ON-RAMPS
to more effective teaching in tectonics

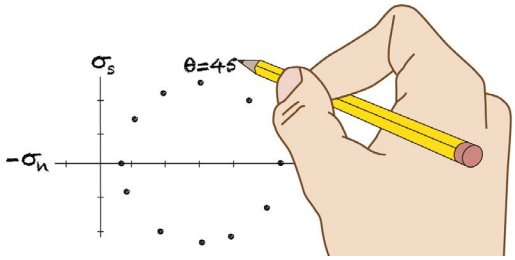
Quantitative skill-building

Strategies for effectively using math, graphs, and real data to build students' quantitative skills.

A simple example

SCENARIO: Many students learn to use Mohr circles but never really understand them or the underlying stress equations. To improve students' understanding of Mohr circles and simultaneously build their quantitative skills:

1. Have students describe each part of the fundamental equations of stress (what symbols stand for, units, etc.) and annotate the equations with their descriptions (*e.g.*, as a concept sketch). Have them add a description in plain English of what the equations mean.
2. Assign several different values of θ to each pair of students, and have them calculate σ_n and σ_s for each. Compile a group table, and have each student plot the results in σ_n /σ_s space, labelling points with θ values.
3. Have students annotate the Mohr circle with a plain English description of how σ_n and σ_s vary with plane orientation. Have students work in small groups to figure out how to use just σ_1 and σ_3 to plot a Mohr circle, as well as find σ_n and σ_s for a given plane.



Why add quantitative skill-building?

- Because mathematics is a tool used in all geoscience disciplines, students must have personal experience with realistic, robust quantitative problems.
- Math aversion, math anxiety, and lack of confidence are common among undergraduate geoscience students. Providing support for students to complete quantitative problems in tectonics successfully is one way to help students build confidence and become more comfortable doing math.
- Students commonly have abstract math skills but need review and help in placing those skills in the context of the geoscience courses that they take. Providing bridges between skills and application supports student success.
- Collaborative graphical and data interpretation are active-learning strategies that connect course content to real-world applications.

How much class time does it take?

- Quantitative activities can take from 5 minutes (a simple back-of-the-envelope calculation) to a class period (*e.g.,* the Mohr circle exercise) to several class periods (complex data processing and interpretation).

Tips for success

- As you design your course, make sure that math skills requried of students align with course prerequisites. If there are no pre-requisites (or if they are inadequate), design quantitative activities to build/review basic skills before moving to difficult problems or complex concepts.
- Integrate quantitative problem-solving throughout your course. Set the tone by starting with a simple calculation on the first day of class.
- Start with basic skills that students are likely to recognize (arithmetic, algebra), and provide support (tutoring, online help) for students who need review. Be deliberate about nesting or scaffolding skills so that students are prepared to move to more complex problems.
- Remind students that they already know how to do the math when they revisit a math concept in a new context.
- Give students a "why" that is placed in a geologic context, rather than just "solve for x" or "complete this operation".
- Have students work in small groups (≤4 students with a variety of skill levels, if possible) to solve quantitative problems, but be sure that everyone does the calculations.
- Combine higher-order learning skills with quantitative work by using follow-up discussions and reflections.
- Contextualize quantitative work within the science. Connect interpretation and scientific implications to the underlying geoscience data and math.
- Make sure that all students have a calculator that is appropriate for the tasks in your course and that they know how to use it. Consider providing simple calculators for students in order to minimize the problems that arise from having students use cell phones in class, lab, or on exams.

The On-Ramps Project provides quick-start guides for faculty interested in incorporating successful and easily implemented teaching strategies to improve student learning in the broad field of tectonics. The Project was funded by NSF grant EAR1841227 and grew out of a recommendation in the 2018 community vision document Challenges and Opportunities for Research in Tectonics.

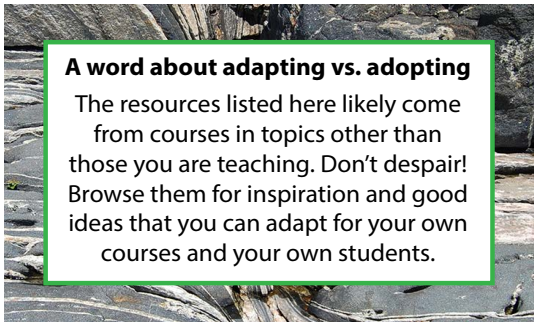
Additional tips and examples for quantitative skill-building

- **Provide support for a wide range of abilities.** Quantitative preparation of undergraduates is highly variable. Find resources that support student learning without too much extra effort on your part. Online tools (*e.g.*, The Math You Need, Khan Academy) or math tutors can provide resources to support students.
- **Encourage students.** Help students recognize that their quantitative skills are not fixed (*i.e.*, they are not inherently "bad" at math) but that, with practice and experience, they can develop and grow their quantitative abilities.
- **Given/Find/Solve approach.** Teach students how to approach a word problem. In class, ask them explicitly to identify **G**iven variables, what they are expected to **F**ind, and any equation(s) necessary to **S**olve the problem.
- **Two-minute graph analysis.** Present students with a graph or simple diagram (*e.g.*, the kyanite-sillimanite-andalusite phase diagram). Have students write a short description of the relationships they observe. You can extend this into a Think-Pair-Share and/or class discussion.
- **Dimensional analysis.** Have students take the equation for S-wave velocity and figure out what the units have to be for the rigidity modulus, μ.
- **A next step.** Leverage students' work with graphical data to give them experience with the primary literature. Ask students to read a published paper and analyze the presentation of quantitative data in the paper's figures.
- **Computational tools.** Design quantitative activities to use Excel, Stereonet, ArcGIS, or other software (*e.g.*, MATLAB), recognizing that you may need time for some extra instruction. Ease with these tools enhances marketable skills and improves career readiness.
- **Field exercises.** Incorporate numerical measurements such as strike and dip into your field trips. Design field exercises to capitalize on quantitative work you have already done in class. Utilize appropriate technology - the Stereonet app plots strike and dip measurements, so students can determine fold axes and axial planes and relate structures in the field to regional tectonics.

Resources on quantitative skill-building

From the NAGT portal *Teach the Earth*

- The Math You Need, When You Need It is a set of tutorials that place foundational math concepts in a geological context.
- Teaching Quantitative Skills offers best practices and tips for including quantitative analyses in a geology course.
- Visit Using Data in the Classroom for using data in your geoscience courses.
- Teach Stress and Strain with these ideas.
- Use seismograph data for locating earthquakes.
- Use Excel in metamorphic petrology for thermobarometry of pelitic schist.
- Hungry for more? Try a lab exercise built around determining viscoelastic rheology using cake.



A word about adapting vs. adopting

The resources listed here likely come from courses in topics other than those you are teaching. Don't despair! Browse them for inspiration and good ideas that you can adapt for your own courses and your own students.

Research papers on quantitative skills

Wenner, Jennifer M. and Eric M. Baer, 2015, The math you need, when you need it (TMYN): Leveling the playing field: Numeracy v. 8, no. 2, article 5.

Manduca, C. A., Baer, E., Hancock, G., Macdonald, R. H., Patterson, S., Savina, M., and Wenner, J., 2008, Making undergraduate geoscience quantitative: Eos Trans. AGU, v. 89, no.16, p. 149–150.

More On-Ramp pdfs & resources: serc.carleton.edu/onramps/index.html

- What are On-Ramps?
- Interactive lectures
- Brainstorming
- Concept sketches
- Jigsaws
- Compelling discussions
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