Teaching and learning project proposal:
GEOL 202 mathematical literacy intervention

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ABSTRACT

The quantity and breadth of background knowledge required to excel in upper-division Earth Sciences courses is large, and constantly growing. Our curriculum has grown to keep pace with the changing field, and changing demands on graduates in the workforce. One place our introductory curriculum has not kept pace with upper-division coursework is in mathematical literacy. Three of the four major tracks in the Earth Sciences department require substantial math and physics coursework, but most students first apply those quantitative skills to geology in upper-level electives. In order to better prepare students for their upper-division coursework in the Earth Sciences major, I plan to add a module to the introductory sequence whose goal is improved mathematical fluency.

The module's objective is improving student confidence translating between their budding intuition about Earth processes, and mathematical notation. It's intended outcome is for students to independently formulate a basic differential equation that describes a natural system.

Much prior work has tested the benefits of inquiry-based learning across STEM disciplines. Most workers have argued for a heavy focus on student-led discovery over direct dissemination of results and facts. This approach has proven beneficial in many direct comparisons. However, some students find the unconfined nature of inquiry-based coursework stressful.

In my own teaching I have encountered multiple students who articulated a well-reasoned, metacognitively-derived desire for practice with structured, disseminated "toy" problems, before attempting to develop ideas and results independently. This anxiety with open-ended inquiry isn't inherently bad, but it begs the question: can a hybrid approach between traditional dissemination- and inquiry-based learning be a more effective pedagogical tool than either of the extremes?

To test this question, I will do a trial run of my module that aims to compare an inquiry-based lesson plan with a hybrid structured/discovery-based design. This will take the form of a "jig-saw" exercise, in which students prepare in different ways, and then collaborate to solve multi-faceted conceptual and technical questions.

GEOL 202 has 43 enrolled students in Spring, 2018. They are divided approximately equally between two lab sections. In a lead-up to the module, students will complete one of two preparatory homework exercises, assigned randomly. In one lab section, students will work in heterogeneous groups of peers who did either version of the homework. The other lab section will group students with peers who did the same preparatory assignment. Success of the intervention will be measured with a shared assessment on the final exam to compare competency in the intended outcomes. The results will help decide which lab format to employ going forward, as part of the common syllabus.

I hypothesize that students who collaborate in the "jig-saw" lab with peers who did a different preparation will be more successful than those whose partner did the same preparatory exercise, regardless of which preparatory exercise the individual did.

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BACKGROUND

The benefit of inquiry-based learning in STEM has been explored in depth. Freudenthal, (1991) describe a system of mathematics education which emphasizes the importance of mathematical modeling through solving hypothetical real-world problems. The system is known as Realistic Mathematics Education (RME). It outlines specific principles intended to increase student buy-in, and engagement in mathematics education at any level (Heuvel-Panhuizen and Drijvers, 2014). RME principles are broadly inline with established active-learning principles (Handelsman et al., 2006).

One place where RME is more radical than methods discussed elsewhere is the role of problem formulation using mathematical language, c.f. choosing from predefined, well-posed formulas. Rasmussen and Kwon, (2007) go further to encourage complete "reinvention" of key mathematical ideas. Their approach, known as Inquiry Oriented Differential Equations (IO-DE), is rooted in mathematics curriculum, but encourages students to look outside of mathematics to ground their work in real-world applications.

Both RME and IO-DE treat mathematical modeling as a set of skills that bridge "perceived reality," "domain of inquiry," "systematization," and "mathematization" (Blomhøj and Jensen, 2007). The IO-DE curriculum's primary goal is development of the mathematization step. Intuition necessary to connect perception through systematization is then a secondary objective.

In my case, systematization is the primary goal, and the other steps are considered background knowledge. Therefore, rather than encouraging students to search out applications for the tools at hand, as in IO-DE, we encourage students to seek out tools for the types of problems we aim to solve. This can be pedagogically challenging because it limits applicability, and requires balancing geologic and mathematical course objectives. However, approaching modeling from an applied perspective also creates opportunities, because students begin with a more well-developed intuition for the problems at hand.

