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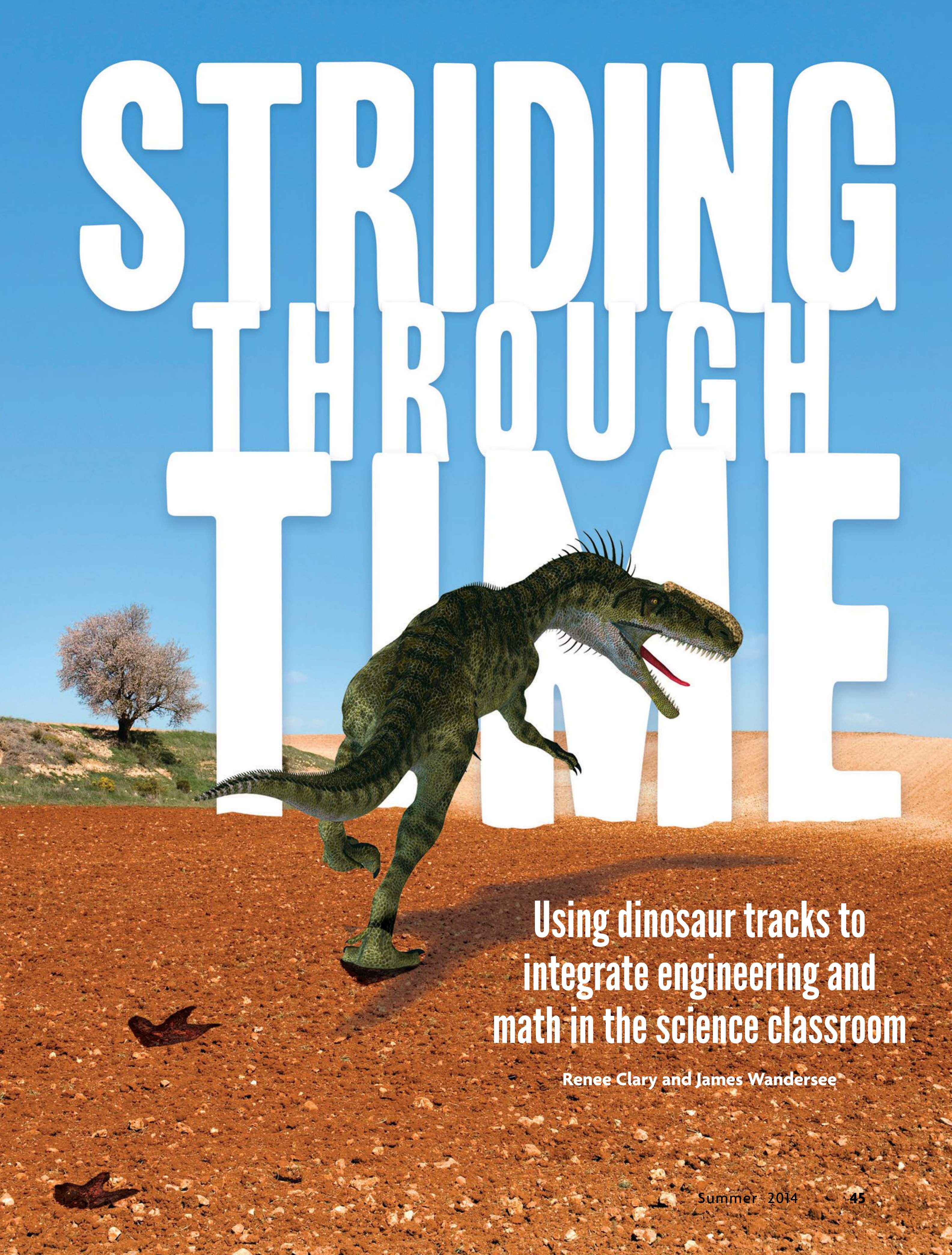
Math-Science Connections

In this issue:

- Striding through time
- Discovering our stellar neighborhood
- Computational thinking

NSTA National Science Teachers Association

STRIDING THROUGH TIME



Using dinosaur tracks to integrate engineering and math in the science classroom

Renee Clary and James Wandersee

When we think about incorporating engineering or math activities into the science classroom, we typically envision a physics project. Students design the most effective catapult or a weight-bearing bridge or the best protective device for an egg-drop experiment. However, if we consider engineering only in the context of physics, we miss out on opportunities for students to engage, design, and apply the science concepts they learn in our classroom. Not only can engineering activities extend beyond physics, but engineering design is integrated in the *Next Generation Science Standards* (NGSS Lead States 2013), joining the traditional disciplinary areas of Earth and space, life, and physical science. Moreover, Using Mathematics and Computational Thinking is identified in the *NGSS* as a core science and engineering practice.

