Multi-institutional college curriculum development using a peer-to-peer auditing and coaching system: Lessons from the InTeGrate project

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Abstract: We designed and tested a curriculum auditing methodology for the Interdisciplinary Teaching of Geoscience for a Sustainable Future (InTeGrate) project. That methodology included selecting faculty from a range of institution types, providing written standards for curriculum development, teaming assessment consultants with curriculum designers and offering professional development. Teams developed curricular materials designed to connect geoscience content to Earth-related grand challenges facing societies, develop students' abilities to address interdisciplinary problems, improve geoscientific thinking skills, make use of authentic and credible geoscience data and foster systems thinking. The work was guided by a materials development rubric. Faculty members participated in workshops to prepare them to write and revise their materials and were teamed with an assessment consultant. Two other assessment team members independently audited the materials before they could be tested with students.

Over 49 faculty from the same number of institutions developed 16 curricular units. Curriculum developers encountered the most difficulty meeting criteria related to metacognition, grading rubrics, writing learning outcomes and objectives, and linking and aligning materials across the curriculum. Changes to the professional development program improved teams' abilities to meet those standards. We find the curricula auditing approach to be an effective methodology for developing materials.

Introduction

For many decades, educators in science, technology, engineering and mathematics (STEM) have taught their disciplines using a content-driven, faculty-centered approach that has been shown to discourage matriculation and persistence of science students (Seymour & Hewitt, 1997). Over the past twenty years, several reports have called for change toward student-centered approaches (National Science Foundation, 1996; National Research Council, 2000; National Science Board, 2003). While some progress has been made, reform has been slow (Sunal, Wright, & Bland, 2004; Macdonald, Manduca, Mogk, & Tewksbury, 2005). The Interdisciplinary Teaching of Geoscience for a Sustainable Future (InTeGrate) project seeks to catalyze widespread teaching reform in what, where and how geoscience is taught within and outside of geoscience disciplines at the University level. Inside the discipline we seek to influence curricula focussed on the atmosphere, oceans, solid earth, climate change and other related earth and environmental studies. Outside the discipline, we seek to embed geoscience learning opportunities in social science and humanities courses across the curriculum.

Major challenges facing society in the next 50 years will require a workforce trained to tackle complex issues, by making use of advanced and diverse skills across disciplines including the social sciences, economics and communication (Business Higher Education Forum, 2011). These complex issues require Earth literacy as described in the geoscience literacy documents (Oceans: NOAA, 2005; Climate: USGCRP, 2009; Atmosphere: UCAR and CIRES, 2008; Earth: Wysession et al., 2009). Earth literacy includes recognizing situations involving knowledge about Earth, both scientific concepts and how we know those concepts, as well as competencies in identifying scientific issues, explaining Earth-related phenomena, and drawing scientific conclusions. It also includes the ability to effectively communicate and to make informed decisions related to the Earth and its environment and resources (Wysession et al., 2009).

One of the primary goals of the InTeGrate project has been to engage teams of faculty in developing and testing high quality higher-education curricular materials to meet the Earth literacy goals that are central to the project. Traditional curricular materials are often content-rich, application-poor and focus on confirmation inquiry even in laboratory materials (Bruck, Towns, & Bretz, 2008). In contrast, InTeGrate curriculum developers are creating learning resources that address Earth literacy goals and content taught in the context of societal issues using practices supported by research on learning. To accommodate this significant shift in curricular focus, the InTeGrate leadership team developed a modified internal and external operational auditing process (Sayle, 1981; English, 1988; Glatthorn, 1994; Foshay, 2000).This was done to ensure quality of the curricular materials developed through the project; this process is adoptable and adaptable by other projects with similar goals (Figure 1).

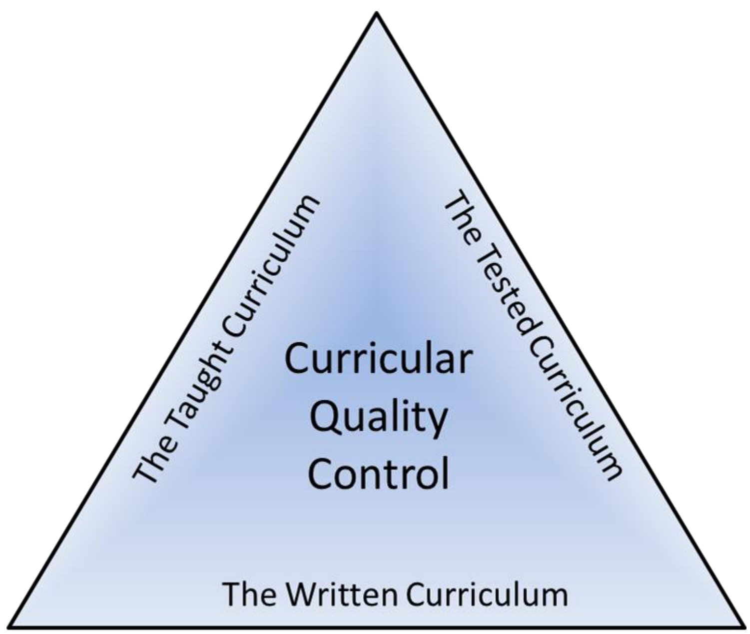

Figure 1. Conceptual Model of a Curriculum Audit. A full curriculum audit involves use of quality control measures before, during and after development, teaching and testing of curriculum. The process is intended to improve student learning through an improved curriculum (modified from English, 1988).

