

Using Logic Problems in Introductory-Level Geoscience Courses to Develop Critical Reasoning and Basic Quantitative Skills

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ABSTRACT

Problems that involve quantitative skills require students to reason logically. Strong logical-reasoning and problem-solving skills are necessary for students in proceeding with the application of mathematical methods. Introductory geoscience courses offer an excellent opportunity for students, especially nonscience majors, to develop their problem-solving and quantitative skills. A series of logic problems that increase in difficulty level as the course progresses are given to students in my introductory geoscience courses. Because each student works through problems at his/her pace, many exercises are given as homework. To tie the problems to the course material, real geologic data are used. For example, one logic problem uses streamflow discharge data for a local river. Each student must perform unit conversions, solve the problem, plot data, and provide a written interpretation of the graph. At the end of one semester, a majority of students state that their self-reported ability to solve logic problems has increased. It is essential that students have the confidence and ability to solve relatively simple problems before they can go on to complete problems requiring the use of more complex quantitative methods.

Keywords: Education – geoscience; education – undergraduate; miscellaneous and mathematical geology.

Introduction

Using logical-reasoning skills is important in developing the problem-solving abilities of students. It is not until students are confident with their ability to approach problems that they can successfully and effectively develop quantitative skills. Typical high-school and introductory college-level math courses teach mathematical function or formula one at a time and how to complete exercises with that one function, but not necessarily the *application* of the math function. It is critical for students to be able to think through problems and understand what mathematical functions must be used and how to properly apply them. This is where having students in introductory-level courses work on exercises to develop their logical reasoning can greatly assist them when they need to apply their quantitative skills.

Although it is true that many students are weak in the application of mathematical methods, I felt that I needed to focus my attention on developing one additional skill first. I knew I could teach my students

formulas and show them multiple ways to work with numbers; however, I have found that my students initially struggle when reading through a problem for the first time. Students not majoring in the sciences typically struggle with, not only how to solve problems, but where to begin. To address this weakness, I decided to focus attention in my introductory-level geoscience courses on developing skills pertaining to problem solving. I want to teach students how to read through problems and how to extract the necessary information to continue. It is with logic-building exercises that students can become stronger problem solvers and confident with the application of their quantitative skills.

Few papers document the use of logic problems to develop critical thinking in the K-6 classroom (for example, see Sadler, 1993), and an even smaller number of papers have been written that discuss the use of logic problems in the college classroom. Some investigators at the college level have documented student weakness in reasoning skills and have developed a variety of approaches to addressing the weakness. Eflin and Eflin (1998) have developed discipline-specific examples relating to global environmental issues to teach students the tools of critical reasoning. They emphasize that students cannot make critical judgments without first understanding the structure of critical reasoning and that the logic of argument forms used to make critical judgments is a necessary tool that can be conveyed through interactive classroom activities. Castro-Acuña and others (1999) also stress the importance of developing reasoning skills in students and have designed logic puzzles that require knowledge of chemistry and the capacity to use data as part of a logical approach to finding answers. At Florida International University, Aladro and Ratner (1997) have developed a course titled “Sets, Logic, and Writing,” where the objective of the course is to enhance critical-thinking skills through set theory and symbolic logic, while involving writing as a critical-thinking tool. The students develop problem-solving skills in both mathematics and composition during the semester. None of these papers, however, has as its objective having students complete logic problems not only to develop better problem-solving abilities, but to enhance quantitative skill building.

To develop the logical-reasoning skills of my students, I decided to integrate a series of logic problems into my classes. Instead of just giving students problems already written and photocopied out of a book, I develop a series of problems I call *GEOLogic* problems that relate to the course material. Unlike logic

problems from puzzle books in the local bookstore or on the Internet, GEOLogic problems deal with geologic processes and location names, and they use geologic terminology. Most of the problems require students to perform calculations or work with formulas, thereby helping them develop basic quantitative skill.

Why Logic Problems?

In general, I believe that logic problems are beneficial in that they allow students to develop critical and stronger reasoning skills. The logic problems require students to approach problems from multiple points of view, and allows students to successfully solve problems with confidence. In order for students to follow through with the application of their quantitative skills on any problem, logical reasoning must come first. I have designed the *GEOLogic* problems for students in introductory-level geoscience courses. These students are mostly non-science majors, taking what is both their first and last science course. They commonly do not have self-confidence in their problem-solving abilities, no matter what their actual skill. The problems are at a basic level, which the *Dell Book of Logic Problems* defines as, "... common sense, some reasoning power, and a basic grasp of how to use the charts or other solving aids provided" (Rothstein, 1992). The difficulty level of the logic problems increases throughout the semester by increasing the complexity of the clues and the charts. The increase in difficulty level is designed to keep the exercises challenging to the students.

