InTeGrate

Interdisciplinary Teaching of Geoscience for a Sustainable Future

MID-PROJECT EVALUATION REPORT

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October 26, 2014

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Introduction

InTeGrate is funded by a five-year STEP Center grant from the National Science Foundation. The program supports the teaching of geoscience in the context of societal issues both within geoscience courses and across the undergraduate curriculum. Our goal is to develop a citizenry and workforce that can address environmental and resource issues facing our society.[2]

The InTeGrate Center includes three program elements designed to mutually reinforce one another and create feedbacks that improve the quality of the center's work and expand the scale of its reach:

1) *Production of freely available teaching materials and examples of their use in courses that will result in improved geoscience literacy*
2) *Demonstration of implementation programs that will increase the number of students developing geoscience literacy or majors prepared to address issues of sustainability*
3) *A dissemination and professional development program designed to support the development efforts and foster adoption and adaptation of InTeGrate's materials and programs.*

The InTeGrate project began its work on December 1, 2011. This report summarizes the project status slightly past the mid-point of InTeGrate's expected five-year funding period as seen through the eyes of its external evaluation team. Evaluation findings are grounded in a wealth of data and observations, including interviews, surveys, student assessments, attendance at virtual and face-to-face meetings, and review of documents and websites.[3] Our understanding of the underlying theory of change, and the structures, functions, and behaviors of the complex system called InTeGrate has been supported by developing a set of logic models, which map out the conjectured and observed flows of information and influence through various components of InTeGrate (Appendix A).

The report is organized according to the program elements from the InTeGrate proposal, as follows:

- Introduction
- Program Element #1: Materials Development
- Program Element #2: Implementation Programs
- Program Element #3: Dissemination and Professional Development Programs
- Overarching Themes

This report would not have been possible without the generous amount of time and thoughtful reflections provided by project leaders and program participants whose contributions we have used to help formulate and present this picture in time of InTeGrate's work.

[2] InTeGrate website, home page [open access]: http://serc.carleton.edu/integrate/index.html

[3] Note on sources: InTeGrate uses its inward-facing, password-protected website as a venue to organize and archive documents, drafts, notes, data, and various interim products, as well as a locale for housing tools to enable collaboration across a geographically distributed team. This report draws heavily on such materials, noting such sources in the footnotes as [restricted access].

Program Element #1: Materials Development

> *The first goal of our proposed center is to develop curricula that will dramatically increase geoscience literacy of all undergraduate students, including the large majority that do not major in the geosciences, those who are historically under-represented in the geosciences, and future K-12 teachers, such that they are better positioned to make sustainable decisions in their lives and as part of the broader society*[4].

In this section, we

- describe InTeGrate's strategy for developing curriculum materials;
- outline the development process designed and revised over time to guide developers and ensure materials would achieve project goals;
- examine the development teams' reflections: whether the process worked, how well the process supported their effort, what challenges they faced;
- identify the current status of InTeGrate's curriculum materials: what is completed, in the final revision stage, being piloted in faculty classrooms, still under development, and in the planning stage; and
- discuss the impact of the development process on participating faculty.

Strategy and Goals

Since InTeGrate's start in late 2011, the leadership team[5] has designed a complex strategy to recruit, guide, and support undergraduate faculty from all types of universities and colleges to work collaboratively in inter-institutional teams. These three-plus person teams, from distinct schools, develop, pilot, refine, and publish curriculum materials that can be adapted for use in the full range of instructional settings they represent and are appropriate for the diverse populations of students they serve.

The end result of this curriculum development effort is intended to be

> *... a new breed of teaching materials that can be utilized in general education courses, teacher preparation courses, core courses within geoscience majors, and courses designed for other majors including environmental studies, social science, engineering, and other sciences.*[6]

The materials form the cornerstone of the InTeGrate program, designed to

- address one or more Earth-related grand challenges facing society,
- develop students' ability to address interdisciplinary problems,
- improve student understanding of the nature and methods of geoscience and developing geoscientific habits of mind,
- make use of authentic and credible geoscience data to learn central concepts in the context of geoscience methods of inquiry, and
- foster systems thinking"[7]

[4] InTeGrate proposal.

