Inquiry Based Pedagogy for Computational Surfaces in Geoscience

Several occurrences have awoken me to the kinds of barriers to teaching computational thinking as well as to the needs that exist for developing a curriculum in the Geosciences. I did not have a background in programming when at the start of my PhD program in Geology I was given a modeling type of project in Geomorphology. However, I did have a background in Philosophy and in the roots of logical reasoning. While learning programming and applying numerical methods did not come easily, I had a sense and appreciation for the reasoning, which in the end allowed me to ask the questions I needed in order to unpack my dissertation. In discussions with other graduate students I realized that their experience with applying programming for complex analyses and experimenting with models was unlike mine. Even our experiences with the layouts of our projects were very different, even though modeling was involved. I certainly did not use as advanced techniques in MATLAB as most modelers do. Yet in the process of producing raw point-cloud generated hillslope surfaces with a terrestrial LiDAR and importing them into MATLAB, learning what combinations of little codes could be applied to reconstruct the natural surface and experimenting with different parameters that degraded it through time, I learned what evolution of the land surface meant, I learned what modeling was, and I learned what questions could, should and needed to be asked. I am still convinced that little could have substituted for the understanding I gained by the approach I took.

A subsequent awakening moment occurred when teaching an Honors class with a mix of majors. I tried to explain different ways of reasoning and started with deduction and induction as examples of formats. None of the students knew what they were. Only one, a physics major, said he had heard “deduction” used in an upper level math class, but it was never explained. The rest said they had never heard of them. This encounter certainly explained much of what I have been experiencing as an instructor. Without ever having been taught to reflect on one’s own thought process or on what is prerequisite for thinking, how can science and scientific methods ever be taught and learned? If it is true that students are no longer being taught the basis of formal reasoning, except behaviorally in math classes where they solve math problems, we need to think about what the consequences can be for cognitive development, where future generations do not know the foundations of formal thinking that underlie language, the ability to formulate hypotheses and question assumptions, and the sense to know what evidence is and how to evaluate it. How will such a gap affect students’ abilities to read and comprehend? Can we expect students to be able to even form the mental constructs to receive and understand explanations? The longer I am in higher education, the more the situation appears to be the norm, rather than an exception.

Since no one has provided an alternative to the formal reasoning traditionally associated with all that most have come to relate with science, I feel an urgency to do something. I am also intrigued by the messy process I came to learn about quantifying a hillslope surface, a very formal matter for a computer and a programmer. Reflecting on this, I have been eager to develop curriculum to teach computational thinking about the Earth’s surface. What I suggest is something akin to teaching reasoning through a natural language approach. That is, teaching logical reasoning through the back door, where students are starting out. In other words, first have students track physical objects that will be tied to numerical constructs. Put students in the experience of having to need computation to understand data they physically generated. Terrestrial laser scans work really well for this: once the workings of the laser mechanism and the instrument positioning are explained there is a straightforward connection between digital points (point clouds) generated and coordinates in a measurable 3-D framework. For a natural surface, a collection of millions of sets of coordinates can be imported into MATLAB as a simple text file. From these points, with a physical grounding, a quantified surface can be constructed. This is the first of many steps where students reflect on the physical relevance of the data. The direct connection between the physical origins of the numerical data is important for understanding the significance of the computations that generate models of processes. This step paves the way for the teaching numerical modeling of a land surface through different time scales and for testing environmental parameters. Without this initial direct connection, modeling can easily become an exercise of number crunching and detached abstractions. It also allows inquiry and questioning that require reviewing the natural conditions against the models.

Using the MATLAB generated elevation model of a hillslope surface, an instructor can develop lines of inquiry related to asking how might we discover?....the number of years to smooth, degrade, or diffuse a surface given certain parameters and an accepted equation; how did the erosion rate vary across the surface; how did the micro-topography vary across the surface? Attempting to answer such process questions can lead to the students themselves, hopefully, asking the scientific questions of the causes of variability, applications of various time scales and how things might have varied through time, how can we design experiments that would allow us to test different conditions and scenarios, generate new data, and modify models? Using the lines of inquiry, students can be asked to generate the thinking needed and the short sets of code that would enable a program to run and produce the needed values. The final stage would be in implementing the codes, testing for errors and troubleshooting, and optimizing.

There are many options for where the course design might work best - a specialty designed course in Surface Processes, An introductory Earth process modeling course for graduate and senior level undergraduate students, a Geomorphology course (in a department with an expanded curriculum in computation). Departmental support is certainly preferable to trying to develop what is considered novel curriculum in a vacuum. So there may be a need to present and justify the pedagogy to a department before teaching it. Akin to teaching fine arts, there needs to be room and accommodation for experimentation, for messiness, and for working out the reasoning behind the syntax in order to build the mental constructs that might have been missing. The point is, if we are trying to draw in those without background of applying formal reasoning, we need to make programming and computation appear something less formal and more akin to inquiry, experiment, and artistic exploration.