The problems also disguise the fact that the students are developing their skills working with numbers and numerical phrases. The students do not think, and are not told, that they are working with and doing mathematics. Although some of the logic problems I have developed require students to perform basic unit conversions before solving the logic problem, the students do not look at the exercise as an exercise in mathematics. In addition, students must be able to accurately read and interpret phrases such as "x is twice as big as y," "x is the day before y, which is the day before z," and "x has fewer than y," in order to successfully solve the logic problems. Ranking and ordering values properly is essential when applying quantitative skills.

Development and Implementation

The format and structure of the problems are patterned after the published logic-problem books and magazines of Dell Publishing and Penny Press, Inc. My logic problems are personalized by including names of familiar places and subjects, and a new logic problem is assigned every one to two weeks. The problems are to be completed in class, during the laboratory period, or as a take-home assignment. Typically included with each logic problem is an Internet exercise or calculation exercise. This part becomes the graded portion of the assignment. Others that utilize logic problems, such as Castro-Acuña and others (1999), state that they give logic problems as extra-credit take-home assignments.

One of the problems students receive early in the semester to get them familiar with the style of logic problems is titled "Office Hours." This problem describes four students, each of whom lives in a different dorm, each student coming to my office at a different time for help in a different course. Students are required to put the events in the correct order of occurrence. Students can certainly relate to office hours, the names of the courses are ones offered in the department, and the names of the dormitories are taken from dormitories on campus.

After they have completed the first two or three logic problems, when students are familiar with the problem format, the content of the problems directly relates and is supplemental to the course material. When I am discussing planetary geology, one logic problem I have given my students is titled "Jovian Planets" (see Figure 1), where students must match up each Jovian planet with its corresponding period of rotation, equatorial radius, and mean orbital velocity. While becoming familiar with relative time, distance, and rate, students must be aware of what the values mean. For example, a large value for period of rotation means that a planet takes *longer* to complete one rotation. Students will commonly associate a higher number with a higher speed, such as when they are driving a car. After students complete a similar problem for the terrestrial planets, I have them compare characteristics within and between the terrestrial and Jovian planets. The students learn more than what is in the text with these problems. They read that the Jovian planets have rings, but they do not realize that the larger, gaseous planets rotate faster than the terrestrial planets.

Another problem lists seven scientists who are examining daily mean discharge data for a river that passes through the town where the college is located. In this problem, students first are required to convert the stream discharge data to appropriate units. Then they must match up the first and last name of each hypothetical researcher with the appropriate year and stream discharge data. Part II of the problem includes a graphing exercise as well as interpretation of the data. Not only are students working on such basic quantitative skills as unit conversions and graphing, but the data in the problem are streamflow data available on the USGS Water Resources Division web site. Students learn about stream-flow discharge rates, what controls the rates, and where to obtain this information from the Internet.

There is a danger of losing students early on in the semester to frustration and the development of a negative attitude towards the problems. In addition to going over a problem the first day of class, I also hold a logic help session a few weeks into the semester for students who are still struggling with the concept of working with problems in this format. Only 26% of my students came to the help session or had come to my office for extra assistance, but of those, 94% stated that just spending one extra hour with me on the problems helped them dramatically.

Jovian Planets

Match each Jovian planet with its equatorial radius (abbreviated in the clues as ER), its corresponding mean orbital velocity (abbreviated as MOV), and its period of rotation (abbreviated as POR).

- 1) Jupiter, which does not have an MOV of 5.43 km/sec, has a larger ER than that of Uranus.
- 2) Saturn, which has an ER 35,504 km greater than that of Neptune, has an MOV which is less than that of the planet that has a POR of 9.92 hours.
- 3) The planet with an ER of 60,268 km has an MOV that is 2.83 km/sec greater than that of the planet with an ER of 25,559 km.
- 4) The seventh planet from the sun has the second slowest MOV, but has the longest POR; Uranus does not have the largest ER.
- 5) The planet with an ER of 24,764 km does not have a period of rotation of 10.66 hours.

		Equatorial radius				Mean orbital velocity				Period of rotation			
		24,764 km	25,559 km	60,268 km	71,492 km	5.43 km/sec	6.81 km/sec	9.64 km/sec	13.06 km/sec	9.92 hours	10.66 hours	16.11 hours	17.24 hours
Planet	Jupiter												
	Saturn												
	Uranus												
	Neptune												
Period of Rotation	9.92 hours												
	10.66 hours												
	16.11 hours												
	17.24 hours												
Mean Orbital velocity	5.43 km/sec												
	6.81 km/sec												
	9.64 km/sec												
	13.06 km/sec												
Planet	Period of rotation (hours)	Equatorial radius (km)				Mean orbital velocity (km/sec)							
Jupiter													
Saturn													
Uranus													
Neptune													

Figure 1. *GEOLogic* problem that challenges student understanding of comparative distance, time, and rate. Students are required to match the equatorial radius, mean orbital velocity, and period of rotation with the corresponding Jovian planet. The problem is loosely based on *The Dell Book of Logic Problems #05, "Vital Statistics"* (Rothstein, 1992).

