Inquiry has been the recommended central teaching strategy since the 1996 National Science Education Standards. With the 2013 release of the Next Generation Science Standards (NGSS), inquiry is now explicitly articulated as eight essential Science and Engineering Practices that scientists employ when investigating and building models about natural phenomena (NGSS Lead States). One of these Science Practices, Developing and Using Models, is likely to be a new feature and a significant change for many elementary teachers and students.

The NGSS emphasize that “the practice of modeling will need to be taught throughout the year and across the entire K–12 experience” and outline a succinct learning progression for developing and using models in the K–5 classroom (NGSS Lead States 2013, p. 6):

Fifth-grade students use computer programming to create models that help them understand patterns in Earth and sky.

By Lisa M. Blank, Avigail Snir, and Morten Lundsgaard
K–2: Modeling in K–2 builds on prior experience and progresses to include identifying, using, and developing models that represent concrete events or design solutions.

3–5: Modeling in 3–5 builds on K–2 models and progresses to building and revising simple models and using models to represent events and design solutions.

Much of the modeling done by scientists is accomplished using sophisticated computer program models. What age-appropriate strategies can K–5 teachers use to embed modeling in their teaching practices so students use and design models as a scientist would?

As STEM educators, we chose to answer this question by exploring the use of Etoys as a computer-modeling tool to support fifth-grade students’ understanding of an essential NGSS Earth and Space Science Disciplinary Core Idea, four Science and Engineering Practices, and two Crosscutting Concepts (see “Connecting to the Next Generation Science Standards,” p. 35).

**Etoys and EIMA**

Etoys is a free, easy-to-learn, modeling and programming environment suitable for use in grades 2–12. Students begin by drawing objects using a simple paint tool. They then move these objects manually or drag and drop computer script tiles to “program” the behavior of their objects. See Internet Resources for an Etoys video tutorial. The program can be downloaded and installed for use on both Windows and Macintosh operating systems. There is also an Etoys To Go version that can be run by simply downloading the program onto a flash drive. We found this option preferable as you don’t need to run the gauntlet of district technology approvals. With this method, all student projects are conveniently saved onto their own flash drives, students can share their work with family, and those who wish to can continue exploring Etoys outside of class.

To organize the modeling experience for students, we used the Engage-Investigate-Model-Apply (EIMA) “modeling-centered” framework (Table 1) that employs four distinct learning episodes: Engage, Investigate, Model, and Apply.

### TABLE 1. EIMA Framework.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engage</td>
<td>The teacher engages students in the target science concept and provides an opportunity for students to reveal and reflect on their own ideas.</td>
</tr>
<tr>
<td>Investigate</td>
<td>Students investigate the idea or phenomena.</td>
</tr>
<tr>
<td>Model</td>
<td>Students create a model, compare the model with the scientific one, and revise their model.</td>
</tr>
<tr>
<td>Apply</td>
<td>Students apply the model to a new situation.</td>
</tr>
</tbody>
</table>

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el, and Apply (Schwarz and Gwekwerere 2007). Schwarz et al. (2009) argue that this framework helps scaffold student learning as they progress through four levels of understanding models as a tool for predicting and explaining phenomena (Table 2).

In the engage phase of this lesson, students collect data to construct a model – Level 1. In the investigate phase, students construct a model using Etoys and use the model to support their thinking about patterns in the Earth and sky – Level 2. In the model phase, students begin to identify the advantages and disadvantages their Etoys model provides when compared to the actual phenomena – Level 3. Finally, in the apply phase, students consider a variety of models to support their thinking – Level 4.

### Engage

Co-teaching in a fifth-grade classroom of 27 students, we began by asking students where the Sun rises and sets in relation to the school playground: “If you are standing on the playground at sunrise, where would you see the Sun? If you are standing on the playground at sunset, where would you see the Sun?”

After several minutes of discussion and some disagreement, we decided to confirm or “test” our ideas by making more observations that evening and the next morning, warning students never to look directly at the Sun.

Launching the lesson by encouraging students to identify observable variations across the day fosters student understanding of the NGSS Crosscutting Concept of Patterns and begins development of the ideas of Systems and System Models to represent and predict these patterns.

