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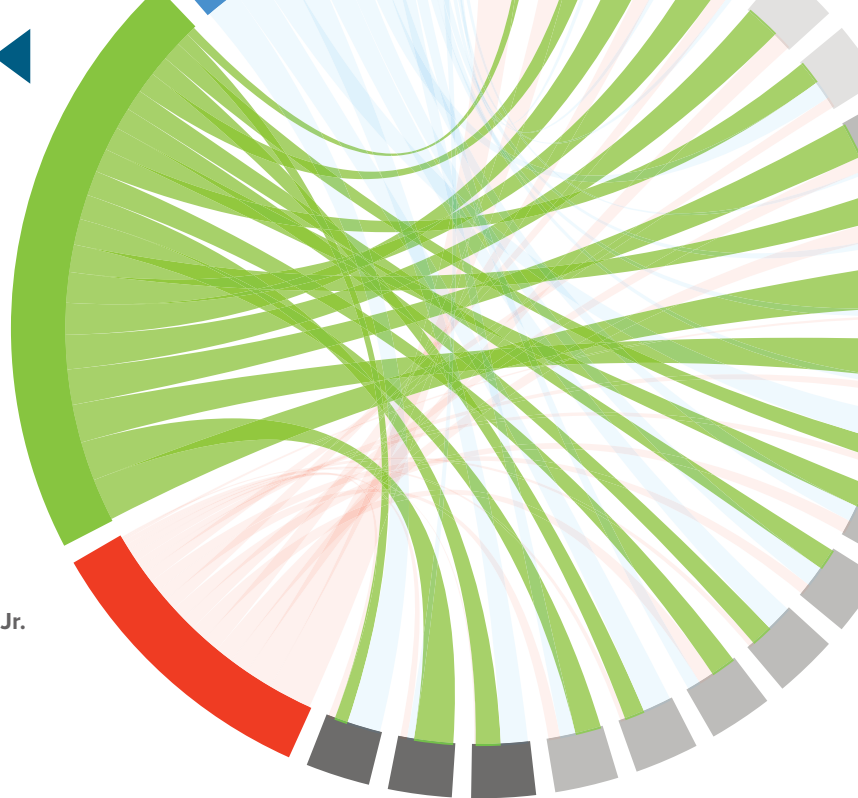
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Assessing an Undergraduate Oceanography Curriculum

By Bradford S. Barrett,
William A. Swick,
and Dwight E. Smith Jr.



INTRODUCTION

Despite being a relative newcomer to the geoscience disciplines, the ocean sciences play an important role in the geosciences: the ocean controls the planet's energy budget, directly drives or influences all major patterns of weather and climate, shapes the planet's geologic evolution, and links the planet's food and nutrient chains. Coupling the ocean's fundamental importance with an excitement among students to learn about the ocean (Garrison, 2014), a rigorous and well-designed undergraduate degree program in oceanography that engages students in the inquiry-based learning process (e.g., Hassard, 2005) throughout their undergraduate careers is needed. However, the tools most often used at the undergraduate level, such as lectures, whose delivery is made relatively easy by the utility of Microsoft PowerPoint, and recipe-driven confirmatory exercises, whose outcomes are often known before the task even begins, do a poor job of promoting student retention or independent thinking (Handelsman et al., 2004; Mazur, 2008). Such activities often rate low in promoting critical thinking and can be considered to fall near the bottom of Bloom's Taxonomy (Bloom et al., 1956; Anderson et al., 2001) or

Webb's Depth of Knowledge (Webb, 1997, 1999). However, inquiry-driven activities, such as assigning think-pair-share questions (Kagan, 1994); asking for critique, evidence, and reasoning of a scientific claim (McNeil and Krajcik, 2008); assigning students to predict, observe, and explain a phenomena (White and Gunstone, 1992); and dispelling student misconceptions (Feller, 2007), fall much higher in critical thinking ratings. These more advanced teaching methods are critical to engaging students in the classroom (Feller and Lotter, 2009) and promote rigorous understanding. At all levels of education, active learning techniques positively impact knowledge retention (National Research Council, 2000).

