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Building Quantitative Skills in the Geosciences: An Example from Undergraduate Physical Hydrology

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Abstract

California University of Pennsylvania (CalU) has experienced unprecedented growth in its Geology program over the last five years. But many incoming students choosing to pursue Geology do not have adequate quantitative skills to adapt quickly to the rigorous coursework. Rather than remove quantitative materials from the curriculum, however, we have made a concerted effort to raise students' skill levels through increasing math requirements, as well as remediating within Geology courses in a science-based context. Hydrology is the first quantitative course in the Geology curriculum at CalU, and assumes a basic aptitude in Algebra and Physics and minimal familiarity with Calculus, but most students are still lacking in these areas by the third semester when most take the class. In order to maintain a reasonable pace of content learning, along with establishing the fundamentals of Hydrological analysis, it is necessary to remediate several quantitative skills to level the playing field and establish foundational skills for all class participants. For the past three years, CalU Hydrology students have used The Math You Need, completing quizzes as a part of their course requirements that focus on basic quantitative skills of unit conversions, scale, and rate calculations. The Math You Need incorporates discipline-specific questions and problems to present and test basic quantitative reasoning.
While students recognize that the quizzes are "extra" work and in some cases the material is below their skill level, they have demonstrated no resistance to completing them. On the contrary, students appreciate the quizzes for review and practice with concepts. On average, students improved, measured by pre- and post-test scores, approximately fifteen percent. Lower-scoring students demonstrate large improvements in basic skills, many over thirty percent. Follow-up attitudinal surveys of the students reflect generally positive reviews about the quizzes and the skill remediation as part of class. Students have requested using The Math You Need in other Geoscience classes. For Fall 2013, a new implementation will be used in Geomorphology.

The Math You Need

TMYN is used in connection with the Washington Mathematics Assessment and Placement (WAMAP) program (banner screenshot below). WAMAP was created and is managed at Highline Community College through the Mathematics program. TMYN, an NSF-sponsored program, provides a subset of questions within the WAMAP collection of libraries. These questions, in a geological context, were organized into individual assessments.

For the past three years (2011-2013), over the first half of the semester, students of EAS 303 – Hydrology at CalU completed a set of assessments within The Math You Need to set the stage for the higher-level physical concepts that we address throughout the course. The TMYN implementation includes six TMYN modules and quizzes assigned weekly for the first 8 weeks of the semester. Five of the quizzes were independent topics based on TMYN classification (Table 1), and the last quiz was a "Review" of the questions that students struggled with most. The quizzes were bracketed by a Pre-test of 25 questions, which were mirrored in the final assessment, a Post-test. For grading, to make sure students were motivated to complete the assessments, the Pre-test was Pass/Fail and each quiz score counted 0.5% and the Post-test counted 1.5%, for a total of 5% of the Total semester grade.

The TMYN Assessments were followed up with an in-class attitude survey to gauge the students feelings about the program, its implementation, and their own performances.

Course Implementations

EAS 303 - Hydrology
- Intended Sophomore-level course
- Offered every Fall
- Averages about 40 students (37 for Fall 2013)
- Pre-requisites : College Algebra (MAT 181) and Introduction to Geology (EAS 150)
- Intended to be "math-heavy" to introduce general math principles and physical concepts that will serve students in subsequent, upper-level classes; quantitative skills are an integral part of the course objectives
- Fall 2013 Demographics are below:

EAS 343 - Geomorphology
- Sophomore- to Junior-level course
- Two-year rotation
- Fall 2013: 50 students enrolled
- Pre-requisites : Introduction to Geology (EAS 150)
- Generally non-quantitative; Map evaluation of landforms including areas and slopes

Hydrology Participating Majors (37)		
Geology	17	Required Core Course
Meteorology	11	Required Core Course
Environmental Science (Bio)	7	Recommended Elective (Required beginning Fall 2013)
Environmental Earth Science	2	Required Core Course

Hydrology Grade Level	
First Year	0
Sophomore	14
Junior	18
Senior	5

Geomorphology Participating Majors (50)	
Geology	42
Meteorology	0
Environmental Science (Bio)	4
Environmental Earth Science	4