### Investigate

The following day, students shared their observations and confirmed as a class where the Sun appears to set and

<table>
<thead>
<tr>
<th>Level</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Students construct and use models to illustrate a phenomena. Students view models as a means of showing others what the phenomena looks like, but not as a tool to generate new knowledge.</td>
</tr>
<tr>
<td>2</td>
<td>Students construct and use models to illustrate and explain how a phenomena works. Students view models as a means of communicating their understanding of a phenomena rather than a tool to support their own thinking.</td>
</tr>
<tr>
<td>3</td>
<td>Students construct and use models to explain and predict phenomena. Students view models as tools that can support their thinking about existing and new phenomena. Students consider alternatives in constructing models based on analyses of the different advantages and weaknesses for explaining and predicting models possess.</td>
</tr>
<tr>
<td>4</td>
<td>Students construct and use models to generate new questions about the behavior or existence of phenomena. Students consider how the world could behave according to various models.</td>
</tr>
</tbody>
</table>

### FIGURE 2.

How to animate objects.
rise. Following this, we challenged them to record their observations using Etoys. (Each student had their own laptop, but this could be done in groups of two at a computer station.)

Drawing observations served as a natural introduction to Etoys. Most students intuitively navigated the paint tool without formal instruction and quickly became familiar and proficient with the basic Etoy features used in the curriculum. A few used the written instructions we prepared. Those students who finished quickly were challenged to add shadows to their drawings of the Sun at sunrise, noon, and sunset. See Figure 1, page 31, for sample student work.

Model

As a class, we compared students’ Etoys drawings to their observations and introduced the idea that the drawing was a representation or model of a pattern in the natural world. In looking at the Etoys drawings, students noticed that some of them had painted the Sun rising on the left side of themselves while others had it rising on the right side.

From this we were able to explore improvements to our models that would better represent the actual rising of the Sun in the west and setting in the east. Some students suggested the use of a compass rose to indicate east and west. Others wanted to include landmarks such as the playground swings to indicate direction. In this way, students were able to distinguish between the model and the actual event that the model represented. By the end of our discussion, a majority of students wished there was a way to make their paintings move to more accurately model the target phenomena. This was an excellent transition for introducing the ability of Etoys to “program” the motion of an object. We directed students back to their Etoy projects and, as a class, introduced how to change the behavior of the Sun using a programming tile.

Within Etoys, students can use scripting tiles (computer code) to animate objects. They do this by selecting tiles from the “viewer.” To open the viewer for an object, students right click on the object (e.g., Sun) and a “halo” of icons appear around the object. By clicking on the “blue eye” icon, the viewer is revealed (Figure 2).

Within the viewer, we introduced students to the “Sun turn by” tile, which is a command tile. A command describes an action (in this case “turn by”) that is to be carried about by the object. By clicking on the yellow exclamation point icon, students observe the “Sun turn by 5” once. Not surprisingly, students were unhappy with this action because it is inconsistent with their experiences of how the Sun appears in the sky. Students wanted to revise their model.

Note: While the Sun does rotate around its axis (about once every 27 days), this rotation is not observable to the naked eye (though it can be observed by tracking sunspots over time).

By right clicking on the Sun, we opened the “halo” and pointed out that each object in Etoys has a rotational center. If students want the Sun to move in the sky as observed, they need to move the Sun’s rotation center from the Sun to the feet of the observer. They do this by holding down the shift key, clicking on the rotation center, and dragging it to the desired location.

Once everyone moved the rotation center and ran the new script, most students observed their Sun rising and setting as they experienced it on the playground. Some found that their Sun was still rising in the west and setting in the east. We challenged the class to find a solution to this by thinking carefully about their scripts. Eventually students figured out that they could change the numerical value of the tile “Sun turn by” from a 5 to a −5 to make the Sun rise in the east and set in the west.

While students are not introduced to negative numbers until grade 6 in the Common Core Math Standards, this is an excellent opportunity to explore the geometry “behind” Etoys and highlight the relationship between math and its...
use in computer programming to manage object behavior. Each object in Etoys exists on a coordinate plane. Direct students to right click on the Sun and open the halo. To the right of the object, students can view the $x$ and $y$ coordinates for the Sun. Challenge students to increase and decrease the values for $x$ and $y$ and observe how this changes the position of their Sun. The larger the $x$-value, the farther to the right the object moves. The larger the $y$-value, the higher the object moves.

At this point all students had successfully created a Sun, programmed it to move, and were quite excited by their ability to program. When asked once again to compare and contrast their model with the actual phenomena, a few students pointed out that the Sun doesn’t actually rotate around us on the Earth; rather, the Earth rotates around the Sun. While our model successfully depicted events as we observe them, it wasn’t scientifically accurate. Students agreed that we may see the Sun “moving” across the sky, but it is actually the Earth that is doing the moving.