Both the US Coast Guard (Futch and McConnell, 2013) and the US Navy (Aaberg et al., 2013) recognize the importance of employing officers with backgrounds in ocean science, and both branches are developing targeted training programs to meet that need. One of the challenges facing an undergraduate oceanography program is to ensure that all of its courses employ at least some of the active learning techniques shown to promote higher-order critical thinking skills. Another challenge facing undergraduate

oceanography programs is to ensure that as students progress through the degree program, they are presented with course options that increase the level of required critical thinking and rigor.

Bloom's Taxonomy is a mainstay for categorizing educational activities and questions according to their levels of abstraction (Bloom et al., 1956; revised by Anderson et al., 2001). Activities that fall on the upper end of the process dimensions are considered to be those with the highest order thinking. Another commonly used model for assessing cognitive complexity, the Depth of Knowledge, was developed with a focus on both content and required tasks (Webb, 1997, 1999). These two classification schema have been used to assess complexity of a range of university-level meteorology (e.g., Palmer et al., 2009; Barrett and Woods, 2012) and oceanography (e.g., Yuretich et al., 2001) activities and courses.

The two classification schema were combined into a "cognitive rigor" (CR) matrix by Hess (2006) to allow educators to examine the rigor associated with tasks that might, at first glance, seem to have similar complexity (Hess et al., 2009). To our knowledge, the CR matrix has not been commonly used as a tool for

assessing an entire course or sequence of courses. Thus, the methodology of this present study is somewhat novel in its approach. In this paper, we report the results of our primary objectives: (1) to assess the rigor of the courses offered, and (2) to determine standards for each of the course levels the department offers. Our study was motivated by our desire to ensure that our core courses retain appropriate levels of rigor.

OCEANOGRAPHY CURRICULUM

The Oceanography Department curriculum is designed for students with a strong interest in the physical and dynamical properties of the ocean and the atmosphere. At all course levels, instructors incorporate laboratory and field work, as appropriate, including rotating tank experiments (e.g., Illari et al., 2009) and observational measurements taken from short cruises in Chesapeake Bay on our Yard Patrol craft (Compton et al., 1987). A detailed description of each department course is available at <http://www.usna.edu/Oceanography>. Course sections typically have between 16 and 20 students. The 200-level course sequence is largely introductory. More technical and more mathematically involved coursework begins at the 300 level, where students learn topics and derivations in atmospheric thermodynamics and fluid dynamics. At the 400 level, the courses further subdivide into three types: (1) core courses that continue instruction of the mathematically technical topics, (2) elective courses that focus heavily on a practical subdiscipline of oceanography or meteorology, and (3) the capstone course, designed to be taken during the final semester and to offer students the opportunity for guided research on a topic of their choosing. This breadth of content, along with the laboratory and hands-on field experiments, provide undergraduates with the kind

of exposure that Brix et al. (2003) identified as characteristic of a successful oceanography program.

METHODOLOGY: COGNITIVE RIGOR MATRIX

We selected Hess's CR matrix as an assessment tool because we found it applicable to the entire range of courses and content offered and teaching styles used in our department. In his matrix, the four Webb's Depth of Knowledge categories were matched with the six revised Bloom's taxonomy categories. In Hess (2006), the 24 intersections of level and category were associated with key action verbs that described that level of cognitive rigor, with rigor levels increasing diagonally down the matrix to the right. To adapt the rigor matrix for use in our department, we tested it on a 300-level, three-semester-hour course, designated SO335. This course was selected as a benchmark by which the other courses could be evaluated because it had been taught by five different faculty members (over one-third of the regular faculty members) and was considered one of the department's best-designed courses. Courses with less rigor than SO335 could be designated at the 200-level, courses with similar rigor could be designated at the 300-level, and courses with more rigor could be designated at the 400-level.

The following instructions were given to faculty members for evaluating the cognitive rigor of their courses:

Using your course syllabus and the attached CR matrix, consider the cognitive rigor of each of the lecture topics and in- and out-of-class activities that typically comprise your semester course. Then consider the number of hours students typically spend in each lecture and activity. Allocate these student-hours to each of the cells in the CR matrix. The number of hours will necessarily vary across courses, and will also

vary across instructors in the same course. We are not interested in the number of student-hours, but rather, in their relative allocation across the CR matrix. When finished, you will have several boxes filled in, and these give a basic weight by course. The total hours should add up to the total hours taught teaching the course and any hours you expect your students to spend in any of the categories outside of classroom instruction (for example, completing homework assignments, laboratory activities, or papers).

