Einstein once commented that scientific theories should be able to be described so simply that a child could understand them. I recently had the opportunity to test this idea in my daughter's grade school, the Open Classroom (OC) in Salt Lake City, Utah. The Open Classroom is a magnet-type school where parents are required to perform co-op teaching at least one time per week. This can be a source of great joy for both parents and their children; and as the kids get older a potential source of great embarrassment for the children unless the parents act and dress "just right."

So, I decided to try teaching math concepts to the third graders: Specifically, I taught a beginning algebra class to a select group of six third graders in the spring of 2001. I was aided by an algebra teaching kit which used a balance scale to teach simple algebraic concepts such as the addition and subtraction rules for solving a linear algebraic equation in one variable. After two classroom exercises, I departed from the teaching text and juiced up the exercises by putting on contests such as "Who wants to be a mathematician millionaire," where the kids were asked to solve a linear equation, using lifelines and such. This is the just the kind of politically incorrect activity not encouraged by the founders of the OC, but the kids seemed to relish this fun competition. I always made sure everyone won ... really! For the last couple of exercises, I taught the kids how to graph an x-y plot of the solutions to a linear equation, and then had them solve a $2 \times 2$ system of equations by graphing. One of them figured out that the common solution was the intersection point of two lines. By the end of the teaching period I was surprised and very pleased that the third graders (and one second grader) could balance a linear algebraic equation, solve for the variable, graph equations, and (perhaps) recognize that they could solve a $2 \times 2$ system of equations by graphing.

In the fall of 2001, my daughter Sarah entered the fourth grade at the OC and I decided to continue teaching algebra but would make it more interesting by combining it with science. Naturally, I selected science topics that I had some experience with: 3D seismic data interpretation, image processing, and seismic tomography. Having taught these topics to University of Utah students with a wide range of backgrounds (math-poor freshman to math-sophisticated graduate students) I discovered that many geophysical topics can be explained with intuitive ideas and simple pictures. I now report on my experiences in teaching 3D seismic interpretation, image processing, and seismic tomography to a select group of fourth graders at the OC during the 2001-2002 school year. The classroom exercises are described at http://utam.gg.utah.edu/sarah.

**3D seismic data interpretation.** The goal here was to get the kids to interpret a 3D seismic data set donated by ExxonMobil for undergraduate and graduate student teaching. Because the kids did not know how to construct or interpret a contour map, I first explained the basic principles of constructing a topographical map. In the first exercise I gave them a gridded piece of paper, a ruler, and colored pencils. I then demonstrated how to construct a topo map by placing my hand flat on the gridded paper, and measured my hand’s height above each pixel. Placing the height numbers in the appropriate pixel, I then showed how to associate the range of numbers with a color scale, and proceeded to color the grid of numbers. Poof! ... a color topo-map of the hand. This application introduces the concept that grids of numbers, i.e., matrices, can be associated with physical objects.

The kids were pretty excited about this and demonstrated their skills by creating their own hand-topo maps. Once their abilities were validated, I then asked them to find an object from around the classroom and secretly create its topo map (Figure 1). After doing so, we had the teams (each science team consisted of two students) display their secret objects and let the others figure out which map belonged to...
which object. The children were encouraged to let their imaginations picture the actual object from the topo map. The kids had a fun time trying to figure out which was which.

After about three weeks, the kids had a sufficient understanding of contouring so that we could start on the 3D seismic data. I showed the kids 11 inline sections of ExxonMobil’s Timbalier seismic data (Figure 2). I explained the meaning of a seismic section by saying that geophysicists had a seismic camera that could take pictures of the earth’s interior. These pictures could show layering in the earth, and to reinforce this point I placed a stratified rock next to a seismic section. As you can see from Figure 2, the colors and layer thicknesses of the rock are similar to those of the seismic section; but the scale of the section was in miles while that of the rock was in inches. They understood, I hoped. I then demonstrated the principle of how oil flows and accumulates in rocks. The idea that rocks can contain fluids was illustrated by showing a rock with obvious holes in it, and pouring water on it to soak it up. They were convinced that oil can move and accumulate in rocks. I showed a pan of water, and asked the kids what would happen if I dropped some oil in it. Would it float or sink? Half said it would sink, the other half said it would float. Those that said it would sink thought that I would have to look for oil at the bottom of the seismic section. When they saw that it would float, they all agreed that we should look for oil at the top of the seismic section. I then explained about traps, and told them that the yellow line on the seismic section in Figure 2 indicated the trapping layer (too bad the line wasn’t white, I would then only be guilty of a white lie).

