 10: Stance angle for *T. rex* drawings by Ithaca College students (median = 54, median absolute deviation [MAD] = 16) and by a variety of precollege students (ages 5–15) (median = 46, MAD = 16). Very few of the drawings in either group depict a modern interpretation, but there was a higher proportion of these in the precollege students.

While early conceptual change and misconceptions research frequently portrayed misconceptions as something to replace (Posner et al., 1982), more recent work treats the existing conceptions as something like the raw material for building understanding of the scientific conception. Misconceptions are "both flawed and constructive" (Smith et al., 1994). Assessment typically shows a mix of scientifically accurate and inaccurate ideas, as is the case here. Clearly, these students, no matter the level, are not blank slates. The goal of instruction relevant to this study should therefore not

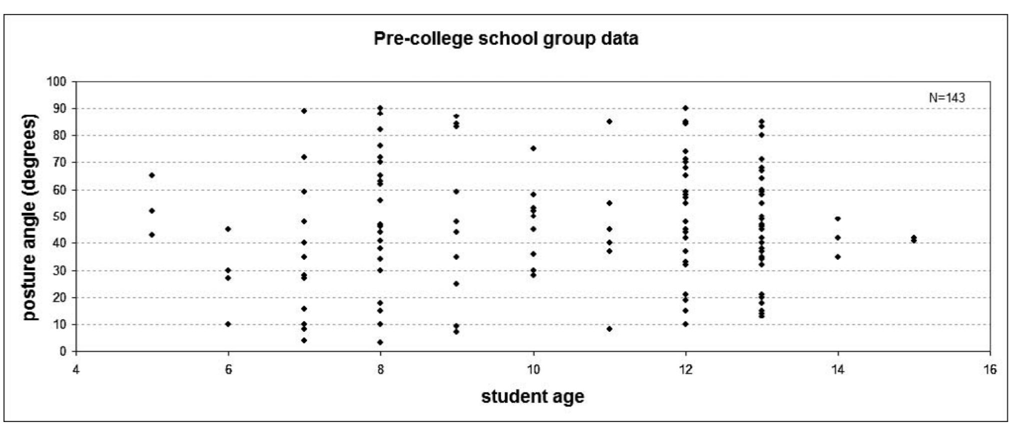

FIGURE 11: Stance angle for *T. rex* drawings plotted against age of precollege student participants from school groups. There was no statistically significant relationship between age and posture angle ($n = 143$, $R^2 = 0.0044$).

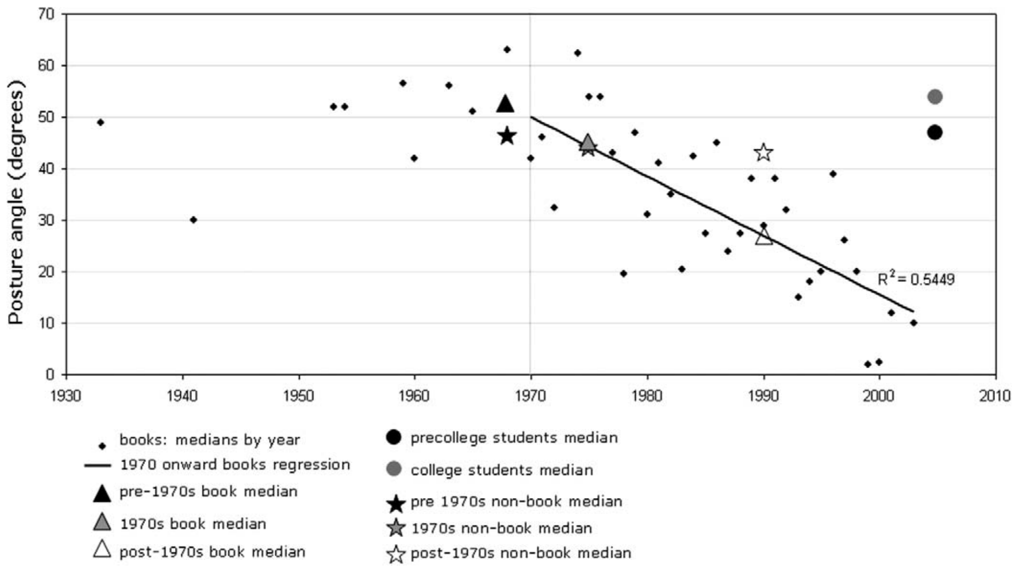

FIGURE 12: Results of analysis of spinal angle of images of *T. rex* reconstructions in popular dinosaur books from 1941 to 2006 compared with angles measured from student drawings and toys and merchandise, 1960s–present.