[5] InTeGrate's leadership team provides overall guidance for the project. They are Cathy Manduca (PI), David Blockstein, Tim Bralower, Diane Doser, Anne Egger, Sean Fox, David Gosselin, Ellen Iverson, Pamela Matson, David McConnell, Elizabeth Nagy-Shadman, Laura Serpa, David Steer, John Taber. Webpage "Leadership Team" [open access]: http://serc.carleton.edu/integrate/about/leadership.html

[6] InTeGrate proposal.

and, to incorporate

- "effective pedagogy, as defined through research and experience,
- integrated, metacognitive opportunities for students to reflect on their own knowledge and learning processes in the earth sciences, and
- strategies known to increase student learning, improve recruitment, and promote retention."[8]

The Development Process

Members of InTeGrate's leadership team, as well as key staff from the Science Education Resources Center (SERC) at Carleton College, have played crucial roles in the materials development process. A brief summary of InTeGrate's process is outlined below.

Community Outreach

InTeGrate cast a broad net calling for instructors to participate in the development of courses or modules[9] for undergraduates. They also issued targeted calls for specific types and uses of materials. The solicitations required that each team include members from at least three institutions and work in diverse instructional settings. The requirement that materials be co-developed by multi-institutional diverse teams was intended to result in materials that could be used in a wide range of settings (Appendix fig. A5) and contribute to building a community of practice (Appendix fig. A-6). Applicants were invited to apply as individuals, as a partial team, or as a complete, pre-formed team. Proposals were carefully vetted, and existing or re-configured teams were selected to participate in the development process.

Face-to-Face Meetings for Development Teams

As each cohort began the development process, InTeGrate held a kick-off meeting to launch the collaboration and provide participants with information to clarify project expectations. At this meeting, project staff introduced tools and resources to guide, support, and assess developers' work. There was also time for collaborative work.

Multiple tools and resources were developed to support the materials development process and nudge the materials towards InTeGrate's curriculum goals (Appendix figure A4). These include:

1. InTeGrate's Curriculum Development and Refinement Rubric (CDRR)

> *This rubric is designed to guide InTeGrate curriculum developers as they create modules and courses to improve geoscience literacy. The rubric incorporates broad goals of the InTeGrate project and researched guidelines for best practices in curriculum development.*[10]

The CDRR is used to assess the extent to which the curriculum materials align with and effectively address InTeGrate goals, and to determine teams' progress throughout the development process.

2. InTeGrate Website

The website serves several functions in the development process: (1) it provides an extensive set of online instructions, guidelines, timelines, and resources; (2) it houses teams' workspaces for ongoing communications, posting of materials in progress and ready for review by leadership team members and

[7] InTeGrate proposal.

[8] InTeGrate proposal.

[9] An InTeGrate module comprises approximately 2-3 weeks of instruction.

[10] InTeGrate Curriculum Development and Refinement Rubric [Version 9, 6/6/13]. Entire rubric is included in this report as Appendix B.

assessment consultants; and (3) it is the vehicle for publishing and distributing completed modules and courses.

3. Assessment Team

InTeGrate invited individuals with curriculum development and assessment expertise to work with the leadership team to design student assessments, to review the curriculum materials at critical checkpoints, and provide feedback to development teams as to whether materials are aligned with and fully address rubric elements.

A second face-to-face meeting, held mid-way through the development process, again brought teams together to examine student assessment results from classroom pilots, to review teams' progress, and to plan the revision process.

Ongoing Support System

Initiated during the introductory meeting and continuing throughout the development, piloting, and revision stages of the process, this system includes the following people and resources:

- InTeGrate leadership team members[11] provide overall guidance, facilitate the development process, and provide advice to development teams on an as-needed basis.
- Online resources on the InTeGrate website are updated continuously to address emergent needs.
- Real-time and archived webinars offer background information to get the development process started, and address topics development teams find most challenging.
- SERC's web team provides support for those unfamiliar with or struggling to become facile with InTeGrate's content management system (CMS); designs the structure and formats teams' workspaces to facilitate communication and house materials in development; and reviews module and course materials ready for publication. They are instrumental in the design of the final product.
- Assessment consultants review materials at critical junctures in the development process, providing feedback to the development team on addressing rubric components, developing embedded student assessments, and interpreting testing results.
- SERC's internal evaluation team works closely with the assessment team to assist developers in the administration and collection of student responses during pilot testing; score and analyze student products; and provide teams with data to inform materials revision.