The InTeGrate leadership and assessment teams developed their materials development rubric to assist faculty teams as they prepared their materials. The elements of the InTeGrate curriculum evaluation rubric and lessons learned from applying the rubric are described here as a model for any STEM curriculum development effort seeking to follow best practices of curriculum design. Use of the rubric has allowed us to give extensive and specific feedback to materials development teams, as it was designed to do, while also allowing us to anticipate areas where new teams will have trouble and proactively provide guidance to authors in these areas. Equally important, the rubric has allowed authors to monitor their own progress toward completion of materials that fully incorporate research on effective teaching while addressing project priorities. In this paper, we focus on lessons learned while implementing the quality control measures that were used to ensure that the written curriculum met InTeGrate goals prior to field testing.

Method: Materials Development and Refinement Rubric

The primary goal of establishing the InTeGrate materials development and refinement rubric (Table 1: Short version) was to ensure that InTeGrate materials were held to a consistently high standard. Most of the materials were developed at the scale of a module, or approximately 2-3 weeks of class time in a semester system, though in some cases the materials covered an entire course. The rubric incorporates the guiding principles of the InTeGrate project and researched guidelines for best practices in curriculum development (Wiggens & McTighe, 2005; Cullen, Harris, & Hill, 2012). InTeGrate materials development teams are held to this rubric, and must meet stringent scoring criteria that include mandatory elements as well as section minimums (see Table 1) during internal and external audits. The evaluation scheme is divided into six sections: guiding principles, learning objectives and outcomes, assessment and measurement, resources and materials, instructional strategies, and alignment. What follows is a description of each of those sections and a brief justification for their inclusion in the rubric.

Section 1: Guiding principles

Guiding principles (or overarching goals) lay the framework for subsequent curriculum development (Krajcik, McNeill, & Reiser, 2008). Such principles are used to delineate the scope of the content and specify significant compositional aspects of the materials. In the case of the InTeGrate project, the materials development rubric includes five guiding principles that align with major InTeGrate goals. Developers were required to include all five of these guiding principles in their materials:

1.1 *Courses or modules must address one or more geoscience-related grand challenges facing society:* Grand challenges include resource issues (e.g., minerals, energy, water, food, sustainability) and environmental issues (e.g., climate change, hazards, waste disposal, environmental degradation and environmental health). Grand Challenges related to biogeochemical cycles, biologic diversity, environmental change impacts, resource extraction, land use and land cover, and recycling are listed in the National Academy's "Grand Challenges in Environmental Science" (NRC, 2001).

1.2 *Course/module develops student ability to address interdisciplinary problems:* Interdisciplinary problems require diverse perspectives that promote understandings of the interactions between Earth science and economic, societal and policy issues (Gilbert, 1998; Daily & Ehrlich, 1999; Ivanitskaya, Clark, Montgomery, & Primeau, 2002). Such materials integrate robust geoscience with trans-disciplinary knowledge from other disciplines such as geography, social sciences and humanities and build student capacity to work on interdisciplinary teams.

1.3 *Course/module improves student understanding of the nature and methods of geoscience and develops geoscientific habits of mind:* Geoscience is a discipline based on making observations of the Earth and testing hypotheses about Earth's history and processes against those observations. The methods of geoscience include: comparison of cases to understand commonalities and differences attributable to process, history, and context; developing converging lines of evidence; and testing through prediction (Harrington, 1970; Virgili, 2007;

Dodick, Argamon & Chase, 2009; Ault & Dodick, 2010). Geoscientific habits of mind include recognition of the fundamental role of observation and of a spatial and temporal organizational schema in understanding the Earth, recognition of the Earth as a complex system shaped by a continuum of long-lived low impact processes and short-duration high impact processes and valuing collaboration (Pyle & Brunkhorst, 2008; Kastens & Rivet, 2008; Kastens et al, 2009; Manduca & Kastens, 2012a).

1.4 Course/module makes use of authentic and credible geoscience data to learn central concepts in the context of geoscience methods of inquiry: Curricular materials use the most appropriate data available for the topics under discussion. Large amounts of data that address societal problems are available with increasing frequency and resolution.

1.5 Course/module incorporates systems thinking: Course/module develops students' abilities and propensities to use systems thinking in considering natural systems, human systems, and their interactions. A systems thinker understands basic interactions among the components of the earth system, the difference between open and closed systems (Libarkin & Kurdziel, 2006; Manduca & Kastens, 2012b), possible effects of perturbations and multiple causal factors that could influence a single observation or outcome (Ruddiman, 2001; Ford, 2009). As their systems thinking deepens, they also have the ability to use the concepts of positive (reinforcing) and negative (countervailing) feedback loops, flux, reservoir, residence time, lag (delay) and system thresholds (Assaraf & Orion, 2005; Cabrera, Colosi, & Lobdell, 2008; Midgley, 2008; Stillings, 2012).

An example of threading guiding principles is illustrated in a module about climate change designed for an introductory undergraduate science course. That module explores global challenges associated with climate change and social vulnerability. Students decipher commonalities and differences of three cultures that were impacted by past climate change. They then use actual data to assess the impact of climate variability on modern cultures. Lastly, they consider the roles of forced and unforced climate change and feedback in the climate system. To pass the audit, the guiding principles must be explicit and pervasive throughout the curricular materials, not simply mentioned in passing.

Section 2: Learning objectives and outcomes

Learning outcomes provide a "big picture" view of the module or course (Anderson & Krathwohl, 2001). Well-articulated learning outcomes clarify what you want students to accomplish and effectively communicate expectations to students (Biggs, 2003). They also help faculty select methods, materials, and assignments that are appropriate and guide development of assessments that show what students have learned. Learning objectives specify individual learning components that support student achievement of the larger outcome. Both learning outcomes and objectives must be measurable (Black & Wiliam, 1998). Faculty members describe those levels by developing scoring rubrics for the student.

Learning outcomes and objectives in the InTeGrate project are required to meet the following criteria:

2.1 Learning objectives relate to geoscience literacy outcomes: For InTeGrate, the objectives and outcomes must be directly linked to one or more sub-points of the major big ideas published in the Earth Science, Climate, Ocean and/or Atmosphere literacy documents.