Now that the kids knew how to contour, understood the principles of oil exploration, and grasped the meaning of a seismic section, they were ready to contour up the yellow horizon in the ExxonMobil data. I handed out copies of 11 inline sections and the base map to the ExxonMobil data and asked them to measure the two-way times and place them on the base map. After mapping the times to the base map, they were to color contour the times and find out where we should drill (i.e., the topographic high) for oil. They couldn’t wait to start. They bolted out of the starting gates, but most groups quickly bogged down and made the usual mistakes rookie geophysicists make in the oil companies. For example, “Now, what is it I’m supposed to be doing? ... Hey, you’re holding the ruler the wrong way. ... Hold it, you’re mixing up the centimeter scale on the ruler with the inch scale. ... Whoa! You placed the times for inline

Figure 3. Hannah and Quinn working on their seismic maps.

Figure 4. Two-way-time maps of yellow horizon constructed by (a) OC geophysical team of Matt and Jordan and (b) ExxonMobil team. Although the color scales are different, both maps show a low-to-high trend from south to north; the OC kids correctly identified the topo high in the upper left corner as the place to drill.
Median filtering of Martians and soccer girls. After the seismic interpretation exercise, I started a new phase of the course, image processing. I explained how digital photographs are similar to color-coded contour maps in that colors are assigned numbers, and pictures of objects are represented by grids of numbers. Each number represents the appropriate color of the picture ... kind of like a John Nagy paint-by-numbers thing. “John Who?” “Never mind.”

I demonstrated picture pixelization by bringing a laptop computer to class and showed how zooming into a digital photograph revealed its pixelization. I let them use MATLAB to test the effect of different color maps on digital pictures.

The next week I explained the idea behind a median filter by placing a bunch of small-valued numbers on a grid, with a few large outliers. I then placed a 3 x 3 mask over the grid and showed how the numbers within the mask could be rearranged into a set ordered from small to large numbers. I then explained how the middle number or median number should replace the central number in the mask. Slide the mask over one pixel, and iterate until you have the new filtered image. Could they do it? Yes ... and indeed all teams were able to manually median filter an 8 x 8 grid of numbers. I was surprised when precocious Quinn came up to me the following week and discussed how he would handle the edge effect problem where parts of the mask hung off the grid’s edge. His strategy was to reduce the size of the boundary masks so that they fit onto the grid. Beautiful.

Now it was time to explain how median filtering was used to eliminate spurious noise in photographs. As an example, I gave each team a laptop computer with an installed version of MATLAB. I taught them how to download photographs of soccer girls and Martian landscapes (Figure 5) into MATLAB. These photos were deliberately corrupted with noise. I then taught them how to use MATLAB’s median filter medfilt1 and they applied it to both photographs. They played with different sized filters (5 x 5 seemed to work the best), and obtained results (bottom of Figure 5). They were especially excited about the “Face on Mars” photo that suggested signs of an old civilization on Mars, perhaps a monument with neighboring pyramids! Of course, I did not try to convince them otherwise but rather built up the tension by saying that the resolution (by now they understood the idea of a poorly resolved image) of this image was insufficient to refute or validate the conjecture of a past Martian civilization. “Hey mom, Sarah’s dad says there are alien civilizations on Mars and I will validate this claim next week by applying a 5 x 5 median filtering to hires digital photos!” “That’s good, now go clean up your room.”

Now that I had them in the palm of my hand, I built up unbearable tension and said that the next time we meet I would bring in the digital photos from the latest Martian orbiter that had more than twice the resolution of the current photos. This would prove once and for all, Martians or no Martians. They couldn’t wait. The week after New Year 2002, we reassembled and I brought in the deliberately corrupted photos (Figure 6) from the latest Mars orbiter. They eagerly set to work and applied median filtering to the digital photo. Again, a 5 x 5 median filter seemed to work best (bottom of Figure 6). To some this was a huge disappointment, it looked more like a mountain than a monument. However, a few holdouts still thought it could be a sign of ancient civilizations (Figure 7).

**Traveltime tomography.** Because the kids understood contour mapping, 3D seismic interpretation, grids of numbers, and had some linear algebra experience from third grade, I decided it was time to teach traveltime tomography. The beginning classes in the winter semester of 2002 introduced the concept of the traveltime equation.