Materials Review

When the development teams signal that the draft materials are complete, the InTeGrate team leader and assessment team members conduct a final and full review of the materials using the CDRR. If they successfully pass the review, the materials are deemed ready for the next phase—pilot testing materials in authors' classrooms.

Piloting Materials

Each team pilots the materials at their home institutions, keeping a log of their own and their students' experiences. Faculty administer and collect student assessments: specific assessments embedded in individual curriculum materials, as well as InTeGrate-wide instruments.

[11] Specific leadership team members take responsibility to mentor clusters of materials development teams, e.g. pre-service teachers, teachers of intro courses, etc.

Revision, Documentation, Final Reviews and Publication

Finally, based on their piloting experiences and students' outcomes, the teams revise the materials, and create comprehensive sets of documentation to support materials use by other faculty. The last step in the review process is an external review for scientific accuracy. Materials are published on InTeGrate's website.[12]

Teams' Reflections on the Materials Development Process

InTeGrate is designed to be transformative. Its strategy for developing materials is experimental, experiential, and dynamic. The structure, developed to both guide and support faculty teams, has been revised and refined over the past three years based on the experiences, candid feedback, and recommendations of all the participants—the leadership, assessment, and development team members. As a result, each new cohort of materials developers has profited from the work of those that went before them.

To understand whether and how effectively the development process was working, the leadership team and evaluators asked participants to provide their perspectives on the experience. Phone conferences, email exchanges, and shared workspaces provided informal information. In addition, several methods for formally collected participant data were used:

- Workshop "road checks" and end of meeting surveys.[13]
- Reflection questions embedded in teams' website pages, seeking participants' responses, either as individuals or as teams, at four points in time—when they completed the materials review process and were ready to pilot the materials, when they finished piloting, after they planned their revisions, and at the end of the development process.
- Team interviews conducted during the two face-to-face meetings of the teams—once as they began their work and again when most teams had piloted their materials and were making plans for revisions.

These data sets were analyzed and teams' feedback was used formatively, to improve the development process, as well as to document what knowledge and skills faculty gained about curriculum development, new content, pedagogical approaches that enhance student engagement and learning, and classroom instructional practices. In this section of the report, we discuss teams' feedback on the materials development process and their influence on the design of the materials development process.

Lessons Learned from the First Cohort

When the first teams met in spring 2012, the materials development process was still under construction: the CDRR was in draft form, the assessment team had just been formulated, a set of student assessments were being reviewed and refined, and glimpses of what has now become the well-articulated system for supporting teams were just emerging.

These first cohort (six teams) called themselves the guinea pigs or, more fondly, the pioneers. Team members involved with the three completed modules have recently submitted their final reflection. Their view is from two-plus years out—after a lengthy but successful development process.

[12] Webpage "InTeGrate-Developed Modules and Courses" [open access]: http://serc.carleton.edu/integrate/teaching_materials/modules_courses.html

[13] "Road checks" are brief, end-of-workday surveys that allow meeting leaders to "check-in" on how participants are faring, whether next steps are clear, and if additional time or support is needed, and then to structure or revise the next day's agenda accordingly.

I think all of our biggest challenges can be attributed to the fact that we were one of the first teams to go through the process. There were no models for us to follow, and we (as well as the InTeGrate leaders) were in the position of figuring it all out as we went along.

The InTeGrate leaders seemed to have a clear vision of where the project needed to go and that ultimately served as our guide in module development (even if the means of obtaining that final vision were not clear to anyone).

I know we were the first group to go through the process and many of the frustrations we faced about the evolving expectations have been worked out. Communication about the timing of reviews and expected responses wasn't always clear. The website wasn't always correct about what was needed for each Checkpoint. (It is now, I checked!)

We felt comfortable telling InTeGrate leaders when things weren't clear and when we needed help. Everyone was open to hearing our frustrations and tried to offer help where they could.

As the first cohort progressed, InTeGrate worked to clarify expectations based on teams' struggles: to elaborate the instructions, timeline, and checkpoints on the Materials Development section of the website; develop new, standardized structures and recording formats on teams' workspaces; and formalize the roles and responsibilities of the leadership and assessment teams. Over time, InTeGrate has continued to refine the process, clarify next steps as teams arrive at new phases of the work, and add new resources.