2.2 Instructions and/or rubrics provide guidance for how students meet learning outcomes: When appropriate, rubrics are developed that provide the student a clear indication of the performance conditions and standards necessary to meet learning outcomes. The metrics used to measure indications of such change must be described for the student unless this degree of specificity is not possible (e.g. internal cognition, affective changes).

2.3 Learning objectives and outcomes are appropriate for the intended use of the course/module: Lower-division courses should address content mastery, critical thinking skills, and core learning skills related to introducing guiding principles. Upper-division and graduate courses may focus on advanced guiding principles related to global interdisciplinary problems.

2.4 Learning objectives and outcomes are clearly stated for each module in language suitable for the level of the students: Learning objectives and outcomes should avoid jargon and highly technical language unless required. They should be written at a level that the student can aspire to achieve the outcome and recognize when it has been achieved.

2.5 Learning objectives and outcomes address the process and nature of science and development of scientific habits of mind: According to the AAAS (2009), the process of science and scientific inquiry (or habits of mind) include the notions that science demands evidence, science is a blend of logic and imagination, science explains and predicts, scientists attempt to avoid bias, and there are accepted criteria for evaluating the credibility of data. Scientific habits of mind also include recognition that science is a complex social activity underpinned by accepted ethical principles (Wynne, 1991; Lederman, 2007). The nature of science purports that the world is understandable, there are credible and non-credible scientific arguments, scientific knowledge is long-lasting but subject to change and science cannot answer all questions (Linkens, 1999; Bell, 2004).

For example, a team of faculty that developed a module addressing sustainable agriculture wrote learning outcomes that require students to: 1) Demonstrate the ability to critically analyze geological data and use their analyses to develop sustainable soil management plans in diverse agricultural settings, and 2) Apply climate change and systems concepts to predict future agricultural challenges. Each unit of the module had supporting learning objectives.

Section 3: Assessment and Measurement

Properly written learning goals and objectives are measurable (Biggs, 2003), allowing instructors to use formative and summative assessment strategies throughout the curriculum to monitor learning and progress toward mastery. Assessments should include clear standards that instructors can use to grade the student work. Additionally, assessments should be consistent with the content covered, be logically organized in the flow of the instruction, and address multiple cognitive levels (Anderson & Krathwohl, 2001). Materials developed for the InTeGrate project were evaluated using the following criteria:

3.1 Assessments measure the learning outcomes: Embedded formative assessments (Black & Wiliam, 1998; Boyle & Charles, 2014) and summative assessments and assignments (Popham, 1999) provide logical tools to determine the extent to which students have met the course/module outcomes. These assessments must match course content such that these tools help the student achieve the outcomes.

3.2 Assessments are criterion referenced: Assessments include a clear and meaningful articulation of criteria used to judge the quality of student products and performances. This could involve a rubric for each type of assignment, a list of criteria and associated point values for specific assignments or a sample of acceptable or unacceptable student work (Popham, 1997).

3.3 Assessments are consistent with course activities and resources expected: Assessments and assignments should support course activities and be designed to measure the extent to which the student has accomplished one or more of the outcomes. Resources (e.g. materials, equipment) needed for learning activities, assignments and assessments are clearly stated (Popham, 2008).

3.4 Assessments are sequenced, varied and appropriate to the content: The sequence and schedule or pace of the assessments match the content. Assessments should vary in type and duration and can build on previously acquired knowledge within the course or in prerequisite courses.

3.5 Assessments address objectives and/or outcomes at successively higher cognitive levels: If appropriate, assessments progress from lower level knowledge recall and understanding to higher order thinking, application of knowledge and even knowledge generation (Anderson & Krathwohl, 2001). Feedback from these assessments informs the student of their level of learning.

A module that addresses human dependence on mineral resources includes many examples of the types of assessments required. Students analyze scenarios related to resource use, population and development; they explore the economics of rare earth elements during an in-class exercise. These exercises are all assessed on a formative basis: low-stakes, but checked for understanding and prompting feedback and reflection. As a summative exercise, students construct concept maps to illustrate major concepts and interconnections related to the geologic nature of a resource, the factors that determine demand, the mining processes involved and the potential environmental impacts.

Section 4: Resources and Materials

There are several characteristics of curricular resources and materials that contribute to a successful curriculum. Primarily, curricula must link to the broad learning goals and underlying learning objectives - and that linkage should be obvious to students. In addition, effective curricula use methods that scaffold learning and engage multiple modalities that support learning (Zeegers, 2001). The resources used to support curricula should be current, scientifically rigorous, and follow accepted scholarly documentation practices. Special materials (e.g. software, instruments or technology) should be clearly stated. Materials were reviewed to ensure that:

4.1 Instructional materials contribute to the stated learning objectives: Course materials such as textbooks, monographs, articles, lecture notes, audio or video recordings, games, or websites should directly support one or more overarching goals, literacy goals or core concepts embedded in learning objectives and outcomes.

4.2 Students will recognize the link between the learning objectives, outcomes and the learning materials: Curriculum should be designed such that students can recognize the purpose of all content, materials, resources, technologies, and instructional methods used in the course; how each resource helps them achieve the stated learning outcomes; and which materials are required and which are recommended resources.

4.3 Instructional materials should be sufficiently diverse and at the depth necessary for students to achieve learning objectives and outcomes: Instructors should provide meaningful content using a variety of sources (e.g., text, articles, presentations, websites, lecture notes, outlines, and multimedia). The level of detail in supporting materials is appropriate for the level of the course, and provides depth sufficient for students to achieve the learning outcomes.

4.4 Materials are appropriately cited: All learning materials, software and learning resources must conform to copyright law and proper citation protocols unless there is a specific statement attached to the materials stating that they are in the public domain.