METHOD / ANALYSIS

In designing my module, I have employed many of the same principles of RME and IO-DE, with an emphasis on "systematization" of a geologically-relevant problem. The format of the module is as follows:

- Students will receive a homework assignment during the prior class session. I have written two parallel homework assignments which address similar concepts. One version focuses on student-oriented introspection about the nature of calculus, and its connection to natural systems. The other exercise presents technical word problems, and asks students to solve them using basic calculus concepts. The two exercises will be divided randomly among the students. They have five days to complete the exercise.
- On the homework due date, all students participate in the same 1 hour and 20 minute "lecture" session, in which they will be asked to participate in several activities. Each activity explores the conceptual basis of mathematical modeling.
- During lecture, I will announce the final exam question, allowing students time to consider it before the exam.
- Both lab sections meet the same afternoon (after lecture). Students will continue their group work in lab, but now on a set of more technical problems. Both labs will receive the same assignment. One lab section will be asked to partner in groups who did the same homework

version. The second section will form mixed groups of students who did different homework versions.
- Students will be given a follow-up survey after the module, but before the final exam, to assess their subjective experience with the module. Completing the survey will be worth 1 extra credit point, but will not be graded.
- The final exam will include one question that asks students to carry a conceptual model through from intuition to mathematization, as a holistic measure of their ability to solve word problems.

Following Moody, (2017), I will use student competency, as demonstrated in the shared final exam question, to determine the efficacy of each lab/homework combination. It thus becomes necessary to define competency for the purpose of assessment design, and comparison.

Blomhøj and Jensen, (2003) define competency in numerical modeling as "insightful readiness to carry through all parts of a mathematical modeling process in a certain context". To assess student competency with systematization, the final exam question will require formulating a mathematical system that describes a phenomenon with which everyone has some prior intuition. I chose heat conduction through a mug, but any number of similar problems can substitute. The question requires students to describe in words how they came to their conclusion. The question is phrased to provide multiple entry points, so that students who are stumped by one aspect can demonstrate their knowledge in another aspect for partial credit.

Secondarily, students are asked to come up with a different system that obeys the same equation. The intent is to assess the ability to traverse the modeling process in both directions: from reality to math, and back.

Assessment of response quality will be based on demonstration of logical progression of thoughts from perceived reality to the final mathematical system. Most weight will be put on demonstration of systematization skills including their decision about choosing variables, and recognition of mathematical concepts (derivatives, in this case) in the problem.

HYPOTHESIS TESTING

Our methods divide the students into four groups, representing combinations of homework version, and lab section. Based on prior studies, we might expect that the highest performing group would be the students in the jig-saw lab who did the conceptual homework exercise. They benefit from both the conceptual nature of the preparatory exercise, and the jig-saw structure of the lab. We would expect the lowest performing group to be the students who did the technical homework assignment, and worked with other students who did the same. Contrary results between these first two groups would be an interesting unexpected result, and worthy of further investigation.

The other two groups are of more interest to this study. No prior work that I'm aware of has tested this comparison. I predict that the benefits of a jig-saw structured lab will outweigh any adverse effects of a non-inquiry-based preparatory exercise. This hypothesis is based on conversations with students from prior technical courses, about their comfort with open-ended inquiry-based course design. Comparison of the two will be novel. A statistically significant difference between the two would be of interest to the broader STEM education community, and would likely result in a publication.

In the null case where no statistically significant benefit is shown, the lab going forward will be the hybrid model where students work in heterogeneous groups, because the "jig-saw" format is more closely aligned with established active learning practices (Handelsman et al., 2006). A null result may also be publishable, but likely of much lower impact. In such a case, it is possible to run the same experiment again on future GEOL 202 courses to aggregate more data.

OTHER CONSIDERATIONS

We have to work with two fundamental limitations of this study. The first is variable prerequisite knowledge of individual students. Most, but not all, students in GEOL 202 have taken GEOL 201, and are typically on track to enter one of the Earth Sciences major tracks. Most have taken, or are currently co-enrolled in calculus. I do not readily have access to information on students prerequisite coursework, and therefore would have difficulty normalizing for its effects.

The second limitation of this study is the small sample size. Considering students heterogeneous backgrounds, including prior coursework, and myriad social constructs that prevent comparison of people by almost any metric, I expect statistical significance may prove difficult to achieve. I have discussed a plan for null results above, but it is possible that this same study could be run again during future GEOL 202 course offerings to increase the net sample size.

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