The Curriculum Development & Revision Rubric (CDRR)

A key change was made based on teams' reports on their difficulty understanding the importance and intended use of the CDRR as a guide for their work. InTeGrate redesigned the initial workshop for the second cohort of development teams. The leadership team realized that more explicit discussion and hands-on experience working with the rubric elements were needed. The next workshop centered each day's work around rubric components – the project's guiding principles; setting learning goals and objectives; student assessments, resources and materials; and instructional strategies. This effort proved successful both in helping to clarify and streamline the development process and to ensure the materials were aligned with project goals. Over time, InTeGrate has continued to refine the development process, clarify next steps as teams arrive at new phases of the work, and add new resources.

The shift in teams' reports on using the CDRR reflect InTeGrate's design change, as shown in the two sets of comments below. Reflections from the first cohort of materials developers:

Given that the materials rubric was under development during the period of time in which we did the primary planning for our modules, we actually didn't look at it until we were near the end of the process.

The development of the material was not … based on the rubric, which may have been a key issue for our module's delay.

These comments, from development team members after the redesign of the workshop, revision to website, and more organized feedback from leadership and assessment team advisers, demonstrate the effectiveness of InTeGrate's efforts to improve the project's support.

The rubric made us pay closer attention to the evaluation of student work (scoring rubrics) and student metacognition.

We worked to incorporate more student activities, more interdisciplinary materials, and a greater focus on systems thinking.

It helped us better articulate how our lessons should be taught.

The rubric really helped me focus my materials, resources, and activities on geoscientific habits of mind and mak[e] sure the learning objectives were part of the larger framework and referenced throughout the different modules.

The rubric pushed us in directions that we might not have gone—the interaction between earth science and economic, societal, and policy issues.

Assessment Team Consultant

Teams reported variations in their experiences with their assessment team members. Some teams found them especially helpful in navigating the development and review process, while others reported that communication was difficult and feedback a long time in coming. Some of this variation stemmed from early confusion about and lack of clear delineation of assessment team members' roles and responsibilities vis a vis the project leaders' during the first year. Project leaders provided guidance and support to the development teams, while the assessment team was charged specifically to review and score the materials on how well they met InTeGrate's standards and to report their findings to developers. It must also be noted that assessment team members' content specific expertise, availability to review materials on short notice, and their personal style of communicating results varied.[14]

We were a little confused about (Assessment Consultant's) role (and I think s/he was a little unclear about what it should be, too) and had initially thought she would help read things through more often until we (and she) learned that it was really just focused on the checkpoints. I thought she gave us good feedback in a constructive way and she seemed to appreciate and be supportive of our efforts.

Our Assessment Consultant was not helpful. I am still not sure of the purpose or role of the assessment consultant on our module.

We had a really thoughtful Assessment Consultant who always had perceptive and helpful advice. (S/he) was very easy to work with and had great suggestions.

The Assessment Consultant provided excellent feedback and careful reviews of our materials in a timely manner… We incorporated all of her suggestions and it made the materials better.

Our assessment Consultant provided useful feedback at key points in the process, but for most things we relied on our team leader. Working with (Leadership Team member) has been wonderful. (S/he's) been really helpful in providing tangible suggestions when we've struggled with sections of the module.

Other Challenges

The materials developers noted that the modules and courses they developed differed from undergraduate curriculum materials they had created in the past in the following ways:

- Learning experiences were designed to engage students in more interactive, collaborative, and reflective work.
- Student assessments were designed to intentionally and explicitly align with the module or course learning goals.
- Modules and courses included more on-line resources.

[14] There are two weaknesses in the data presented here, and caution is advised in drawing conclusions at this time. First, these reflections from materials developers were written shortly after they had received assessors' feedback. Later in the report, we present developers' perspectives on the value of the recommendations in the reviewers' feedback based on data collected after piloting and during revision stages. In some cases, it took time and more work to fully understand the import of the information they received. Second, the data is not fully triangulated. We interviewed some of the assessment team members during the first two meetings at Carleton, and not after most had conducted their first set of materials reviews. We did however attend sessions where the review process was discussed, and had informal conversations with project team leaders where they noted the concerns expressed by some of their teams.