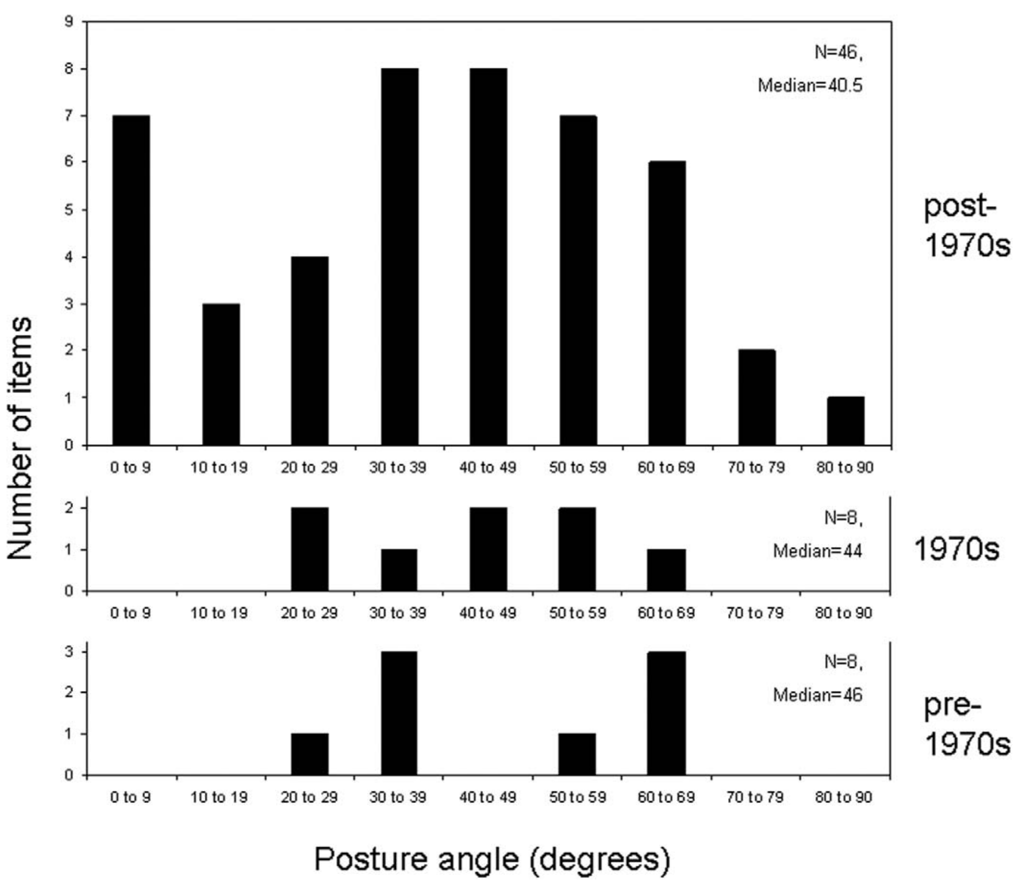

FIGURE 13: Distribution of stance angle in *T. rex* non-book items in time interval before 1970 (before scientific reinterpretation) (median = 46, MAD = 11.5), in 1970s (median = 44, MAD = 8), and since the 1970s (median = 40.5, MAD = 16). There is no change in the first 10 years after the reinterpretation. The interval after the 1970s does have objects with low angles consistent with a modern interpretation, but this interval also contains large numbers of items with traditional stances; the median angle is less than 4 degrees less than that in the 1970s.