In our Earth science and biology classrooms, we wanted to incorporate a hands-on application activity in which students investigate the relationship between a vertebrate's stride length (SL) and speed. The "Dino-Track" project we came up with requires students to collect and measure stride lengths from their classmates, graph their results, and apply them to dinosaur trackways. We then opted to extend our project by requiring students to design and develop a public trackway of dinosaur footprints within a confined space. We consider our activity an engineering application of mathematics into the Mesozoic. This article describes the activity in more detail.

Vertebrate trackways: An initial investigation

In the beginning of the year, our Earth science and biology classes study different fossil preservation types, including

- permineralization (e.g., fossilized or petrified wood),
- molds or casts (e.g., original material dissolved away to produce a cavity, which is subsequently filled with sediments), and
- unaltered remains (e.g., insects trapped in amber).

Perhaps the most important fossil type we investigate for the purpose of this activity, however, is the trace fossil. Whereas body fossils provide information about the anatomy of an organism, trace fossils supply details about its environment and behavior, including its movement and speed. Trace fossils can include trackways (a set of impressions left in soft earth that have been subsequently preserved in stone [Figure 1]; gastroliths (stomach grinding stones); coprolites (fossilized feces); nests; and burrows. We ask our students to consider how scientists determine behavior from trace fossils like these. Then we remind them about *uniformitarianism*—the idea that "the present is the key to the past." We also remind them that scientists investigate extinct life forms based on observations of the living.

British zoologist R. McNeill Alexander (1976) researched modern vertebrates and derived a general formulaic relationship that is the crux of this activity. His formula relates an animal's speed to its hip height (or leg length [LL]) and its stride length (SL). This formula has been simplified for classroom use and has been modified for greater accuracy. In this activity, students first generate their own data for Alexander's formula and then apply the formula to tracks preserved in stone, made by animals that are no longer alive.

FIGURE 1

Dinosaur trackways.

These tracks from the Arabian peninsula provide information about the speed of the animal and the type of environment in which it walked.

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The human experiment

The Dino-Track investigation begins by plotting the relationship between humans' gaits and speeds and then exploring connections between footprint size and height. We provide students with a project handout to organize the steps of our Dino-Track project, which is available online (see "On the web").

We have implemented this activity as both a required class project and an optional research project. In our class project, we organized students into groups of six to collect data. For the optional research project, we directed them to find volunteers on their own.

To begin, students measure a 20 m path, either on a school sidewalk or a track. Each student takes a turn walking the path, then running the path. The walker or runner ties a red bandana around his or her left ankle, and the student serving as the stride recorder counts the number of times the bandana foot hits the pavement within the 20 m walk and then the run. Another student, the time recorder, uses a stopwatch to time both the walk and the run. Students record this data in a chart that is available online (see "On the web"). At the end of the experiment, each group has six sets of data, with each student having walked, and then run, the 20 m track. Those who are unable to walk or are uncomfortable with walking or running are assigned the timing duties.

We next turn to Alexander's formula and attempt to replicate his graph of relative stride length plotted against dimensionless speed. (Alexander used the *Froude number* for this dimensionless variable by taking the square root of the speed squared, which is divided by a characteristic length [i.e., the leg length] that was multiplied by the acceleration due to gravity. The number is dimensionless because the units cancel.) This graph enables students to calculate stride length from an animal's footprint or determine an animal's general speed and mode of locomotion (e.g., walking or running) from a set of preserved tracks.

Calculating dimensionless speed

Students determine stride length by dividing the length of the path (20 m) by how many times the student's left foot hits the path. Remind students that *stride length* is the distance from left foot impact to left foot impact and not the distance between left foot and right foot impact, which is *step length*.