In addition, they reported that:

- The process was 'more ambitious, more rigorous, and more intense' than their experience developing curriculum materials in the past.
- Working collaboratively as a cross-institution team required members to consider not only students in their own classrooms, but different populations of students, as well as those learning in significantly different settings from their own.
- Completing the module development took teams longer than expected due to some teams' difficulty managing the web-based interface [CMS], the extra time and effort needed to integrate group members' work, researching appropriate resources and securing copyright permission for their use, and revising and preparing materials for publication.

The inexorable progression of linear time was the biggest challenge.

Perhaps the biggest challenge was all of the web-master duties that went with writing these materials. I had gone into the project focusing on the actual documents that we would write rather than all of the web pages that we would have to author. Those really slowed me down, but I understand why they had to be done.

It seemed like expectations, protocols, and timelines kept changing throughout the development process, and I think that this impeded progress to some extent.

It was really hard to collaborate with people in other time zones…

It was particularly challenging to work with others who had a different tolerance for uncertainty of workload than I did, but being able to talk amongst ourselves was great, and we just adjusted who did what at different times to meet everyone's needs.

One of the challenges was feedback. There were a few points where we felt like we were told, 'you are almost there' but perhaps not enough guidance on how to get 'there.'

I realized that apparently, most of the materials that I've developed in the past have incorporated at least an element of already existing teaching materials. Building the InTegrate materials 100% from scratch was seriously one of the most challenging endeavors that I have undertaken in my career.

The greatest challenge was probably coordination among team members. We had a large team and developed a full course – 12 modules of material, so achieving alignment was difficult.

InTeGrate's System of Support for Material Development Teams

Materials developers who have completed their modules reflected on the parts of the development process that they valued and felt worked well. They identified both specific phases of the process as well as components designed to support their work, including the workshops at Carleton, advice from InTeGrate's leadership team, and technical support from their website consultant. Teams varied in their experiences with Assessment Team members. Some found them especially helpful in navigating the development and review processes, while others reported that communication was difficult and feedback a long time in coming. Most teams worked together effectively, even those that had not known one another before.

What worked well? The materials development phase. The review process and revising and preparing materials for publication were more difficult.

I really enjoyed working with my team, working with our assessment leader, doing the integrate workshops, and making the materials. Having a good working group was crucial to our success in the project.

Having time to get to know my teammates, brainstorm ideas, set some goals and a schedule, and then time to revise at Carleton in year 2 were critical to the creative process.

Semi-regular check-ins via phone with [leadership team member] were very helpful and kept us on course or at least let us know whether we were on course.

(Leadership team member) has been a tremendous leader. I am grateful for (his/her) guidance and our team benefited so much from his/her help.

Technical assistance with the CMS was superb! You guys are awesome!

I enjoyed teaching with the new materials, and comparing experiences teaching the same materials with my teammates.

Finally, for some team members, participating in InTeGrate's materials development process was especially rewarding.

My team was in frequent communication and we worked well together. By luck or plan we all have small children, which meant we were all most available for conference calls post-bedtime. We have become friends, and colleagues, and I'm so grateful to the ITG leadership for the brilliance of bringing faculty together to collaborate in this way.

The development process, the rubric, and teaching of these materials have been valuable to my own teaching in ways I hadn't expected.

I'm really happy to have this opportunity to be involved in the project. I was inspired to work with great colleagues, share new ideas, and be involved in a new paradigm in curriculum development. I learned a lot and I would love to do a project like this again.

We discuss further the impact of team members' involvement later in this section, under "Impact on Faculty."

Progress to Date

The effort will engage over 150 faculty from across the nation collaboratively developing and testing materials including no fewer than 25 faculty from two-year colleges and minority serving institutions.

—InTeGrate proposal

While InTeGrate has not yet met its proposed goals in terms of the number of faculty participating in its materials development process or the diversity of their institutions, the project is, at the end of Year 3, very close and within reach of its targets. The number of developers, testers, and assessment team members involved in InTeGrate's materials development process is 138; 17 are from two-year colleges and 7 from minority serving institutions (Exhibit 1).

Exhibit 1: Faculty and instructors by institutional setting

Institution	Authors*	Testers	Assessment Team
Associate's Colleges	9	7	1
Baccalaureate Colleges	10		3
Master's Colleges/Universities	24		2
Doctoral/Research Universities	25		6
Totals	*68*	*7*	*12*
Minority Serving Institutions	6		1

*Data on materials developers' institutions are incomplete at this time. Not all existing team members completed the full set of information requested; data on teams entering the development process or with pending proposals are also incomplete.