RESULTS: RIGOR MATRIX FOR QUANTITATIVE METHODS COURSE

The three most common blocks in SO335 were found at the intersections of (1) Analyze (Bloom's) and Strategic Thinking/Reasoning (Webb's) at 13%, (2) Evaluate (Bloom's) and Strategic Thinking/Reasoning (Webb's) at 12%, and (3) Apply (Bloom's) and Skills/Concept (Webb's) at 11% (Table 1). Greatest spread between instructors' ratings of SO335 rigor was found at the lowest and highest ends of the CR matrix. Standard deviation values were lower in the middle of the matrix, indicating greater agreement among faculty evaluators (Table 1). Blocks in Table 1 with 0% indicate that none of the faculty rated an activity at that level. It was interesting that none of the SO335 faculty evaluators rated activities at Webb's "Extended Thinking" level. That is one area of the course that could be improved.

Based on the SO335 results, 300-level rigor in the Oceanography Department was defined to occupy the L-shaped section of the CR matrix spanning Bloom's Apply and Analyze levels and Webb's Strategic Thinking and Reasoning level (Table 2). This section was labeled as "Apply." Rigor at the 400 level was labeled "Create" and defined as the L-shaped section of the CR matrix spanning Bloom's Evaluate and Create levels and Webb's Extended Thinking level (Table 2). Rigor at the 200 level was labeled "Recall" and comprises the remaining blocks in the CR matrix: Bloom's Remember and

Bradford S. Barrett (bbarrett@usna.edu) is Associate Professor, **William A. Swick** is Commander, and **Dwight E. Smith Jr.** is Commander, all in the Oceanography Department, US Naval Academy, Annapolis, MD, USA.

Understand levels and Webb's Recall/Reproduction and Skills/Concepts levels (Table 2). This classification scheme achieved the objective of having over 50% of the time spent in SO335 at the Apply cognitive rigor level. A chord diagram (Vassiliev, 1990) in Figure 1a shows the distribution of time in each of the three categories. Other Oceanography Department courses were evaluated for rigor using this three-tier classification scheme, and they are shown in a chord diagram in Figure 1b.

RESULTS: RIGOR EVALUATION OF ALL COURSES

The majority of time in the two sophomore-year courses, SO271 and SO272, was spent in the 200-level portion of the CR matrix (83% and 52%, respectively; Figure 1b). This was not surprising, given that those courses are intended

as introductory. What was somewhat surprising was the amount of time spent at the 300 and 400 levels in SO271 and SO272: 17% and 48%, respectively. This evaluation method indicated that we were engaging our students in higher-order thinking even in the first two introductory courses. Chord diagrams in Figure 2 show the percentage of time spent in the Recall, Apply, and Create categories for all courses. In another 200-level course, SO273, only 31% of time in the course was spent at the 200 level, with 69% spent at the 300 and 400 levels. It is possible that SO273 will be re-designated at the 300 level in the next year, based on the result of this rigor assessment.

At the 300-level in SO335 and SO345, the majority of the time in the semester was spent in activities at the Apply CR level (58% and 65%, respectively; Figure 1b and Figure 2). Similar to SO272

and SO273, around 10% of the time in the SO335 course was spent in activities at the Create CR level, indicating that we continued to challenge our students at the highest level of critical thinking during their junior-year courses. The SO345 course did not register any time spent on activities at the Create CR level (Figure 2), suggesting potential for modifications in future versions of the course to increase its CR.

At the 400-level, significant spread was found between courses. Of the 15 400- and 500-level courses examined (500-level courses are honors versions of similar 400-level courses), 10 of them spent most of their time in activities at the Apply CR level. Furthermore, in three of the elective courses, the activities at the Recall and Apply CR levels comprised over 80% of the semester (Figure 2). Additionally, in the SO414 Waves and Tides course, 93% of the semester was spent in activities at the Recall and Apply CR levels, and less time was spent at the Create CR level than in the SO272 course. The honors version of Waves and Tides (SO506) registered 13% of the semester at 400-level activities. Only three 400-level courses (the Capstone course and two electives) and two 500-level honors courses reported spending most of the semester in activities at the highest critical thinking levels (Figure 2).