4.5 Instructional materials are current: The materials represent up-to-date thinking and practice in the discipline.

4.6 Instructional materials and the technology to support these materials are clearly stated: If specific technology is needed, what is required is clearly stated, e.g. computer lab with licenses to a specific software application.

The types of resources developed and used varied widely in InTeGrate materials based on the content. As an example of this variety, a module covering environmental justice and freshwater resources requires that students explore authoritative web resources to discover concepts related to environmental equity, environmental justice and environmental racism. Students expand on these concepts using Google Earth activities and exercises linked to case studies from Trinidad, Kenya and India.

Section 5: Instructional Strategies

InTeGrate materials are designed using student-centered pedagogy (Trigwell & Prosser, 1991). Ideally, there are ample opportunities for student-student and student-instructor interactions. Additionally, students are provided opportunities to reflect on their learning as they complete various activities that scaffold from lower- to higher-level cognitive tasks (Anderson & Krathwohl, 2001). Specifically, materials developers were required to meet the following instructional criteria:

5.1 Learning strategies and activities support stated learning objectives and outcomes: The learning activities promote the achievement of the stated learning objectives and outcomes using evidenced-based teaching and learning practices (Edelson, 2001; Handelsman et al., 2004; National Research Council, 2012). The strategies should actively engage students with the course content using a variety of different types of activities that support reinforcement and mastery in multiple ways.

5.2 Learning strategies and activities promote student engagement with the materials: Activities should connect to personal experiences of students, motivate and engage students, connect to real world experiences, and build on what they know and address their initial beliefs. Activities should foster instructor-student, content-student and student-student interactions where appropriate (e.g. group discussions or blogs, small-group projects, peer critiques).

5.3 Learning activities develop student metacognition: Students should be given opportunities to reflect on and think about their own actions and ideas as compared to others, and confirm that they are on the right track (Flavell, 1979). The activities should provide opportunities for students to iterate and improve their understanding incrementally.

5.4 Learning strategies and activities provide opportunities for students to practice communicating geoscience: It should be clear that the students at all levels will be engaged in independent thinking, problem solving, and communicating their understanding. Activities should challenge misconceptions, provide opportunities for students to practice judging what constitutes credible evidence and opportunities to practice effectively communicating geoscience concepts verbally and in writing (Hurd, 2000; Weigold, 2001). This rubric element is also motivated by research showing that organizing ones thoughts for communicating can trigger the self-explanation effect, in which the quality of thinking and problem-solving improves (Chi, DeLeeuw, Chiu, & LaVancher, 1994; deLeeuw & Chi, 2003).

5.5 Learning strategies and activities scaffold learning: Activities should promote deep learning by stimulating student intellectual growth from an initial point to more advanced levels, considering the needs of non-traditional students, as appropriate (Hatano & Oura, 2003; Bransford, 2000). Activities should be structured to allow students to first note obvious connections and then grasp the significance of those connections (Bransford & Schwartz, 1999; Engle, Nguyen, & Mendelson, 2011). At higher levels, students should be challenged to appreciate the significance of the parts as related to the larger concept and eventually extend those concepts to general principles outside the discipline (Crawford, Schlager, Penuel, & Toyama, 2008).

The instructional aspects of the rubric are exemplified by a module designed for use in an introductory geoscience course for elementary education majors. In this module, students are organized into small groups that work collaboratively to collect and interpret data during several activities. The hands-on activities involve experiments, stream table analyses, computer exercises, and analyses of authentic river data. Students communicate their results to each other while using the activities to develop K-12 lesson plans. They reflect on their own learning by first describing their initial ideas, and then revisiting those ideas near the end of the module and describing how they have changed. Overall, the materials support strategies that recognize students' backgrounds and help them reflect on and develop their own skills and knowledge.

Section 6: Alignment

A constructive alignment approach (Biggs, 1996) is one in which outcomes, learning activities and assessments within each section of the module or course directly align with one another and with stated learning objectives and outcomes. This last category in the rubric serves as a final check to ensure all aspects of the curricula are integrated:

6.1 Teaching materials, assessments, resources and learning activities align with one another: A curriculum map that identifies core skills and content, learning strategies and resources can be used as an effective way to ensure alignment within a unit of the curriculum.

6.2 All aspects of the module/course are aligned: An alignment approach suggests that curricular materials align directly with stated module/course goals holistically across the entire module/course.

This last category facilitated identification of missing or unused content, assessments or curricular materials and helped streamline all of the materials.

Methods: Applying the Rubric

Assessment team members applied the materials development and refinement rubric (Table 1: short form) to 16 sets of materials developed during years one through three (2012-2014) of the InTeGrate project. Author teams developed modules addressing content areas related to climate change, freshwater resources, mineral resources, natural hazards, earth surface processes, energy, teaching geoscience, agriculture, carbon cycling, soils, renewable energy, the critical zone (lithosphere-atmosphere-hydrosphere-biosphere interface), and coastal processes. In general, material developers designed modules to include an average of six units targeting introductory-level undergraduates. The resources within each unit included student readings, in- and out-of-class activities, formative learning opportunities, summative assessments, and instructor notes. A course would generally consist of eight to ten modules. Published examples of the modules and types of curricular resources can be found on the InTeGrate project website (http://serc.carleton.edu/integrate/teaching_materials/modules_courses.html).

Each development team consisted of three to five authors working collaboratively together under the guidance of a member of the InTeGate leadership team and an assessment consultant. The group leader was responsible for facilitating interactions, reviewing curricular materials and providing advice throughout curriculum development. The internal assessment consultant audited materials and provided formal guidance at the 50% and 75-90% complete stages. Once the materials were complete, the internal assessment consultant and two others who had not previously viewed the curriculum (external auditors) independently audited the curriculum.

Scores were compared and used to determine if the materials were ready for testing with students or required revisions.