To calculate the student's speed (S), the distance (20 m) is divided by the time (in seconds) it took the student to walk or run the path. We ask students to record any trends they observe. Most note, for example, that the taller students have longer strides and that running requires fewer strides than walking.

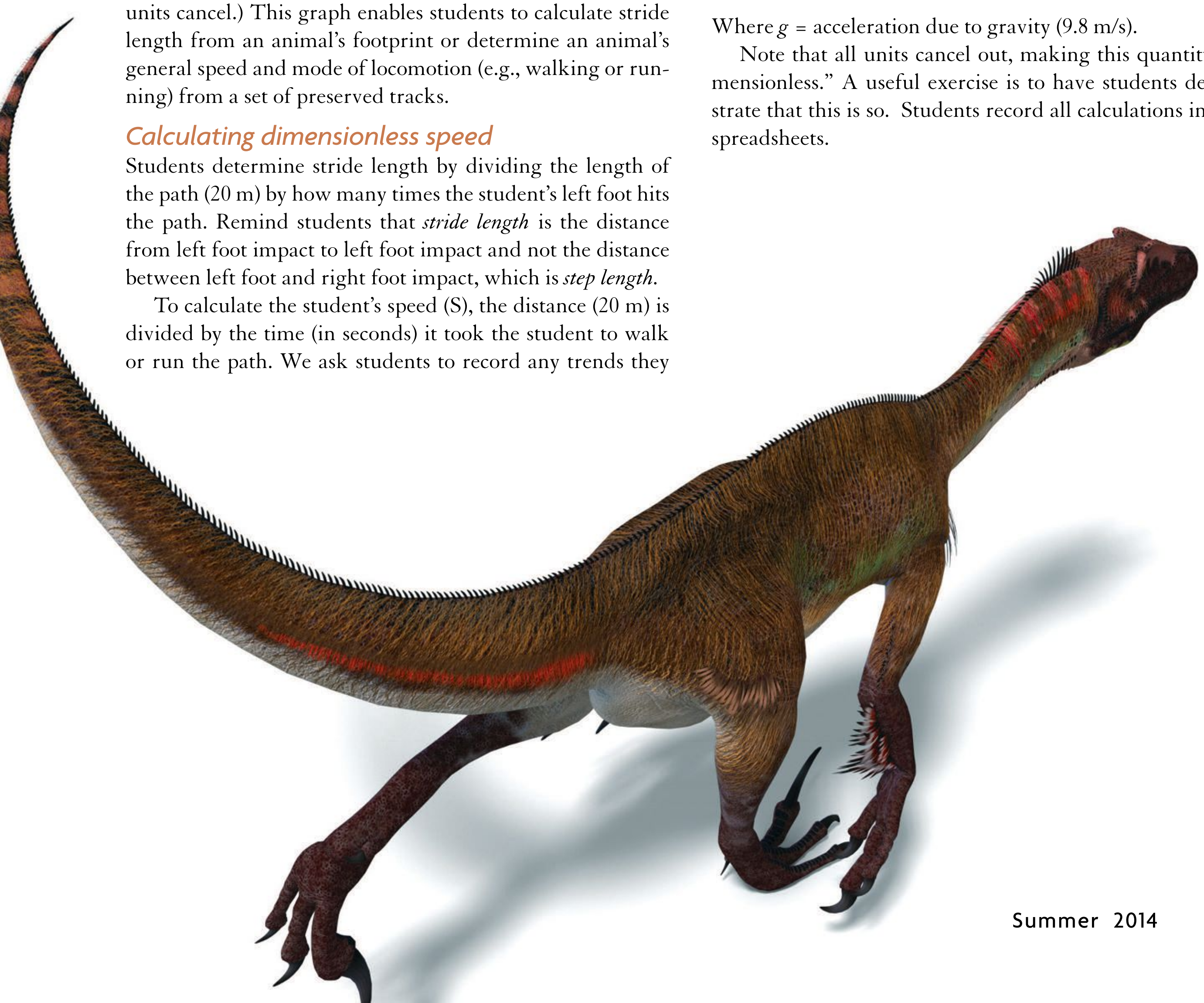
Because taller runners typically have a longer stride length, Alexander converted the variable to a dimensionless number, or relative stride length (RS). To calculate RS, each student's leg length (LL) is measured. This is the distance from the anklebone to the hipbone. The relative stride length (RS) is the stride length (SL) divided by the leg length (LL), or RS = SL / LL. Students should be cautioned to use the same unit—meters or centimeters—for both stride length and leg length when performing this calculation.

