As a part of our faculty-STF partnership this semester, we began to delve into the challenges of better understanding what students write:

- Does clear writing always (or generally) represent clear thinking?
- And why are some written explanations so much better?
- Do "bad" explanations always represent fuzzy thinking by students?
- Why are many student written explanations not very "good"?

In Introduction to Sedimentology and Stratigraphy, an upper level majors' geology course, students write short answer or longer essay-type questions for most assessments (including homework, quizzes, exams, and lab exercises). In examining student writing, we wondered:

1. Why are many student written explanations not very "good"?
2. Why are they so often poorly organized, miss the point, are incomplete, or seem like a brain-dump of everything a student thinks they know about a concept?
3. Do "bad" explanations always represent fuzzy thinking by students?
4. Why are some written explanations so much better?
5. Does clear writing always (or generally) represent clear thinking?

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Introduction
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What do we mean by "good" written explanations?
"Good" explanations are what scientists/experts write.

When we examined our own practice, we noted a typical pattern:

1) Start with a statement proposing an answer to the question. This is often in the form of a complete sentence (can be a thesis statement).
2) Support the statement with relevant data and reasoning, pointing out general patterns, relationships, and/or trends that link to the original statement.
3) Often, but not always, we use a simple sketch or diagram to anchor our explanation.

Poor explanations are often incomplete or imprecise, and/or have poor organization. Preliminary analysis of one midterm exam question and one homework question for all students (augmented by additional quiz, homework, and lab exercise questions for a few students each), revealed a few common modes within these two categories.

In "brain dump":
- Students write as much as they can to make a complete answer.
- Students generally do not think about the process of organizing data.
- Students write explanations that are long, meandering, and sometimes disconnected.

"invisible ink" writing spirals towards a coherent explanation:
- Explanations have characteristics of both mode.

"brain dump": significant extraneous information (although may be true)
- Invisible ink": students think they’ve communicated information that is not there from the instructor point of view.

Asking: Above is a crude diagram showing a mountain source and a plain stretching away from that high area and going into the ocean. Minerals like halite and calcite are found in the shallow marine setting on the right side of the diagram. Explain how those minerals are the result of weathering of the granite source rock. Be sure to include what kind of weathering must have been involved.

Expert-like student explanation
Chemical weathering of granite source rock (mountains) will produce soluble constituents such as iron, calcium, and carbonate ions. These ions precipitate out of aqueous solutions (as in a shallow marine environment) to form calcite and halite. Chemical weathering involves the breakdown of source rock into altered mineral forms due to water and carbon dioxide reaction with the granite. Thus new minerals, composed of soluble constituent ions (which once was granite) are formed after intense chemical weathering and mechanical transport (as indicated in the diagram). (student annotated the diagram as part of the explanation.)

"Brain-dump": If the source rock is granite, its main minerals are likely to be quartz, feldspar, plagioclase, micas, and maybe hornblende. Feldspar and plagioclase and mica are not very stable and were probably chemically weathered to produce clay. The clay likely made it to the ocean from the mountains. Halite is an evaporite that forms during periods of very dry conditions, it is mostly salt. Salt is mostly NaCl. Na could have been provided by the sodic rich feldspar that was weathered in situ and then eroded to the ocean. Calcite is a common cement that can be precipitated. Calcite can be produced from the weathering chemically of granite, especially micas.

What can we do to improve the quality of student written explanations?
Adopting prior work:
Claim-evidence-reasoning instructional model of McNeill and others: McNeill and colleagues (references below) describe an instructional framework for supporting student construction of scientific explanations. This model explicitly articulates three components of scientific explanations:

1. Claim - an assertion or conclusion that answers the original question.
2. Evidence - scientific data that supports the claim needs to be appropriate and sufficient to support the claim.
3. Reasoning - a justification that links the claim and evidence and shows the evidence as appropriate and sufficient scientific principles.

The instructional framework provides a structure to how students articulate their understandings, designed to guide their sensemaking; students are exposed to the structure through an introductory unit and then scaffolded instructions throughout later investigations. Although designed for a middle school science curriculum, this model seems highly applicable for the undergraduate science curriculum. The three part framework explicitly articulates three components of scientific explanations we identified in our own practice. We attempted to implement a scoring rubric used for this model, with some success, but found that explanation questions in assessments for this course usually did not require as complete an answer as questions in the model.

Examples

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Modes of student written explanations

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<th>Poor organization</th>
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<td>&quot;brain dump&quot;</td>
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Good student written explanations have many of the characteristics as identified as expert-like they begin with a sentence or phrase stating their answer. Then, they support that statement with relevant data and reasoning, and their explanations are concise and precise.

Student reflections on writing explanations
Interviews and informal conversations with students reveal their views on the purpose of "explanation" questions, and on their views of what was expected of them. In each case, student description of their practice was broadly consistent with their written explanations in course assessments.

Four students identified as having exemplary written explanations on course assessments participated in formal interviews, all of these students explicitly described a "method" or strategy they used in writing explanations for this course as well as in many other courses. All students also described having learned this method or strategy prior to instruction, and viewed it as valid and expected in this context (even if they had learned it in a significantly different context). Most students identified High School instruction as important in establishing their practices.

More than 10 other students participated in interviews in which they were asked to construct an explanation or reflect on writing explanations in course assessments. None of these students described an expert-like strategy; rather, they used phrases like "writing as much as I can to make a complete answer.", "I don’t explain every step because she should know what I mean, this is an upper level course", and "coming up with correct examples". Other students explained that in other contexts, they did use a different (and apparently more expert-like) strategy or approach in writing, but didn’t see that appropriate here. In informal conversations, some students described this course as the first one in Geology in which they had non-multiple choice exams; however, two of the four students with consistently good explanations had equivalent experience in Geology courses.

Although only a few of the students explicitly discussed their study strategies, students with more expert-like writing practices seem to report more advanced study strategies and be more successful at monitoring their own thinking and understanding, whereas less expert-like writing was associated with study strategies focused on recall and definitions.

Concluding thoughts:
"Good" explanations by students resemble expert-like writing in both organization and completeness/precision. Student explanations often have characteristics of both mode, and can be incomplete/imprecise. Students who generally write expert-like explanations seem to have picked up on appropriate strategies in other settings, and see those strategies as appropriate and expected. Students who generally don’t write expert-like explanations either don’t know expert-like strategies, don’t use them in this context, and/or don’t see them as expected or valuable here. There are also hints that the quality of student writing relates to the quality of their study strategies.

Prior work does provide guidance on instructional strategies that may be adaptable to this and similar courses, but adaptation seems necessary. To affect improvement, it appears that sustained and significant effort (and time) is necessary during a course. Implementing such an effort in a content-rich course is challenging. Additionally, providing sufficient feedback to students can be prohibitive in terms of time commitment to grading.

Communicating effectively through writing is a critical skill for future scientists and citizens, and yet there is no concerted effort across the University, College, or Department supporting the development of this set of skills.