Assessment team members used the 28 elements of the rubric (Table 1) to evaluate materials on a scale from 0 to 3. A score of 3 points means the rubric element was explicitly and extensively addressed in module/course materials; 2 points indicates the rubric element was addressed in majority of the materials; 1 point indicates the rubric element was addressed in some of the materials and 0 points implies the element was not addressed in the module/course materials. Individual element scores were converted to a composite score by comparing points awarded. If all three scores or two-of-three scores matched, and the non-matching score only varied by 1 point, the matching score was awarded. If the non-matching score varied by two or more or the three scores did not match, the assessment team discussed that element until they came to a consensus. The composite score was used to determine if the module passed the rubric or required revisions. In order to pass, materials had to score 100% on Section 1 (guiding principles) and ~85% or higher on each of the other five sections; materials were required to pass the rubric prior to being testing in the classroom. If the materials failed to meet the passing criteria, the assessment consultant provided constructive comments to the development team, who revised materials as needed. After the development team revised the materials, the original assessment consultant re-reviewed them to ensure the curricula met standards in those areas that had fallen short.

Results

The first cohort of materials development teams was marginally successful at meeting requirements when audited against rubric standards. Of the six modules assessed against the rubric in the first year (2012), two passed on the first attempt, two passed after minor revisions, and two required substantial revision and reassessment (Table 2 and Figure 2: gray bars). Three of the four module author teams that did not pass on the first audit did not meet the mandatory 3 out of 3 score for the systems thinking guiding principle (Table 2: rubric item 1.5). In general, all faculty members had difficulty meeting requirements in areas related to developing grading rubrics (Table 2: rubric item 2.2) that were criterion referenced (Table 2: rubric item 3.2), linking materials to learning outcomes (Table 2: rubric item 4.2) and fostering student metacognition (Table 2: rubric item 5.3). Assessment team members were also less likely to agree when scoring these elements in the rubric.

The second cohort of materials development teams was more successful at meeting all rubric requirements compared to the first set of teams (Figure 2 – black compared to gray bars). Of the ten sets of materials reviewed in years 2-3 (2013-2014), seven passed on the first attempt, one passed after minor revisions and two required substantial revision and reassessment (Table 3). Of the three that did not pass on the first audit, all missed key metrics related to guiding principles (which require 100% compliance). More broadly, material development teams in the second cohort continued to experience difficulty meeting the requirement to include metacognitive strategies in their materials (Table 3: outlined element).

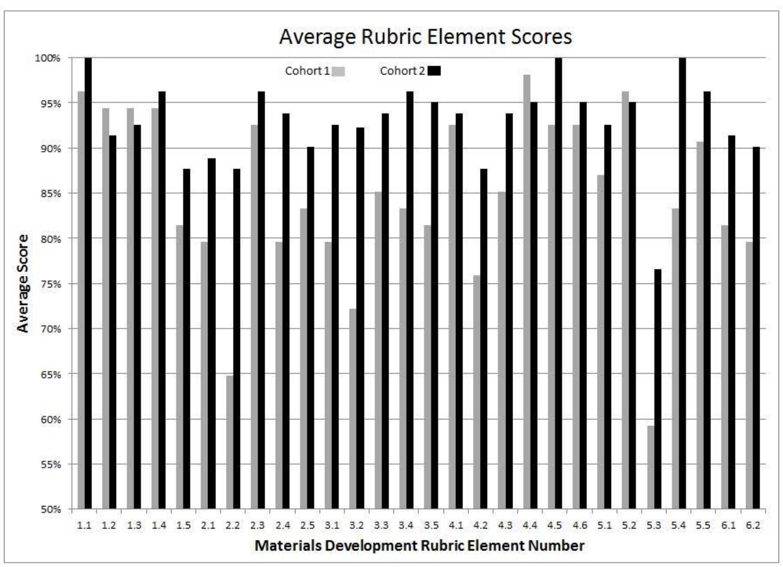

Figure 2. Team Rubric Scores. Average materials development scores by element (linked to Table 1). Cohort 1 (gray) and Cohort 2 (black)

Discussion

We interpret discrepancies in the Cohort 1 scores as areas where materials development teams (and perhaps some assessors based on scoring discrepancies) struggled to understand what was described in the rubric. The element dealing with metacognition was the most difficult criteria for the first cohort of teams to achieve (Table 2: element 5.3; 59%). Metacognition deals with one's ability to self-assess and monitor one's own learning (NRC, 2000). There are two main components to metacognition: knowledge and regulation (Schraw & Moshman, 1995). Knowing includes procedural aspects related to recognizing one's self as a learner and what factors influence our learning. For example, metacognitive students would realize that taking an exam when external distractions were present might negatively affect their scores (Fox, Rosen & Crawford, 2008). Such a learner also generally knows which learning procedures have been most effective for him/her in the past (e.g. memorization, outlining, summarizing) and when each strategy is most effective (Schraw, Crippen and Hartley, 2006). Regulation of cognition involves selecting learning strategies, planning when and where to use them and evaluating if the strategy is working (Schraw & Winne, 1995; Schraw et al., 2006). In many cases, students engage in these processes without even being aware they are using them (Pressley, Borkowski & Schneider, 1989). In many cases, curriculum developers simply overlooked the importance and complexity of this element. Once the values of these practices were recognized, developers met the criterion by including techniques such as minute papers, muddiest points and knowledge surveys (Angelo & Cross, 1993) in their instructional materials.

Cohort 1 material developers had difficulty meeting other standards in the rubric. Grading rubrics were sometimes omitted, or the criteria being assessed was not clearly identified and/or there was not a clear differentiation between achievement levels (Table 2: elements 2.2 and 3.2; 65% and 72% respectively). Other areas of weakness included the mandatory 100% score element related to systems thinking

(Table 2: element 1.5; 81%) and linkages between curricula, activities and assessments (Table 2: element 4.2; 76%). For the most part, these deficiencies were readily corrected once they were pointed out by the assessment team.