**Apply**

We encouraged students to work in groups of two to solve the problem of modeling the Earth orbiting the Sun. Students were provided with styrofoam models of the Earth and Sun to use in developing their ideas about how to revise their computer model.

After lengthy discussions, most students came to the conclusion that they needed to draw a new set of objects where they were located on Earth and then they needed to program the Earth to orbit the Sun, but not rotate about its axis (Figure 3, p. 33). To model orbit and rotation, we had students view the “Sun Earth Moon” project in the Etoys Illinois library collection (see Internet Resources).

**Outcomes**

We began and ended our use of Etoys with a 15-question assessment (multiple choice) of students’ understanding of modeling, Earth/Sun movements, and STEM interest (see NSTA Connection). On the pretest, students understood that the Earth spins on its axis and that this rotation was responsible for night and day. Students could define rotation and revolution but struggled to differentiate between which events on Earth were attributable to rotation versus revolution (e.g., rising and setting of the Sun vs. different constellations observed in the night sky throughout the year).

In terms of understanding models, many students agreed that objects could be represented with a model, but not events or processes. Students also believed that a globe could be a model of the Earth, but not a map because models had to be the exact same shape as the object to be considered a model. On the four STEM-interest items (Tyler-Wood, Knezek, and Christensen 2010), most students indicated that they found math and science “boring,” technology was “interesting,” and a career in STEM “means nothing” or is “boring.”

In the postassessment, results indicated that students developed a conceptual understanding of both rotation and revolution and understood that models can represent objects, events, or processes and help support and explain their thinking. In terms of STEM interest, students responded that science and a STEM career were interesting, math was still boring, and technology was now exciting.

While modeling the movement of Earth and Sun can be understood without the use of technology, we found using Etoys advanced students’ awareness of how scientists build and apply computer models. Our fifth graders began with the familiar concept of the Sun rising and setting and left excited about their ability to understand and represent these events using Etoys as a modeling tool.

Elementary schools in Brazil, Uruguay, Peru, Spain, Japan, Portugal, France, India, Africa, Germany, and Illinois are successfully using Etoys to advance computer modeling opportunities for young students and develop student understanding of essential science ideas. You can view examples of student work by visiting www.squeakland.org and selecting “Showcase.” In addition to using Etoys as a programming tool, thousands of ready-to-go projects can be downloaded from EtoysIllinois.org. Using Etoys in the classroom fosters problem-based learning by encouraging students to bring their ideas to life using simple “scripts” they assemble. Providing students the opportunity to “write” the language of computers increases students’: (1) computing fluency; (2) confidence in their creative capacity; and (3) awareness of computer science as a possible STEM
career. Finally, the integration of Etoys advances student understanding of patterns in the Earth and sky by developing and using models as a scientist would.

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References

Internet Resources
Etoys Illinois
http://etoysillinois.org
Etoys Illinois: Sun Earth Moon project
http://etoysillinois.org/library?sl=169
Etoys Video Tutorial
www.youtube.com/watch?v=PwFPEpype8
Learning With Etoys: Imagine, Invent, Inspire
Squeakland: Home of Squeak Etoys
www.squeakland.org

Connecting to the Next Generation Science Standards (NGSS Lead States 2013)

5-ESS1 Earth’s Place in the Universe
www.nextgenscience.org/5ess1-earth-place-universe
The materials/lessons/activities outlined in this article are just one step toward reaching the Performance Expectations listed below. Additional supporting materials/lessons/activities will be required.

Performance Expectation
5-ESS1-2 Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.

Science and Engineering Practices
Developing and Using Models
Analyzing and Interpreting Data
Constructing Explanations

Disciplinary Core Idea
ESS1.B: Earth and the Solar System
• The orbits of Earth around the Sun and of the Moon around the Earth, together with the rotation of Earth about an axis between its North and South poles cause observable patterns. These include day and night; daily changes in the length and direction of shadows; and different positions of the Sun, Moon, and stars at different times of the day, month, and year.

Crosscutting Concept
Patterns

Connecting to the Common Core State Standards (NGAC and CCSSO 2010)

CCSS.MATH.CONTENT.5.G.A.1
Use a pair of perpendicular lines, called axes, to define a coordinate system, with the intersection of the lines (the origin) arranged to coincide with the 0 on each line and a given point in the plane located by using an ordered pair of numbers, called its coordinates. Understand that the first number indicates how far to travel from the origin in the direction of one axis, and the second number indicates how far to travel in the direction of the second axis, with the convention that the names of the two axes and the coordinates correspond.