Through his research, Alexander discovered that graphing relative stride length—a dimensionless number—against dimensionless speed produced a nearly linear trend for vertebrates, regardless of the species and whether the animal was walking or running. Therefore, students next calculate dimensionless speed. This is the actual speed (S) of the student, divided by the square root of the product of gravitational acceleration (g = 9.8 m/s^2) and the leg length (LL), or DS = S / $(g$*LL$)^{1/2}$.

$$DS = \frac{speed}{\sqrt{(leg\ length \times g)}}$$

Where g = acceleration due to gravity (9.8 m/s).

Note that all units cancel out, making this quantity "dimensionless." A useful exercise is to have students demonstrate that this is so. Students record all calculations in their spreadsheets.



Graphing the results

Students then graph their results by plotting the relative stride length (RS) against the dimensionless speed (DS) (Figure 2). The relative stride length should be plotted on the *x* axis and the dimensionless speed on the *y* axis.

When we first implemented this project, we found that some groups had outlier values that skewed their trend lines. Therefore, we now ask all groups to share their data in a single electronic spreadsheet, which is available online (see "On the web"). Students compile data and use it to graph their results. This has had two positive impacts on our classrooms: Outlier data points do not skew the graph to an appreciable extent, and numerous examples of peer teaching are observed as students check one another's calculations before adding new data to the spreadsheet.

After completing the graph, students examine it for trends. Our students' results do not completely replicate Alexander's graph, but general trends are noted and are sufficient for this classroom project. For example, students find that increased relative stride length is observed with increased relative speed.

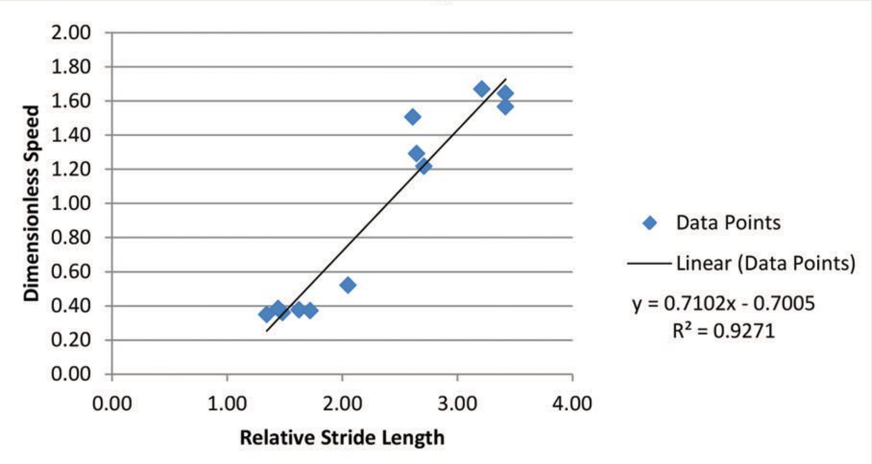
Exploring relationships among footprint size, animal size, and speed

Now that students have replicated part of Alexander's research and developed a graphical relationship between a relative stride length and dimensionless speed, we ask them to consider tracks that scientists may discover. If the scientist does not observe the creator of the track, for example, how can he or she reconstruct the size of the animal (e.g., its leg length) and calculate the speed at which it was moving? If a trackway exists, then the stride length can be measured between successive left tracks or right tracks. However, students must first determine what the relationship is between the track length and the leg length to determine relative speed from the graph.

FIGURE 2

Dimensionless speed versus relative stride length.

Students plot dimensionless speed (DS) against relative stride length (RS) to investigate trends between gait and speed.