Assessment

The logic problems force the students to examine a problem from many different viewpoints and use several different approaches to reach a solution. I feel that these problems assist students with their critical-thinking and problem-solving skills and, therefore, the application of quantitative skills, although this is difficult to measure.

A student survey was given to my introductory-level students at the beginning and at the end of the semester on their self-reported ability to solve logic problems. The survey of the 70 students in my class showed that a little over half the students had attempted and/or successfully completed logic problems in this format previously. Overall, students self-reported that they felt their logical-reasoning skills had improved. At the beginning of the semester, 66% of the students rated their logic skills as "pretty much nonexistent," 25% as "so-so," and 9% as "excellent." By the end of the semester, the same survey showed that 6% of the students rated their logic skills as "pretty much nonexistent," 67% as "sometimes successful with problem solving," and 27% as "excellent." Overall, 48% of the students thought they had made "some improvement" in their skills during the semester (even if they were still just "so-so" or "excellent"), and 46% thought that they experienced a significant increase in their confidence level in solving problems with logical reasoning.

The student response to the problems ranged from frustration to eagerness. Surprisingly, all students are motivated to conquer the logic problems. One student stated that "they are fun when I manage to complete them, I feel a kind of triumph." It is very common when I am handing out a new problem in class to hear students comment, "I am going to solve this one this time." The students also appear to enjoy this nontraditional approach to developing problem-solving skills in my introductory-level courses. One student commented that the problems are "...teaching us how to learn 'off the beaten path' – at first they tortured me but now I really enjoy them."

Fortunately, my students realize the value of exercises involving logic. One student commented that "science is based on methodology which in turn is rooted in logic" and that the problems "...develop more intricate thinking – they make you think harder and pay more attention to detail." Another student stated that the problems "...get us thinking in ways that most of us probably haven't before!" I tell the students that most colleges and universities offer entire courses called "Logic" and that typically the Philosophy Department, not the Mathematics Department offers these courses. This comes as a surprise to the students. The students, most of them freshmen and sophomores, are also surprised to learn that one-third of the GREs is a section on logic and the LSATs has a logic section as well.

Although 87% of the student feedback has been extremely positive, students have raised some valid concerns. I have developed the logic problems with a geologic focus, but some students do not see the purpose of them in my course. For example, one student

commented that "I understand the need for exercises in conditioning the mind – however, I do not exactly see the relevance as pertaining to geology. However, I do not mind attempting the problems as part of a *science* class." Not only have I made an effort to include real geologic data in the logic problems, but the problems expose students to the common forms of units (rates, distance, time, and so forth) used in geology.

The issue of whether the problems should be graded also concerns students. A student commented that the problems, "...are actually kinda fun, but it would probably be way too stressful to make them graded." When surveyed, 79% of the students thought that the logic problems should not be graded but instead preferred that extra credit should be given. Several students commented that the purpose of the course is for me to teach geology, not to test students on how well they can solve problems. The students must show a strong effort at solving the problem in order to receive credit for the assignment. However, I do emphasize that part of my purpose in this introductory-level science course is to expose students to the methods of science and to try to get the students to think like scientists. I even had a student comment that "I appreciate that you recognize this (how these problems allow you to use your logic in thinking) and try to improve our problem-solving skills."

Conclusions

The *GEOLogic* problems are a valuable tool to help students develop reasoning and critical-thinking skills. When students are confident with how to approach a problem, then they can successfully and effectively develop higher-level quantitative skills. Although it is difficult to measure the results quantitatively, the majority of students report they feel more confident and comfortable with the problems and believe that their own problem-solving skills have improved during just one semester. As noted earlier, the *GEOLogic* problems allow students to further develop their problem-solving skills, to read through and determine what the problem is asking, and to understand how to extract all the useful and necessary information from the problem. With the addition of some basic mathematical functions such as unit conversions and graphing, logic problems are useful in developing simple quantitative and basic problem-solving skills in introductory-level geoscience courses.

Acknowledgments

The author credits the 1999 Project Kaleidoscope Workshop on Building Quantitative Skills for motivating her to start integrating exercises that involve problem-solving skills in the classroom. She thanks her brother and his co-workers for performing a test-run on the problems and the students in her introductory-level geology courses, spring and fall 1999, for giving the problems the "old college try." Eric Grosfils, Heather Macdonald, and an anonymous reviewer provided comments that significantly improved the manuscript.

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About the Author

Laura Guertin received her undergraduate degree in geology from Bucknell University and her PhD in marine geology and geophysics from the University of Miami's Rosenstiel School of Marine and Atmospheric Science. She enjoys teaching introductory-level courses, as well as other "soft-rock" and marine-science courses. She has taught for the past two years at Mary Washington College.