While we were primarily interested in evaluating our courses by the amount of time spent in a semester at the different levels of critical thinking, the assessment itself was valuable to the department. Feedback from instructors after completing the evaluations indicated that this was often the first time they had systematically considered the rigor of their courses. As a result of this assessment, departmental expectations for CR levels were set and communicated: a 200-level course should spend 50% of the semester in activities at the Recall level, while 300- and 400-level courses should spend 50% of the semester in activities at the Apply and Create levels, respectively.

TABLE 1. The Hess (2006) CR matrix applied to course SO335, Quantitative Methods for Meteorology and Oceanography. Percentages represent mean time spent during the semester in each activity level. Standard deviations are in parentheses. Boxes are colorized by mean value, with darker blue representing higher values.

		Webb's Depth of Knowledge Matrix			
		Recall/ Reproduction	Skills/ Concept	Strategic Thinking/ Reasoning	Extended Thinking
Bloom's Taxonomy	Remember	7.9% (12.6%)	0.8% (1.9%)	0.0% (0.0%)	0.0% (0.0%)
	Understand	6.4% (6.1%)	8.0% (3.7%)	4.0% (5.5%)	0.0% (0.0%)
	Apply	7.1% (6.9%)	11.3% (8.9%)	9.6% (6.7%)	0.0% (0.0%)
	Analyze	3.5% (3.2%)	9.0% (9.1%)	13.3% (9.2%)	0.0% (0.0%)
	Evaluate	0.0% (0.0%)	3.2% (4.9%)	11.7% (13.2%)	0.0% (0.0%)
	Create	0.0% (0.0%)	0.0% (0.0%)	4.3% (6.2%)	0.0% (0.0%)

TABLE 2. Categorization of critical thinking activities in the cognitive rigor matrix by course level.


		Webb's Depth of Knowledge Matrix			
		Recall / Reproduction	Skills/ Concept	Strategic Thinking/ Reasoning	Extended Thinking
Bloom's Taxonomy	Remember	200 Level: "Recall"			
	Understand				
	Apply	300 Level: "Apply"			
	Analyze				
	Evaluate	400 Level: "Create"			
	Create				

DISCUSSION AND CONCLUSIONS

As a result of applying the cognitive rigor matrix to our departmental curriculum, we were provided with a comprehensive picture of cognitive rigor. The spread in rigor levels among the 400-level courses could be the result of the subjectivity of the CR matrix. It is also possible that instructors may have conflated the supposed rigor of the material itself (which instructors may have considered to be on a more basic level) and instructional methods, which may have merited higher ratings had they been considered separately. Additionally, 15 of the 20 courses were evaluated by only one instructor.

Despite these limitations, we still consider the results of the assessment to be useful. For example, it confirmed that most of our 200- and 300-level courses contain what we consider to be level-appropriate amounts of rigor, whereby the majority of the time in the course is spent in Recall or Apply activities. At the 400 level, the assessment showed that several of the elective courses could benefit from additional rigor. To score higher on the CR matrix, instructors can include project-based learning activities that challenge students to be creative and think critically about the topics in those courses.

For others interested in a similar

assessment, we suggest several practices to improve the process over what we presented in this paper. Develop action verbs similar to those we developed with your discipline in mind, and use them to help instructors properly categorize their courses. Also, provide each instructor with the Hess (2006) matrix, which offers guidance by describing activities that fit into each intersection in the matrix. Consider using this tool to quantitatively identify any courses with mismatches between observed and expected rigor levels. Analyze possible rigor differences between different sized course sections. Finally, ask students to assess the rigor of their courses and compare to faculty responses. 

