Coding to analyze students' critical thinking

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Using a problem developed from Guinotte *et al.* (pp 141–146), we illustrate a research approach to determine the effectiveness of inquiry-based instruction on students' understanding. Two research studies, one in biology (Udovic *et al.* 2002) and one in chemistry (Wright *et al.* 1998), influenced our thinking about how to proceed. Both are exemplary studies that examined the impact of active learning and cooperative groups on student learning by comparing reformed courses to traditional existing courses. The studies coded and analyzed students' written and oral responses to determine their understanding. Udovic *et al.* (2002) concluded that students in the reformed course showed significant gains in conceptual learning, scientific reasoning, and attitudes about science; Wright *et al.* (1998) concluded that students in the reformed course demonstrated higher-level critical thinking skills in oral assessments given by faculty external to the course.

Human-induced changes in seawater chemistry, as illustrated in Guinotte *et al.*, is a newly emerging topic in biology and is connected to larger issues surrounding global climate change. The main concept of the paper is appropriate for a unit on carbon cycling designed to expand students' understanding of carbon fluxes in both marine and terrestrial systems. For students not familiar with marine systems, it may be counterintuitive to relate addition of carbon to oceans with degradation of calcium carbonate-based skeletal structures such as corals. A common preconception among students is that as more carbon goes into the ocean, more calcium carbonate becomes available to build the skeletons of corals and other marine organisms.

Faculty research outcomes

- Classify student responses for comprehension and critical thinking.
- Code assessment data to provide a basis for asking questions about students' understanding.

Student goals

- Demonstrate critical thinking by connecting ideas and principles in the context of a problem.
- Illustrate understanding of scientific concepts and processes.

Inquiry into learning

Engage students with a pictorial introduction to ocean organisms that build skeletal structures of calcium carbonate, and provide the following problem to solve:

"As humans increase the levels of anthropogenic gases in the atmosphere, why will it be more difficult for corals and other organisms with calcium carbonate skeletons to grow?"

Students read the introduction to the paper and draw a box model or diagram that illustrates how the influx of anthropogenic CO_2 affects coral growth. The model can be derived directly from the reading and should include arrows that represent pathways and processes between components of the model. As students develop their model, they should make a list of what else they need to know to solve the problem. Lists are shared among group members for purposes of comparison.

Groups report their "need to know" list to the class as the instructor refines a master list that includes these five key questions:

- What is the source of anthropogenic carbon?
- What happens to CO_2 molecules when they enter the ocean?
- Why are the oceans becoming more acidic?
- Why does more CO_2 decrease the amount of carbonate available to corals?
- How does coral use carbonate?

For homework, students find answers to these questions and revise their original model so that it includes and interconnects all of the components necessary to address the problem. After the students turn in their model at the beginning of the next class, ask them to write a paragraph that explains the solution to the problem and includes all of the concepts and processes illustrated in their model.

Searching for patterns: coding responses

The instructor codes both the students' revised model and extended response. The term "coding", in a research context, refers to a classification scheme that allows an instructor to search for patterns in student work based on the rubric derived from learning objectives (Bogdan and Biklen 1998; Ebert-May *et al.* 2003). Coding is an iterative process: an instructor sets the criteria for coding in a rubric, but as the criteria are applied to an initial set of student responses, it may become evident that certain criteria need to be modified based on those responses. The initial set of student responses is therefore recoded accordingly. The process changes slightly when coding responses with a certain research question in mind. Once the researcher has categorized student responses using a rubric, s/he can look closely within a category to classify elements of the students responses and their reasoning to

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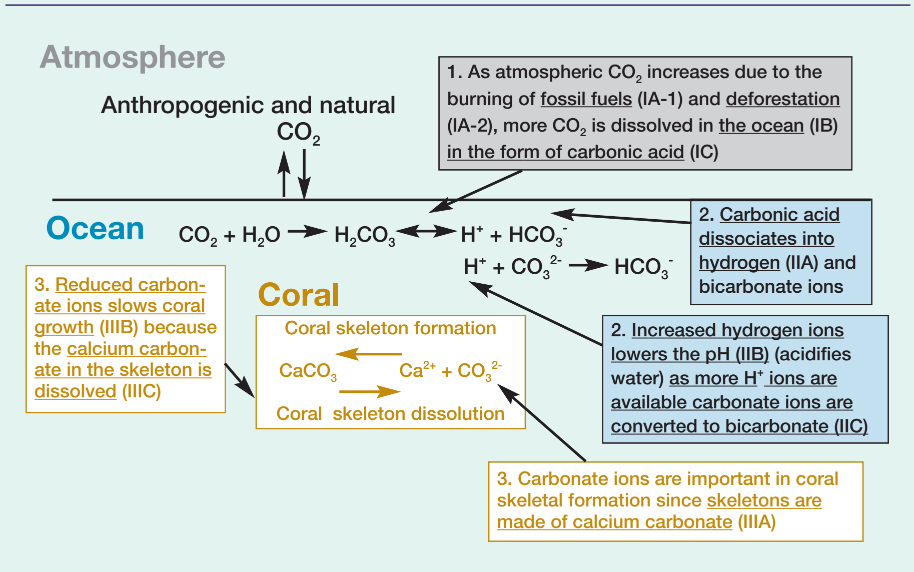
identify patterns of thinking. This may reveal common patterns related to gaps in student understanding or their lack of clarity or capacity to make connections, as well as ambiguity in the question (prompting the rewriting of the original question).

The rubric (Table 1) for this problem is used to code students' understanding of pathways and processes that result in coral skeleton dissolution. After models and extended responses are coded, the investigator looks for differences in the frequencies of each component for each assessment. For example, if students frequently did not accurately and logically explain the chemical reactions with CO_2 in the seawater, they may lack fundamental understanding of acid/base chemistry. The instructor uses the data to decide if further instruction is warranted. Clarifying why students do not understand pH in the context of this problem can lead to further inquiry by the instructor.

A final exam question could focus on the concept of carbon sequestration in the deep oceans as a mitigation measure for fossil fuel use. By coding it the same way, the instructor has a third assessment and data point to compare students' improved understanding during the course.

Panel 1. An example of a model, coded in accordance with the rubric in Table 1, representing the effect of increased CO_2 on coral growth



Next steps for analysis

Coding student assessments provides a systematic method for identifying patterns of critical thinking among students. The next step is to connect each of the categories in Table 1 with student understanding. Use the coded data to explore research questions about why students do not understand particular concepts, in this case by examining the permutations of student responses for each category in Table 1 to see if patterns and hierarchy in the responses can be detected. For example, if students are missing the concept that CO_2 dissolves in water, resulting in carbonic acid, did that influence their subsequent thinking about the main ideas embedded in the original question? Or are students missing many isolated bits of information, thus preventing them from understanding the big picture? If there is hierarchy, what are the key concepts that are critical to understanding subordinate concepts? This is an iterative research process that drives questions and hypotheses about student understanding.

Table 1. Rubric for coral problem

Concept	*Component of model*	*Code*	*Pathways and processes*
1	Ocean carbon input		Source of CO_2
		IA	IA-1: fossil fuels
			IA-2: deforestation
		IB	Dissolved in ocean
		IC	as carbonic acid
2	Chemical reactions in seawater	IIA	Carbonic acid dissociates into hydrogen
		IIB	Carbonate ions converted to bicarbonate
		IIC	Increased hydrogen ions lowers pH
3	Coral	IIIA	Skeletons made of calcium carbonate
		IIIB	Reduced carbonate ions slows coral growth
		IIIC	Calcium carbonate in skeleton is dissolved

References

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