The identification of these areas of weakness allowed the InTeGrate leadership team to be proactive in providing professional development and guidance for subsequent materials development teams. First, a series of professional development webinars were conducted prior to the first meeting for material developers. Those webinars included topics related to backward design, designing and using rubrics, incorporating metacognitive skills into curriculum, designing and aligning learning outcomes and assessments. The webinars are recorded and remain available for reference or use by future teams. Next, the initial meeting of materials development teams was reorganized to more explicitly cover major elements of the rubric. Following a short description of the elements, material development teams worked with their team leader and internal assessment consultant to apply what they learned to their own project. By the end of the two-day meeting, participants had been apprised of the rubric standard, developed ideas for their own project, and received formative feedback from their assessment consultant and the leadership team. We attribute the improved scores (Table 3) to these interventions used to better prepare the second cohort of material developers.

Conclusions

A curricular auditing system coupling well-defined standards with mentoring and coaching support was found to be an effective approach for developing and refining curricula. Use of the materials development rubric allowed evaluators to give specific, constructive feedback to individual curriculum development teams. Material developers who used this rubric and had access to aligned professional development produced pedagogically robust curricula that address Earth-related grand challenges facing society. Those curricular materials cover a variety of topics of interest to the broad community of educators in fields of geoscience, engineering, social sciences and humanities. Overall, the InTeGrate materials development and refinement rubric has proved a valuable component of the project, and one that could be easily used or adapted for other curriculum development projects.

Comparing rubric scores across all modules allowed us to pro-actively prepare professional development opportunities that improved subsequent evaluations. We found curriculum developers had the most difficulty meeting standards related to meta-cognition, including attributes of high quality rubrics, and writing of clear learning outcomes and objects that align well with the broader curriculum. An important implication of this work is that novice curriculum developers who have not previously been involved in creating new course materials can be successful at meeting high standards when guidance is provided. Future work will help us understand to what extent the materials developed through InTeGrate's auditing and coaching system increase geoscience literacy, interest in Earth-related careers, and/or motivation towards environmental sustainability among students.

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This rubric is designed to guide InTeGrate assessment team members as they score modules and courses to improve geoscience literacy. The evaluation scheme is divided into six sub-areas: guiding principles, learning objectives and goals, assessment and measurement, resources and materials, instructional strategies, and alignment. The six sub-areas have a total of 28 elements that are equally weighted at 3 points each and are evaluated using the following scoring scheme:

- 3 points: rubric element explicitly and/or pervasively addressed in module/course materials
- 2 points: rubric element addressed in majority of the module/course materials
- 1 points: rubric element addressed in some of the module/course materials
- 0 points: rubric element not addressed in the module/course materials

A score of 15/15 must be achieved on the Overarching goals portion of the rubric. Scores of 85% or higher must be achieved in each of the other sub-areas of the materials rubric. Materials meeting the above criteria will earn a minimum score of 74/84.

		Points	Score
Guiding principles (Must score 15/15)			
	Course/module addresses one or more geoscience-related grand challenges facing society	3	
	Course/module develops student ability to address interdisciplinary problems	3	
	Course/module improves student understanding of the nature and methods of geoscience and developing geoscientific habits of mind	3	
	Course/module makes use of authentic and credible geoscience data to learn central concepts in the context of geoscience methods of inquiry	3	
	Course/module incorporates systems thinking	3	
Learning objectives (Must score 13/15)			
	Learning objectives describe measureable geoscience literacy goals	3	
	Instructions and/or rubrics provide guidance for how students meet learning goals	3	
	Learning objectives and goals are appropriate for the intended use of the course/module	3	
	Learning objectives and goals are clearly stated for each module in language suitable for the level of the students	3	
	Learning objectives and goals address the process and nature of science and development of scientific habits of mind	3	
Assessment and Measurement (Must score 13/15)			
	Assessments measure the learning objectives	3	
	Assessments are criterion referenced	3	
	Assessments are consistent with course activities and resources expected	3	
	Assessments are sequenced, varied and appropriate to the content	3	
	Assessments address goals at successively higher cognitive levels	3	
Resources and Materials (Must score 15/18)			
	Instructional materials contribute to the stated learning objectives	3	
	Students will recognize the link between the learning objectives, goals and the learning materials	3	
	Instructional materials should be sufficiently diverse and at the depth necessary for students to achieve learning objectives and goals	3	
	Materials are appropriately cited	3	
	Instructional materials are current	3	
	Instructional materials and the technology to support these materials are clearly stated	3	
Instructional Strategies (Must score 13/15)			
	Learning strategies and activities support stated learning objectives and goals	3	
	Learning strategies and activities promote student engagement with the materials	3	
	Learning activities develop student metacognition	3	
	Learning strategies and activities provide opportunities for students to practice communicating geoscience	3	
	Learning strategies and activities scaffold learning	3	
Alignment (Must score 5/6)			
	Teaching materials, assessments, resources and learning activities align with one another	3	
	All aspects of the module/course are aligned	3	
	Total	84	