Materials development teams, those independently testing the materials, and members of the assessment team are spread across a diverse range of institutions. Half of the authors are female. Demographically, 6.3% are Asian, 5.2 % Hispanic, and 2.4% Black.

As of October 2014, our data shows that 34 teams comprising 119 undergraduate faculty and instructors, teaching at 64 colleges and universities (nine at two-year colleges and six at minority-serving institutions (MSI)), and located across 23 states are at work or about to begin work developing curriculum materials at the module or course scale. In addition, 12 members of the assessment team, one from an MSI and seven faculty teaching at two-year colleges, who are not members of a materials development team but have tested sets of the materials with their students, have contributed to InTeGrate's materials development process. To date, only two teams have not continued in the program. One was unable to get started due to members' commitments; another team was unable to make sufficient progress.

Of the 34 remaining teams,

- three teams have completed and published their modules on InTeGrate's website, http://serc.carleton.edu/integrate/teaching_materials/modules_courses.html
- five teams are in the final revision stage and are preparing their modules and courses for publication,
- six teams have drafted materials, have passed the rubric review process, and are piloting their materials in classrooms,
- six sets of materials are still in the development phase,
- nine teams begin the development process in November 2014, and
- five additional proposals are pending (Exhibit 2).

Exhibit 2: *Summary of InTeGrate's Materials Development Effort, 2012-2014: Materials Completed, Under Development, Proposed Materials Development Teams, Faculty, Instructors*

Stage of Materials Development	Teams	Authors
Completed & published	3	9
Final revision; preparing for publication	5	16
Passed rubric; being piloted	6	24
Partially developed	6	16
Starting development process, Nov. 2014	9	37
Proposal stage, pending final approval	5	17
Totals	*34*	*119*

Exhibit 3 provides a list of materials recently completed or still under development from the 2012 and 2013 solicitations. It is organized by the intended use of the materials: general education programs, interdisciplinary courses, teacher preparation programs, materials that extend learning about the earth beyond geoscience programs, and modules and courses for geoscience and related majors. It includes the start date, the title of the module or course, and the current status of the development work.

Exhibit 3: *InTeGrate Materials Development 2012–13*

Materials for General Education Courses				
Start	*Intended use*	*Title*	*Type*	*Status*
2012	Introductory geoscience	Climate of Change: Interactions and Feedbacks Between Water, Air, and Ice	Module	Complete
		Natural Hazards and Risks: Hurricanes	Module	Complete
		Environmental Justice and Freshwater Resources	Module	In final revision
		Human's Dependence on Earth's Mineral Resources	Module	In final revision
2013	Introductory Geoscience	Sustainable Agriculture as Context for Developing Earth Systems Thinking	Module	In final revision
		Living on the Edge: Building Resilient Societies on Active Plate Margins	Module	In final revision
		Carbon, Climate, and Energy Resources	Module	In development
Interdisciplinary General Education Courses				
2013	Interdisciplinary General Education	Gateway to Renewable Energy and Environmental Sustainability (GREENS)	Course	Passed rubric; being piloted
		Engaging Students In Grand Challenges in an Interdisciplinary Water Sustainability Course	Course	In development
Teacher Preparation Modules/Courses				
2012	Teacher Prep	Exploring Geoscience Methods with Secondary Education Students	Module	Complete
		Interactions between Water, Earth's Surface, and Human Activity	Module	In final revision
2013	Teacher Prep	Soils and Society	Module	Passed rubric; being piloted
Materials that Extend Teaching About the Earth beyond Geoscience Programs				
2013	Humanities	Mapping the Environment with Sensory perception	Module	Passed rubric; being piloted
		Climate Facts and Fiction	Module	In development
2013	Social Sciences	Map your Hazards! Assessing Hazards, Vulnerability and Risk	Module	Passed rubric; being piloted
2013	Engineering	Water Sustainability in Cities	Module	In development
Materials for Use in Geoscience and Related Majors				
2013	Upper-level Interdisciplinary	Introduction to Critical Zone Science Course	Course	Passed rubric; being piloted
2013	Interdisciplinary Distance Learning	Coastal Processes, Hazards, and Society	Course	Passed rubric; being piloted
		Energy and Society	Course	In development
		Water Science and Society	Course	In development

Summer 2014 Solicitation

Prior to the most recent call for proposals, the leadership team reviewed the portfolio of materials under development and analyzed existing gaps based on InTeGrate's intended goals and the extent to which the current materials addressed them.