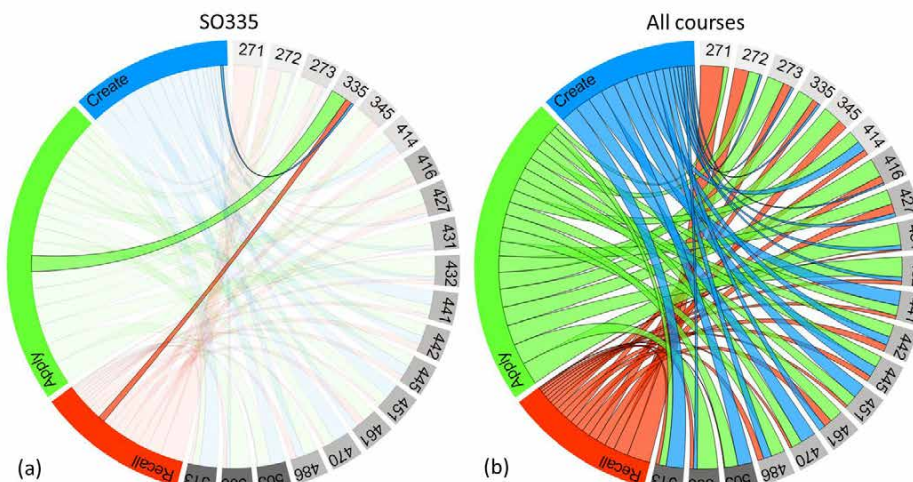


FIGURE 1. Time spent at Recall (red), Apply (green), and Create (blue) cognitive rigor levels for (a) course SO335 (Quantitative Methods), and (b) all US Naval Academy Oceanography Department major courses. Thickness of colored lines indicates time spent on activities at that level of cognitive rigor. Gray shading on the right-hand side increases for higher-numbered courses.

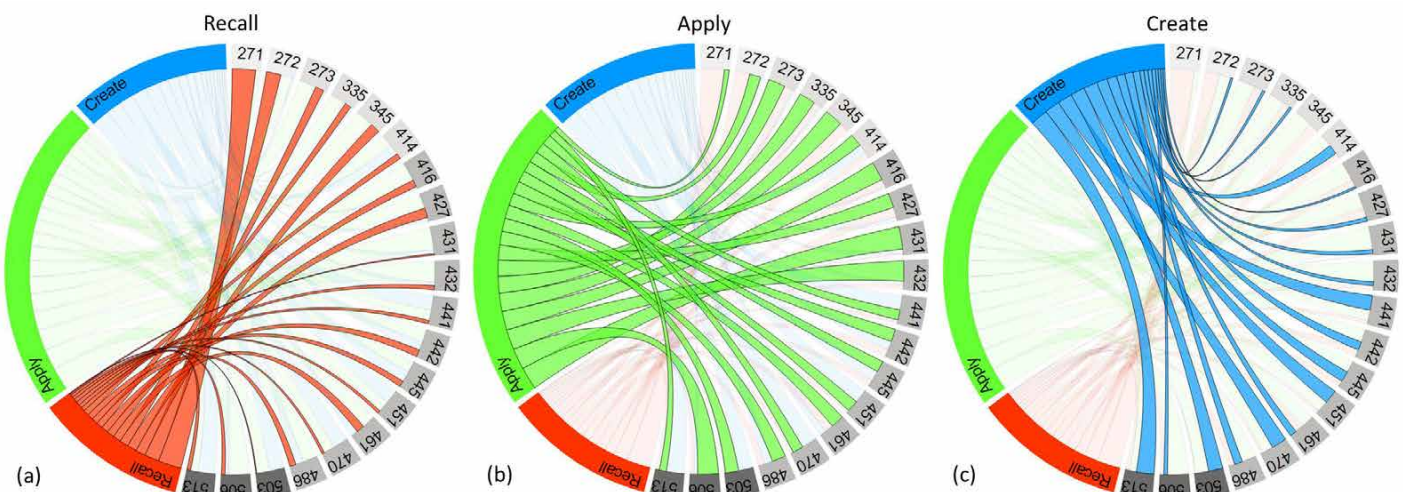


FIGURE 2. As in Figure 1, but highlighting time spent at the (a) Recall (red), (b) Apply (green), and (c) Create (blue) cognitive rigor levels.

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