Table 1: InTegRate Curriculum Development and Refinement Rubric

	Reviewer/Item	1.1	1.2	1.3	1.4	1.5	100%*	2.1	2.2	2.3	2.4	2.5	85%*	3.1	3.2	3.3	3.4	3.5	85%*	4.1	4.2	4.3	4.4	4.5	4.6	85%*	5.1	5.2	5.3	5.4	5.5	85%*	6.1	6.2	83%*
Module 1	C	3	3	3	3	3		3	1	3	3	3		2	3	3	3	3		3	2	3	3	3	3		2	3	2	3	3		3	2	
	I	3	3	3	3	3		3	2	3	3	3		2	1	3	3	3		3	2	2	3	2	3		2	3	1	2	3		2	2	
	E	3	3	3	3	3		2	1	3	3	3		3	3	2	2	3		3	2	3	3	2	3		3	3	1	3	3		3	3	
Minor Revision	Combined Scores	3	3	3	3	3	100%	3	1	3	3	3	87%	2	3	3	3	3	93%	3	2	3	3	2	3	89%	2	3	1	3	3	80%	3	2	83%
Module 2	H	3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3	3		3	3	3	3	3		3	3	
	D	3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	2	3		3	3	3	3	3		2	2	
	B	2	2	2	3	3		3	2	3	1	3		3	2	3	3	2		2	2	2	3	3	3		3	2	1	3	2		3	3	
Pass	Combined Scores	3	3	3	3	3	100%	3	3	3	3	3	100%	3	3	3	3	3	100%	3	3	3	3	3	3	100%	3	3	3	3	3	100%	3	3	100%
Module 3	A	3	3	3	3	3		3	2	3	3	3		3	3	3	3	3		3	3	3	3	2	3		3	3	2	3	3		3	3	
	G	3	3	3	3	3		3	2	3	3	2		2	3	3	2	3		3	3	3	3	3	3		3	3	2	2	3		3	2	
	F	3	3	3	3	3		3	2	3	3	3		3	2	3	3	3		3	3	3	2	3	3		3	3	2	2	3		3	3	
Pass	Combined Scores	3	3	3	3	3	100%	3	2	3	3	3	93%	3	3	3	3	3	100%	3	3	3	3	3	3	100%	3	3	2	2	3	87%	3	3	100%
Module 4	C	3	3	3	3	2		3	1	3	2	2		3	1	3	3	3		3	2	3	3	3	3		2	3	0	3	3		3	2	
	H	3	3	3	3	2		3	2	3	3	2		3	2	3	3	3		3	2	3	3	3	3		3	3	0	3	3		3	3	
	G	3	3	3	3	2		3	2	3	3	2		3	2	3	3	2		3	3	3	3	3	3		3	3	2	2	3		3	3	
Minor Revision	Combined Scores	3	3	3	3	2	93%	3	2	3	3	2	87%	3	2	3	3	3	93%	3	2	3	3	3	3	94%	3	3	0	3	3	80%	3	3	100%
Module 5	B	3	2	2	2	2		0	0	1	0	1		1	0	1	1	0		1	0	1	3	3	2		1	3	2	2	2		1	1	
	D	3	3	3	3	3		2	3	3	3	3		3	2	3	3	2		3	3	3	3	3	3		3	3	3	3	3		3	3	
	E	3	3	2	2	2		1	1	1	1	1		1	1	2	1	1		2	1	2	3	3	3		2	3	2	2	2		1	1	
Major Revision	Combined Scores	3	3	2	2	2	80%	1	1	1	2	1	40%	1	1	2	1	1	40%	2	2	2	3	3	3	83%	2	3	2	2	2	73%	1	1	33%
Module 6	A	3	3	3	3	0		2	3	3	2	3		1	3	1	1	2		3	3	3	3	3	1		3	3	2	2	2		1	3	
	F	2	3	3	3	1		1	2	3	2	3		1	3	1	2	2		3	3	2	3	3	2		3	2	2	2	2		1	2	
	I	3	2	3	2	3		2	3	3	2	2		3	2	3	3	3		3	1	1	3	3	3		2	3	2	2	3		3	2	
Major Revision	Combined Scores	3	3	3	3	1	87%	2	3	3	2	3	87%	1	3	1	2	2	60%	3	3	2	3	3	2	89%	3	3	2	2	2	80%	1	2	50%
		96%	94%	94%	94%	81%		80%	65%	93%	80%	83%		80%	72%	85%	83%	81%		93%	76%	85%	98%	93%	93%		87%	96%	59%	83%	91%		81%	80%	

Rubric Element Short Descriptions

1.1	Grand Challenges	**2.1**	Geoscience Outcomes	**3.1**	Assessments for LO's	**4.1**	Materials Support Goals	**5.1**	Mutitple Learning Strategies	**6.1**	Materials Align
1.2	Interdisciplinary	**2.2**	Grading Rubrics	**3.2**	Critereon Referenced	**4.2**	Materials Link	**5.2**	Student Engagement	**6.2**	Module Segments Align
1.3	Nature of Science	**2.3**	Learning Outcomes (LO)	**3.3**	LO's Consistent with Cours	**4.3**	Diverse Acitivites	**5.3**	Metacognition		
1.4	Data driven	**2.4**	Understandable LO's	**3.4**	LO's Sequenced and Variec	**4.4**	References	**5.4**	Communicating Science		
1.5	System Thinking	**2.5**	Scientific Habits Mind	**3.5**	Multiple Cognitive Levels	**4.5**	Current	**5.5**	Scaffold Learning		
						4.6	Technology States				

* Minimum % required to pass major element. All six major elements must meet stated minimum or entire module fails.

Table 2: Audit scores for Cohort 1 material developers.