Thus, students begin this step of the activity by measuring the foot length of each member in their groups. We ask students to take this measurement with their athletic shoes on because it makes measuring easier. Students' leg length (LL) is then divided by their foot length (FL) to see what general trends exist. Most students, for example, note that the larger the foot, the longer the leg length.

Dinosaur trackways: Applying the research

Once students have completed an investigation of human gaits, speeds, and foot length to leg length relationships, we turn the classroom attention to fossilized trackways. Fortunately, the University of California's Museum of Paleontology has dinosaur trackway reproductions available online for classroom research (see "On the web"). We require students to analyze these dinosaur tracks on the web to determine the dinosaur's leg length and speed.

We also provide photographs of a plaster *Acrocanthosaurus* track in Texas that one of our colleagues obtained when the river level was low, as well as photographs—with measurements—of some of the dinosaur tracks *in situ* (Figure 3). (These photos and measurements are available online; see "On the web.")

Near our school, we found a human trackway made in wet concrete, which we refer to as *Altheticus concreticus* (Figure 4). Students can investigate the trackway themselves or use the dimensions we provide to calculate the leg length and speed of this "mystery animal."

Finding a dinosaur's gait

Next, we introduce students to speeds calculated for dinosaurs by Thulborn (1982) (Figure 5, p. 50), whose findings are based on Alexander's research.

Research by Wright and Breithaupt (2002) can also help us determine if an animal was walking, running, or trotting by investigating the relationship between its leg length (LL) and stride length (SL).

In particular:

FIGURE 3

Trackways *in situ.*

A plaster cast and dinosaur trackways *in situ* in an exposed riverbed in Texas. Measurements are provided in the instructions posted online (see “On the web”).

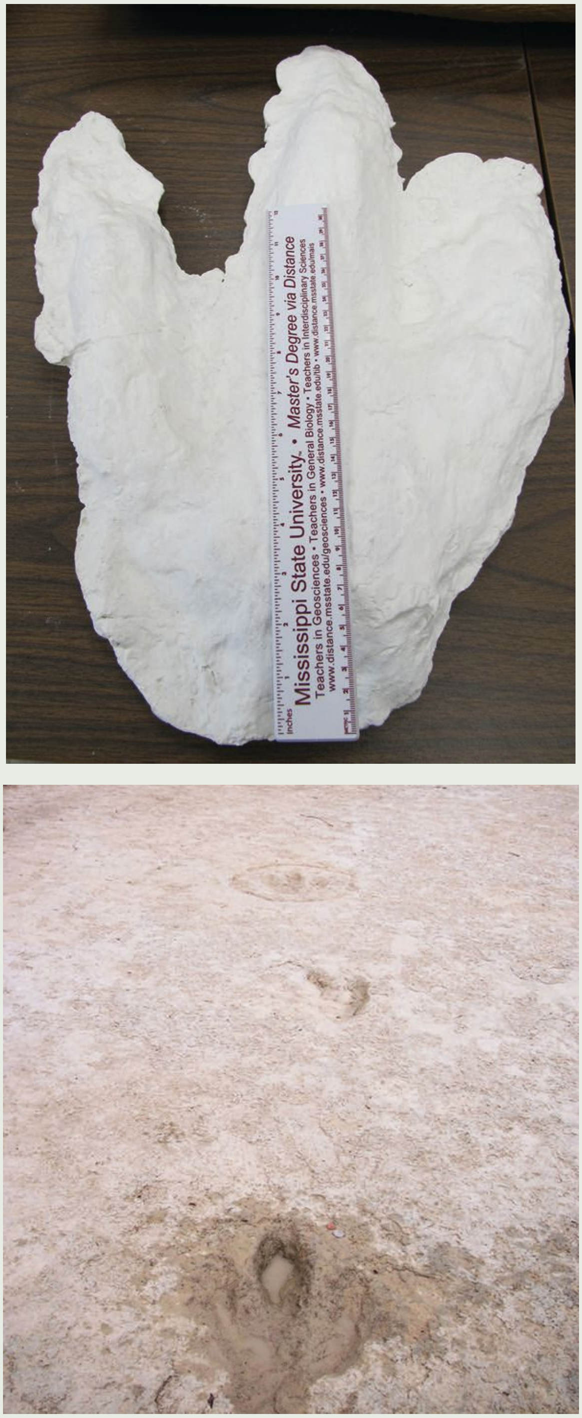


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FIGURE 4

Mystery trackway.