Geomorphology Grade Level	
First Year	0
Sophomore	10
Junior	26
Senior	14

Hydrology

Logistics

- **Why Use TMYN in Hydrology?**
  - Common Problems and Challenges:
    - Algebraic manipulation (Volumes, Areas, Rates, etc.)
    - Unit conversions
      - "A 5-gallon bucket, with a minor leak is left in the yard. It is full of water after a rain event. After 18 hours, the 14-inch diameter bucket only has 1 inch of water left. How much water drained or evaporated from the bucket?"
      - "In an average year, 1.0 meter of precipitation falls on a hypothetical catchment with an area of 1000 (or 10^3) km^2. What is the volume of water received during an average year in gallons?"
    - Basic aversion to math
- Previous Implementations:
  - Fall 2011 (presented at the AGU Fall meeting, December 2011, San Francisco, CA)
  - Fall 2012 (presented at the GSA Annual meeting, October 2012, Charlotte, NC)
- TMYN contains modules for Earth Science-related quantitative topics
- Students were required to participate as part of the EAS 303 - Hydrology course.
- WAMAP Logistics and Settings:
  - Pre-test
    - Assigned week one of Fall 2012 semester
    - Timed at 75 minutes
    - One attempt per question allowed
    - Mix of questions from TMYN modules and WAMAP TMYN libraries
    - Questions selected in proportion to content of the course
  - Quizzes
    - Accompanied TMYN Modules
      - WAMAP is intended for use after students worked through TMYN modules
      - Some WAMAP libraries have no module
    - Assigned roughly one per week
    - Timed at 60 minutes
    - Two attempts per question allowed
    - Students could receive 80% credit for a correct answer on second attempt
    - Several included questions from other modules
      - Scale and Unit Conversions
      - Some libraries lack a large selection of questions
    - Final Quiz was a "Review" of previous modules, especially designed to revisit topics of greatest challenge
  - Post-test
    - Assigned for completion in week eight
    - Timed at 60 minutes with ONE attempt allowed
  - EACH assessment included three uncounted attitudinal questions.

Table 1: Assessment	Completed (of 30 Students*)	Total Possible	Average Score 2013	Average Score 2012	Average Score 2011
Pre-Test	32**	25	**18.5**	17.5	16.1
Quiz 1: Unit Conversions	42	10	8.6	8.2	8.4
Quiz 2: Sci. Notation/Logs	38	10	8.7	8.6	8.3
Quiz 3: Scale	38	10	7.2	7.8	4.0***
Quiz 4: Reading Graphs	37	10	7.4	8.7	7.7
Quiz 5: Density and Rates	33	10	8.5	8.7	8.0
Review Quiz	39	10	7.4	7.3	7.4
Post-Test	38	25	**20.4**	21.2	21.3

*The semester started with 41 enrolled. Four students dropped the course. One student stopped the Pre-test after answering one question, and six failed to follow through on the program. Students completing most of the TMYN sequence are included.
**Includes students that dropped.
*** The 2012 "Scale" quiz had a Total Possible of 5 points.

Improvement Measures

From Above:
- **Pre- vs. Post-Test Improvement → +1.9 pts. = 8%**

Additional Notes:
- **26 of 30 students improved**
- 2011, 39 of 39 improved
- 2012: 37 of 42 improved
- Middle third of students had greatest gains, 4.0%
- Single largest improvement → 6.6 pts. = 30%
- Anecdotal Evidence
  - "It definitely helped!"
  - "WAMAP is extremely useful"
  - "The quizzes seemed to short."
  - **"Can we use this in other classes?"**

Table 2:

Student Groups	Pre-Test Score	Post-Test Score	% Improvement
Lowest 3	10.7	9.4	-6
	11.6	8.6	-14
	12.7	19.3	7
Highest 3	22.3	24.8	11
	22.5	24.0	7
	23.7	24.8	5
Lowest One-Third Avg.	15.4	17.2	9
Middle One-Third Avg.	**19.5**	**23.5**	**18**
Highest One-Third Avg.	21.7	20.6	-4

Geomorphology

Logistics

- **Why Use TMYN in Geomorphology?**
  - Common Problems and Challenges:
    - SAME Reasons as Hydrology!!
      - Unit Conversions and Scale, especially!
      - Spatial understanding of landforms and landform development requires quantitative analysis
    - Examples:
      - Volcanic Landforms: Spatial extent, length of run-out of flows and deposits, slope (Figure 1)
      - Mass Wasting events: Spatial extent, slope, mass vs. distance (Figure 2)