	Reviewer/Item	1.1	1.2	1.3	1.4	1.5	100%*	2.1	2.2	2.3	2.4	2.5	85%*	3.1	3.2	3.3	3.4	3.5	85%*	4.1	4.2	4.3	4.4	4.5	4.6	85%*	5.1	5.2	5.3	5.4	5.5	85%*	6.1	6.2	83%*
Module 7	C	3	2	3	3	2		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3	3		3	3	2	3	3		3	1	
	I	3	3	3	3	3		3	2	3	1	3		3	3	2	3	3		3	2	3	3	3	3		3	3	3	3	3		2	3	
	B	3	3	3	3	3		3	3	3	3	3		3	3	3	3	2		3	3	3	3	3	3		3	3	3	3	3		3	3	
Pass	Combined Scores	3	3	3	3	3	100%	3	3	3	3	3	100%	3	3	3	3	3	100%	3	3	3	3	3	3	100%	3	3	3	3	3	100%	3	3	100%
Module 8	J	3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3	3		3	3	3	3	3		3	3	
	F	3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3	3		3	3	2	3	3		3	3	
	E	3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3	3		3	3	3	3	3		3	3	
Pass	Combined Scores	3	3	3	3	3	100%	3	3	3	3	3	100%	3	3	3	3	3	100%	3	3	3	3	3	3	100%	3	3	3	3	3	100%	3	3	100%
Module 9	G	3	2	2	3	3		2	3	3	3	2		3	3	3	3	3		2	3	2	3	3	3		2	2	3	3	3		2	2	
	A	3	2	2	2	2		3	3	3	3	2		3	3	2	2	3		2	2	2	3	3	3		2	2	3	3	2		2	2	
	E	3	2	2	2	3		3	2	3	3	2		3	3	3	3	3		2	2	2	3	3	2		2	3	2	3	3		2	2	
Major Revisions	Combined Scores	3	2	2	2	3	80%	3	3	3	3	2	93%	3	3	3	3	3	100%	2	2	2	3	3	3	83%	2	2	3	3	3	87%	2	2	67%
Module 10	G	3	3	3	3	3		3	2	3	3	3		3	2	3	2	3		3	3	3	3	3	2		3	3	3	3	3		3	3	
	H	3	3	3	3	3		2	3	3	3	3		3	3	3	3	3		3	3	3	3	3	3		3	3	1	3	3		3	3	
Pass	Combined Scores	3	3	3	3	3	100%	2	3	3	3	3	93%	3	3	3	3	3	100%	3	3	3	3	3	3	100%	3	3	2	3	3	93%	3	3	100%
Module 11	J	3	3	3	3	3		3	2	3	3	3		3	3	3	3	3		3	3	3	3	3	3		3	3	2	3	3		3	3	
	H	3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3	3		3	3	2	3	3		3	3	
	D	3	3	3	3	3		1	2	2	2	3		2	2	3	2	2		3	2	3	3	3	3		3	2	2	3	2		3	3	
Pass	Combined Scores	3	3	3	3	3	100%	3	2	3	3	3	93%	3	3	3	3	3	100%	3	3	3	3	3	3	100%	3	3	2	3	3	93%	3	3	100%
Module 12	C	3	3	3	3	3		3	3	3	3	2		3	3	3	3	2		3	3	3	3	3	3		3	3	3	3	3		3	3	
	D	3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3	3		3	3	2	3	2		3	3	
Pass	Combined Scores	3	3	3	3	3	100%	3	3	3	3	2	93%	3	3	3	3	2	93%	3	3	3	3	3	3	100%	3	3	2	3	2	87%	3	3	100%
Module 13	H	3	3	3	3	3		2	3	3	3	3		2	3	3	3	3		3	3	3	3	3	3		3	3	3	3	3		3	3	
	J	3	3	3	3	3		2	2	3	2	3		2	3	2	3	3		3	2	2	3	3	3		2	2	2	3	3		2	2	
	I	3	3	3	3	3		2	3	3	3	2		3	3	3	3	3		3	2	3	2	3	3		3	3	3	3	3		3	3	
Pass	Combined Scores	3	3	3	3	3	100%	2	3	3	3	3	93%	2	3	3	3	3	93%	3	2	3	3	3	3	94%	3	3	3	3	3	100%	3	3	100%
Module 14	K	3	3	3	3	3		3	3	3	3	2		3	2	3	3	3		3	3	3	2	3	3		3	3	3	3	3		3	3	
	B	3	3	3	3	3		3	2	3	2	3		2	3	2	3	3		3	2	3	2	3	3		3	3	1	3	3		3	2	
	A	3	3	3	3	3		3	3	3	2	3		3	3	3	3	3		3	3	3	2	3	3		3	3	2	3	3		3	3	
Pass	Combined Scores	3	3	3	3	3	100%	3	3	3	2	3	93%	3	3	3	3	3	100%	3	3	3	2	3	3	94%	3	3	2	3	3	93%	3	3	100%
Module 15	I	3	3	3	3	2		3	3	2	3	3		2	3	2	3	3		2	2	3	3	3	3		2	3	1	3	3		2	3	
	F	3	2	2	3	2		3	3	2	3	3		2	3	3	3	3		2	2	2	2	3	2		2	3	1	3	3		2	3	
	G	3	3	2	2	2		3	2	3	3	2		3	2	3	3	2		3	2	3	3	3	3		3	3	2	3	3		3	2	
Major Revisions	Combined Scores	3	3	2	3	2	87%	3	3	2	3	3	93%	2	3	3	3	3	93%	2	2	3	3	3	3	89%	2	3	1	3	3	80%	2	3	83%
Module 16	H	3	3	3	3	2		1	3	3	3	3		3	3	3	3	3		3	3	3	3	3	3		3	3	3	3	3		3	3	
	J	3	2	2	3	1		3	2	3	3	2		3	2	3	3	3		3	3	3	3	3	2		3	3	2	3	3		3	3	
	A	3	2	3	3	1		3	2	3	3	3		3	2	3	3	3		3	3	3	3	3	3		3	3	2	3	3		3	3	
Minor Revisions	Combined Scores	3	2	3	3	1	80%	3	2	3	3	3	93%	3	2	3	3	3	93%	3	3	3	3	3	3	100%	3	3	2	3	3	93%	3	3	100%
		100%	92%	93%	96%	88%		89%	88%	96%	93%	90%		93%	93%	94%	96%	95%		94%	88%	94%	94%	100%	95%		93%	95%	76%	100%	96%		92%	90%	

* Minimum % required to pass major element. All six major elements must meet stated minimum or entire module fails.

Table 3: Audit scores for Cohort 2 material developers. Rubric element descritions by item number are listed below Table 2.