A mystery trackway is provided to students, who must apply their previous research and determine the leg length and dimensionless speed of this “mystery animal.” The measurements are available online (see “On the web”).

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- $SL / LL < 2.0$ means that the animal was walking;
- $2.0 < SL / LL < 2.9$ means that the animal was trotting; and
- $SL / LL > 2.9$ means that the animal was running.

We ask students to return to the trackways they investigated in the initial stage of this activity and determine whether the animals were walking, trotting, or running.

Creative application: Engineering a trackway

In the final stage of the trackway project, students apply their engineering skills while designing dinosaur trackways for public display. Student groups may select whether their dinosaur was large or small and quadrupedal or bipedal. Students must also decide where their temporary trackways will be displayed (e.g., hallway, classroom wall, or side-

FIGURE 5

Average maximum speeds of dinosaurs, as calculated by Thulborn (1982).

Dinosaur	Maximum speed
Sauropodomorphs	5 km/hr
Stegasaurs and ankylosaurs	6–8 km/hr
Sauropods *(Apatasaurus)*	12–17 km/h; maximum 20–30 km/hr
Large theropods *(Tyrannosaurus)* and ornithopods	20 km/hr
Ceratopsians *(Triceratops)*	Up to 25 km/hr
Small therapods and ornithopods	Up to 40 km/hr
Ornithomimids	Up to 60 km/hr
People	23 km/hr

FIGURE 6

Student dinosaur trackway.

This dinosaur trackway display uses brightly colored construction paper on a classroom wall.

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walk). Once their choice is approved, students measure the length of the available space and develop an accurate trackway that fits the selected site. We require that a minimum of two strides, or three left and three right prints, be included. Accordingly, students fit the trackway to the space by

1. selecting the size of the dinosaur's prints that can be included;
2. selecting the gait of their dinosaur (e.g., walking, trotting, or running);
3. determining the minimum or maximum number of prints that can be included by "reversing" our previous calculations (i.e., determining the animal's leg length from foot length, and the stride length that would represent the chosen gait); and
4. selecting the appropriate materials to construct prints (e.g., chalk for sidewalks, spray paint and stencils for grassy areas, or construction paper prints for walls [Figure 6]).

(Note: Students who first select large quadruped sauropods, long-necked dinosaurs known for their enormous size, often have to reassess their choices if display space is limited.)

Each student must turn in a research report explaining the dinosaur selection and providing the calculations that produced his or her display. We provide a rubric (see "On the web") to guide students in their final project report.

Teacher feedback

The Dino-Track project has been well received by students and teachers across the United States. When asked their opinion of the project, teachers have described it as an "excellent student-oriented project" that their "students really got into." Others have noted that the required mathematical calculations were beneficial. One said: "My students have a difficult time applying what they learn in math outside of math class. They need more of this type of project." The only concern was the amount of time required—up to four entire class periods (90 minutes each) if the project is conducted completely during class. This concern can be addressed through collaboration between science and math teachers for an interdisciplinary project.

The physical engineering of the trackway also had a positive effect on students. One teacher said: "Students are amazed when their calculations result in the production of dinosaur tracks based on their own measurements." Teachers also noted that the engineering application "put it all in perspective" and allowed students "to create ownership." By incorporating the physical design of the trackway, the assignment made "the project tactile, integrating the cerebral with the physical. And it enhances the learning that comes with the project." Teachers also noted that dinosaurs were inherently interesting to students.

Conclusion

The *NGSS* focus attention on integrating engineering and math in science instruction. Our dinosaur trackway project shows that it's possible to assign engineering applications to students in disciplines other than physics and to integrate math and engineering applications in the science classroom. We have experienced positive outcomes with this project and encourage our colleagues to incorporate math in the Mesozoic to involve their own students in designing and engineering classroom trackways. ■

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On the web

Dinosaur trackway activity and reproductions from the University of California's Museum of Paleontology: *http://bit.ly/1i8pCnW*

Instructions, graph, and rubric for this activity: *www.nsta.org/highschool/connections.aspx*

Additional resources

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