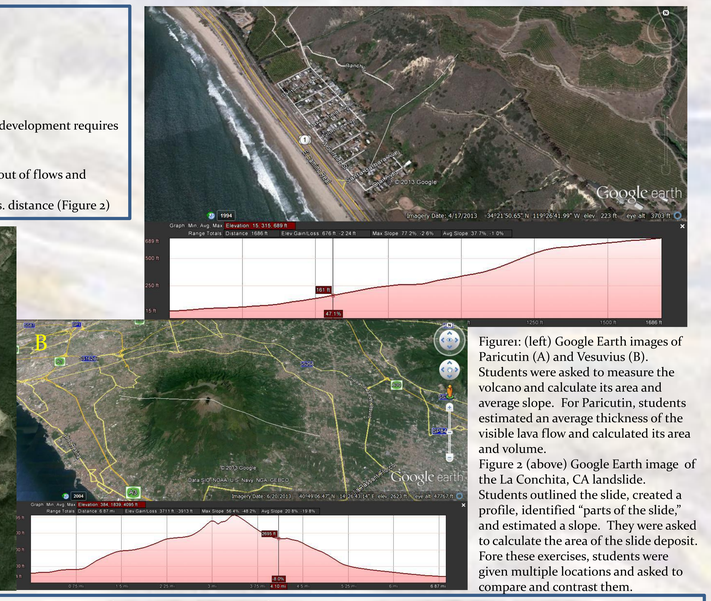

Figure1: (left) Google Earth images of Paricutin (A) and Vesuvius (B). Students were asked to measure the volcano and calculate its area and average slope. For Paricutin, students estimated an average thickness of the visible lava flow and calculated its area and volume.
Figure 2 (above) Google Earth image of the La Conchita, CA landslide. Students outlined the slide, created a profile, identified "parts of the slide," and estimated a slope. They were asked to calculate the area of the slide deposit. Fore these exercises, students were given multiple locations and asked to compare and contrast them.

Student Attitudes

Table 3:
- **Confidence** is the critical factor I was hoping for as an outcome of using TMYN; the survey seems to indicate this was improved. I was curious if these assignments were viewed as busy-work, and was pleased the number is so low.

Table 4:
- Students' "favorite" Unit Conversions was perceived to be the most useful in their careers. However, Scale is the most difficult, and I believe they misconstrue as unimportant!

Table 5:
- Students attribute their improvements to a better understanding of the material. They were encouraged to give an honest answer, and consider the other choices.

Table 3: Attitude Question	Average Response
I feel MORE CONFIDENT in my ability to address quantitative problems.	3.8
The questions/content were relevant to work I will likely do in my career.	3.8
My quantitative skills have improved.	4.0
The instructor used these tasks for busy-work, not to improve my skills.	1.9
The quizzes provided adequate repetition and breadth	3.9

Table 3 (left) responses included a Likert Scale:
- Strongly Agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly Disagree = 1

Table 5 (below) responses to ascertain why the students thought their quantitative skills might have improved

Table 5: Yearly Responses to Improvement Perception, "My skills have improved because of…"	2013 (%)	2012 (%)	2011 (%)
Increased understanding of quantitative principles and methods	52	82	43
Familiarity with Questions (same Pre- to Post-test)	20	14	25
Familiarity with Format (comfort with WAMAP)	17	4	21
Logistical reasons (more time, quieter surroundings, well-rested, etc.)	11	0	11

Table 4 (below) based on students' feelings about each topic covered independently on the five quizzes.

Table 4: Question	Unit Conv.	Sci. Not.	Scale	Graphs	Dens/Rate
Favorite?	**11**	4	2	**11**	7
Least favorite?	6	3	**14**	6	6
Most difficult?	4	1	**21**	5	4
Least difficult?	8	**12**	0	11	4
Most useful?	**15**	1	2	11	6
Least useful?	2	**16**	14	1	2

Conclusions

Challenges:
In 2013, students had more trouble than in previous years with WAMAP, especially with graphing and input of decimal answers. A broader, and more discipline-specific module for Hydrology would significantly improve TMYN for my students.

Advantages and Success:
MUCH less time IN CLASS is spent on fundamental math concepts. Math-averse students continue to make gains and most student responses are positive. Low-impact assessments of WAMAP, as a graded part of the class work are attractive to students that struggle with traditional exams and problem sets.

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