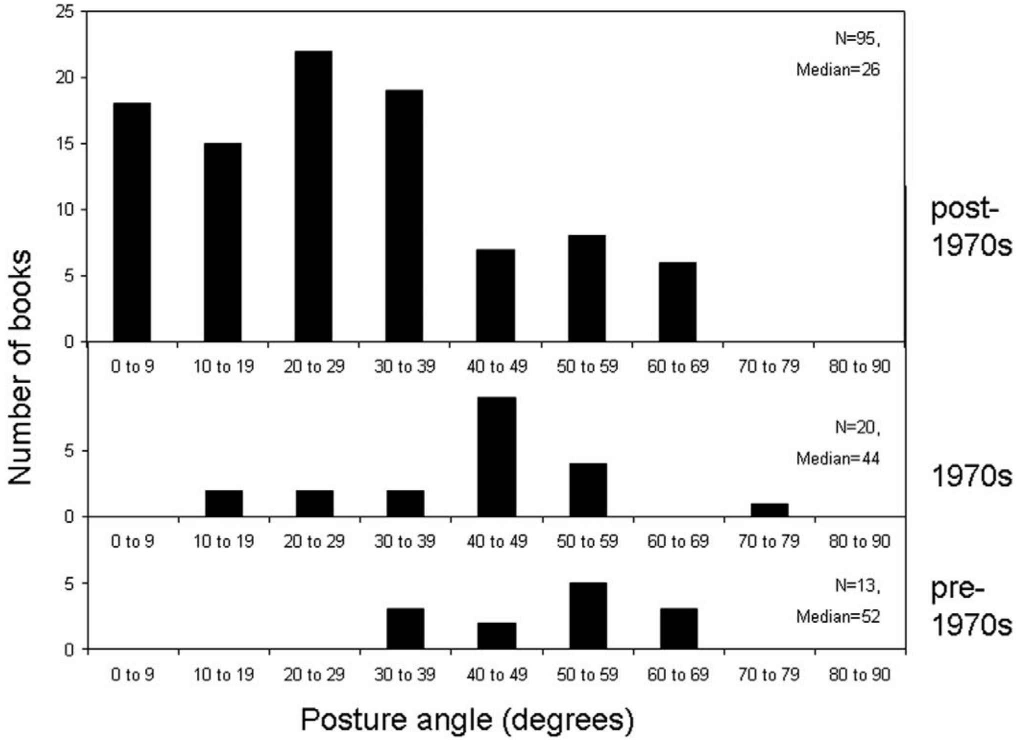

FIGURE 14: **Distribution of stance angle in *T. rex* in books in time interval before 1970 (before scientific reinterpretation) (median = 52, MAD = 4), in 1970s (median = 44, MAD = 6), and since the 1970s (median = 26, MAD = 13). While some books since 1980 still have upright stances, most have stances more consistent with current scientific interpretations with low posture angle.**

be to replace their conceptions of posture but to work with those conceptions to move toward the scientific consensus view.

It is also reasonable to question whether what participants drew is a representation of what they perceived to be scientifically accurate. The Draw-a-Scientist Test (Chambers, 1983) is a similar assessment to our Draw-a–*T. rex* exercise; in the former, students frequently draw male scientists in lab coats and infrequently draw women or field scientists. This finding seems to hold across many studies, but students could hold perceptions different than those they draw. "Sometimes students hold multiple images or simply draw what they think is silly" (Finson, 2002). Would students draw more scientifically accurate images if they were instead asked to draw a scientifically accurate *T. rex*?

The effects of lag, inertia, and risk aversion in textbooks have been well documented (e.g., Gould, 1988). Information and images are often copied from book to book without independent confirmation by authors, illustrators, editors, or publishers, thus perpetuating out-of-date views long past their currency in the scientific community. The effects of such lag in wholly nonacademic, nonintellectual products such as cookie cutters and baby bibs must be even greater, because there is almost no motivation for these images to change to reflect revised scientific views.

Our results suggest that the traditional low-energy view of dinosaurs still has a strong hold on the public imagination, despite decades of dinomania and associated multimedia imagery showing dinosaurs mostly as high-energy animals. Images in popular books (and films and museum exhibits) have changed over the 20th century, but images in other areas of popular culture mostly have not. Most people appear to take their conceptions of dinosaurs from their first experiences with these pop culture images, regardless of what the bulk of pop science tells them later in life.

This conclusion could have broader significance for the general understanding of science by the general public. Dinosaurs have been pointed to by many educators as ideal points of entry and teaching tools for getting students engaged in other areas of science and learning (e.g., Beaty and Fountas, 1992; Rogers, 1993; VanCleave, 1994; Cook and Johnson, 1996, Scotchmoor et al., 2002). What does it mean for science education that even for dinosaurs—arguably the nontechnology science topic most familiar to people in their everyday lives—comprehension of current scientific understanding is influenced so early and to such a degree by such informal and noninstructional contexts?

It is well known that students and others of all ages have prior conceptions in science that influence their understanding and further learning (e.g., Samarapungavan and Wiers, 1997; Henriques, 2002). While lack of knowledge of the current scientific consensus on the nature of theropod dinosaur reconstructions might not be as significant as misconceptions about climate change, evolution, or disease, dinosaurs are instructive because they are among the very first natural history topics in which children take an interest, and they remain one of the most prevalent science topics in popular media for adults. Study of public understanding of dinosaurs could therefore provide insights on the origin,

FIGURE 15: (A) Dino bath squirt toys by Battat, ca. 2003 (B) Yummy Dino Buddies Chicken Breast Nuggets, ca. 2007.

timing, and maintenance of misconceptions or outdated conceptions that might be less easily observed in other scientific fields.

Such prior conceptions can, in fact, be used to raise student awareness of their own misconceptions and serve as the materials from which to shape conceptions that are grounded in science. This is the very nature of having students draws a *T. rex*; after the exercise, students have a more personal investment in what a *T. rex* might have looked like, at which point it can be effective to allow students to contrast for themselves their own drawings with newer scientific images and to talk about the nature of science as a dynamic enterprise. Teachers can use the history of changing reconstructions of *T. rex* and of other ancient vertebrates to help students think about how and what we know about the past, and what kinds of evidence can overturn prior scientific conceptions.

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APPENDIX: SOURCES OF *T. REX* ILLUSTRATIONS

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