I had to first introduce the concept of velocity or speed. They preferred the word speed but I got them used to the more technical term velocity. I used a car as an example, and...
then intuitively derived the velocity formula

\[ V = \frac{D}{T}, \quad (1) \]

and traveltime formula

\[ T = \frac{D}{V} \quad (2) \]

where \( D \) is the distance traveled, \( V \) is the velocity, and \( T \) is the time taken. To appeal to their worldly experiences I developed this equation in the context of traveling to different parts of the world. For example, find the time to go from Salt Lake City to New York by car, and then from New York to London by a Boeing 747, and from England go to Denmark by boat. The solution could be computed by using the following traveltime equation:

\[ T = \frac{D_{\text{car}}}{V_{\text{car}}} + \frac{D_{\text{air}}}{V_{\text{air}}} + \frac{D_{\text{boat}}}{V_{\text{boat}}}, \quad (3) \]

where \( D \) is the distance traveled, \( V \) is the velocity, and the subscript denotes the mode of transportation. I gave each team several “traveltime” problems to solve, where they used the correct velocities and a globe of the earth and string to measure distances. They seemed even more excited when they solved the traveltime equation for their family’s summer vacation.

One of the constant reminders I made was that there were “no naked numbers!” That is, all numbers in equations should have properly labeled units. I must have overemphasized this, because the kids delighted in frequently screaming “No naked numbers” whenever the occasion arose. They would even greet me in the hallways with this refrain.

The third week I introduced the concept of the inverse problem, i.e., given the traveltimes and distances traveled could one solve for the velocities of the boat, airplane and car. First, I used one traveltime equation (SLC-NY-London) with two unknowns \( V_{\text{car}} \) and \( V_{\text{boat}} \), and the distances and traveltime were given. I instructed them to construct a table of possible solutions, and graph these solutions in a \( 1/V_{\text{car}} - 1/V_{\text{boat}} \) plot. As some of them realized from their third grade algebra class, one equation with two unknowns has many different solutions. I then gave them another traveltime equation (SF-NY-London) and they also constructed the table of possible solutions, and graphed these solutions in the same plot as before. They realized the solution of one traveltime equation does not satisfy the other. However, they did realize that the intersection of the two lines provides the common solution. Eureka ... a way to invert for velocities from the traveltimes and distances. Finally, they were given an inverse homework problem to solve and bring in the next time, with the incentive of prizes for the well prepared.

The fourth week I introduced the idea that sometimes there are many unknowns and that it is too messy to try to invert the associated traveltime equations by graphing. Instead we use a black box called Gaussian elimination, but we don’t need to know the details. I then talked about the idea of seismic traveltime tomography where waves travel
through the earth and we measure them with geophones. I explained how seismic waves were generated, how they propagated, and how different rocks had different velocities and the fastest wave could take a travel path. Similar to the car-boat-airplane travelttime equations, we could also set up the travelttime equations for seismic waves traversing the earth. I gave them a picture of simple raypaths in a 2×2 pixelated earth model and had them set up the six associated travelttime equations. They learned the rule of thumb: More equations than unknowns in order solve for velocity!

The concept of recording seismic waves was demonstrated with a Bison 48-channel seismograph. We took the time to perform a seismic field experiment outside the school. They loved banging on the ground with the hammer (Figure 8), sticking geophones in the ground, and performing a crucial noise test by jumping up and down while the recorder was on (Figure 9).

The fifth week we demonstrated the use of tomography by letting them use a simple travelttime tomography pro-

gram that inverted for different models with a crosswell configuration. I also showed them actual tomograms obtained from data generated by earthquakes and shallow refraction experiments. They were impressed by the different colors and wanted to know what they meant.

Postmortem. The kids learned some mathematical-based concepts in exploration geophysics. All of them seemed to understand how to construct and interpret topographic maps. I believe they also grasped the idea behind a seismic section, at least well enough so they could pick times along a horizon and map out the topography of the interface. They also showed good execution skills in manually filtering a grid of numbers using a median filter. Most demonstrated their understanding by playing around with different filter sizes in enhancing the Mars images. I doubt if many of them really understood the tomography exercises; I really did not have enough time to whip them into shape in this area. But they had a grand time performing the seismic experiment. It seemed that their social status was elevated as many jealous classmates could only longingly observe their doodlebugging skills.

As a novice fourth-grade teacher, here are some of the things I learned.

• Never lecture more than 5-10 minutes. Most exercises should be hands on, and kids love to build things right away.
• Nonlinear intuitive approach to teaching seems to work well. Get to the main point quickly using intuitive thinking and examples.
• Emphasize hands-on exercises.
• Contests are important ... so are prizes (bribes?).
• If possible, juice up lessons with dramatic stories and language. It does not hurt to rivet their attention by loudly proclaiming the possibility of alien civilizations, reminding them that they are using seismic data that cost over a million dollars to collect, or the fact that the seismic camera can be used to find dinosaur fossils.
• Bring bananas and apples to fill up their fuel tanks.
• After two warnings, a student must leave (great advice from their veteran fourth-grade teacher Pam).

The above principles work equally well for teaching graduate-level classes.

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