Quantitative skills assessment for undergraduate courses

Motivation

Most faculty and TA's in DEES courses wrestle with issues related to the quantitative skills of the their students. Typical problems include:

i) How to present topics to students from a wide range of math backgrounds

ii) How to teach needed mathematical skills without sacrificing course content

iii) How to convey to students the fundamental role of math in Earth science

Though these problems are not new, several current trends exacerbate the situation including the increasingly broad systems approach to teaching Earth sciences and the expectation that students be able to perform mathematical tasks on a computer, such as using a spreadsheet. Though these challenges are confronted at all institutions, DEES has special circumstances that warrant recognition.

i) Broad faculty push cross−discipline or systems approach

ii) Lamont faculty generally have strong quantitative backgrounds

iii) While Columbia/Barnard students often need review of mathematical methods, most have at least been exposed to topics including algebra, trigonometry and graph reading

Everyone agrees that in order for students to understand modern Earth sciences, basic quantitative skills are a must. If these skills are deemed an essential component of critical science thinking, then they need to be explicitly addressed in individual courses and in the department curriculum as a whole.

This guide provides pointers for documenting, designing and assessing quantitative skills in Earth science courses. While the concepts below are not difficult, and they have been used effectively in numerous departments and classes, few courses address quantitative skills in an explicit way. Without recognizing the specific goals of a course, it is impossible to evaluate how effectively a course is teaching these skills.

Course goals

Define math objectives for a course...

Decide what math skills you expect of students exiting the course. Be realistic and only include skills that are important enough to warrant the possible class time spent teaching them. These objectives can be broad development goals aimed at improving a student's ability and inclination to use mathematics. This is particularly important when a course is part of a sequence. Examples would include use graphs to understand Earth processes or formulate back of the envelope calculations.

Define tasks which achieve these objectives...

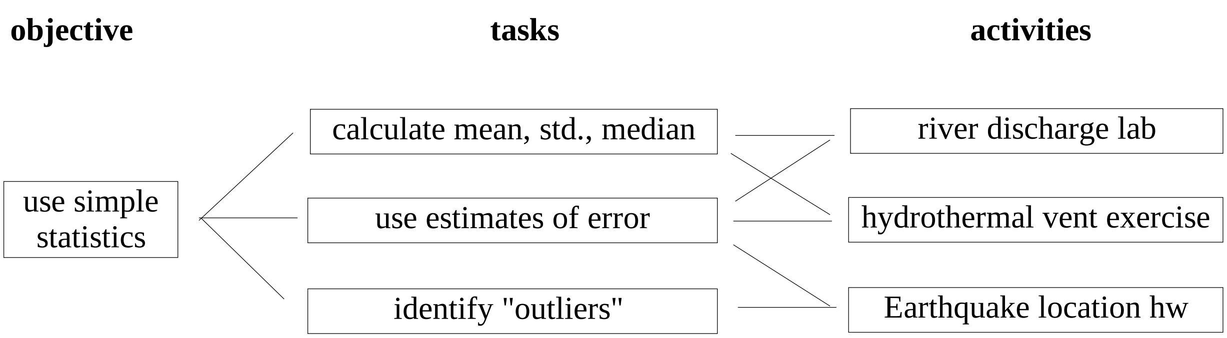
Select specific tasks that will help achieve the mathematical skill objectives. For example, if an objective is to use graphs to understand Earth processes, then possible task goals might include using a spreadsheet to create plots, manipulating logarithmic scales and identifying different types of trends on a plot.

While the distinction between objectives and tasks may seem tedious it separates the goals from what is can actually be taught. If the course catalogue claims students learn certain skills, then there ought to be a lengthy list of the specific tasks which are taught to address this goal. This approach allows faculty to state up−front what their expectations are for students. It also provides students with clear rationale for each of the otherwise mundane math skills they are likely to employ during the course. Manipulating logarithms may seem arcane to students, but the value of a logarithmic plot when studying earthquake probabilities is quickly understood.

Associate each task with appropriate labs or activities...

The final step is identifying which tasks will be addressed in each lab or exercise. By linking each task to one or more student labs, it is immediately clear how well each math objective is truly being addressed by a course. With an earnest assessment of the quantitative skills formally taught in a course, the instructor can then make choices about what types of labs should be added to fulfill the math objectives or where redundancy can be eliminated to free up curriculum space.

Example:



Why should this approach be pursued?

In addition to the altruistic motivation to teach an effective course, there are several practical reasons to explicitly categorize course skills.

i) compare what is actually taught versus expectations

ii) when are skills first introduced (when should they be addressed in class)

iii) is there necessary or excessive repetition of skills

iv) how does this fit in with other courses in the department

v) show students exactly what they are accountable for

By associating tasks and specific labs, it is easy to find the first time that a skill is called upon in a course. This is the logical time to provide a quick review of the subject if needed. While 5 or 10 minutes may be spent on this presentation, much more time may be saved in the long run by explicitly reviewing the subject and giving all students the same foundation.

Some typical quantitative expectations in undergraduate geoscience course

"Read" a simple mathematical equation in terms of an Earth process

- recognize simple mathematical relationships such as direct and inverse proportionality and square laws
- identify the constants and variables controlling an interaction

Make back of the envelope calculations

- feel comfortable working in scientific notation
- make order of magnitude estimates of length, volume, mass, etc.
- manipulate order of magnitude calculations in one’s head

Use concept of flux to evaluate a system

- describe rates of change
- use plots to demonstrate rate of change
- understand concept of a derivative, if not the derivation
- identify sources, sinks, reservoirs and fluxes for a system

Use plots to understand Earth processes

- make a plot of an dependent variable vs. an independent variable
- identify positive and negative correlation
- identify linear and higher−order relationships
- interpret a histogram
- create and read plots on a logarithmic scale
- select the best type of graph to display a given data set

Identify characteristics of a generic wave

- use wavelength, period and amplitude to describe wave phenomena

- recognize that wave patterns exist in space and/or time

Use simple statistics

- calculate mean, standard deviation and median
- interpret error estimates on data
- identify likely "outliers"

Evaluate probabilities

- intuitively feel the difference between probabilities of 99%, 1% and 0.01%
- use probabilities to judge the risks associated with natural hazards, for example
- understand that probabilities never specify what behavior will actually occur

Perform mathematical manipulations to a group of data

- use algebraic expressions as functions to estimate dependent variable
- use a spreadsheet to accomplish simply math functions
- use a spreadsheet to graph results of analysis

Relate quantities using different systems of measure

- identify the most logical system of units for a given problem
- convert units with confidence
- be familiar with the different types of units encountered in Earth processes