- the established needs of InTeGrate's intended audiences—students in general education and pre-service education programs; students majoring in geoscience, engineering, and other sciences; and students majoring in social sciences and humanities;

- the principles and big ideas outlined in the earth, atmospheric, climate, and ocean science literacy documents; and
- critical societal issues identified in recent documents from AGI, GSA, ICSU, ISSC, NRC, ESA, and AAAS.[15]

Based on the leadership team's analysis, InTeGrate's summer 2014 call for proposals targeted the following set of additional materials:

- Modules or courses that use humanities, engineering, or social science frames to teach about the Earth.
- Modules or courses that bring learning about the Earth into the core majors of biology, engineering, economics, or other disciplines or that bring engineering, economics, business, or other disciplines into the core geoscience major.
- Modules for introductory geoscience or environmental science courses that integrate geoscience and societal issues, and focus on the following topics:
  - The Global Energy Balance and the Atmosphere
  - Sustaining the Oceans
  - The Urban Environment
  - The Changing Biosphere: Lessons from the Past
  - Human Health and the Environment
  - Mountains: A Window into the Earth's Interior

Thirty-seven undergraduate faculty and instructors have been invited to attend the introductory workshop at Carleton College in early November [16]to begin the development of nine new modules or courses. Proposals are pending from 5 more teams, some of whom may be ready to start by the November meeting.

Impact on Faculty

InTeGrate theorized that it could transform undergraduate teaching and student learning about the Earth by bringing together teams of faculty from distinct institutional settings, teaching diverse populations of students, to participate in a rigorous, guided process for designing and developing its 'new breed of instructional materials.' This theory of change assumes that the materials development process would alter not only those involved in the development process (Appendix fig. A-6) but also the other faculty or faculty teams, undergraduate disciplinary departments, and/or programs through broad dissemination of the materials. InTeGrate's implementation programs, discussed in the next section of the report, are intended to encourage and support the widespread adoption and adaptation of the materials as well as have an impact at the institutional level.

In preceding sections, we described InTeGrate's materials development process, discussed how it has been revised and strengthened based on participant experiences, and identified materials completed or in the development pipeline. In this section, we look at team members' reports of the impact their involvement has had on their understanding of curriculum design, effective ways to engage students and

[15] AGI: The American Geosciences Institute; GSA: The Geological Society of America; ICSU: International Council for Science; ISSC: The International Social Science Council; NRC: The National Research Council; ESA: Ecological Society of America; AAAS: American Association for the Advancement of Science

[16] Webpage "InTeGrate November New Course & Module Team Meeting" [restricted access]: http://serc.carleton.edu/dev/integrate/info_team_members/meetings/nov14_participants.html

foster their learning, assess student outcomes, and incorporate the research-based instructional practices advocated by InTeGrate.

Data sources include participants' written reflections at several intervals in the development process: after the materials development phase, after piloting materials with students, after revising the materials, and finally, when the materials are ready for publication. The questions probe team members' experiences at each stage of the process. As shown earlier, teams enter the process at different times, develop half or full semester courses or modules of 2-3 weeks duration, and progress unevenly. The data sets reflect these differences. Currently, InTeGrate has 20 teams with 65 faculty members developing materials. Data available at this time, and analyzed for this report, include:

- 39 individual responses to reflection #1 from 13 teams (development complete);
- 25 responses from 9 teams for reflection #2 (after piloting materials); and
- 6 materials developers have completed the final reflection (Reflection #4).

Reflection #3 captures information about teams' specific plans for revising the materials and is less relevant to this discussion.

- In addition, evaluators conducted interviews with 9 materials development teams and several InTeGrate Leadership team members during face-to-face meetings held at Carleton College. The interviews with the development teams focused on two questions.
- Has/how has Integrate's design process and your work developing your materials influenced what you teach (content)?
- Has/how has Integrate's design process and your work developing your materials influenced how you teach (instructional approach)?

Interviews with members of the project leadership asked about their perspective on how well the meeting was achieving its goals and whether the materials development teams were making progress. A summary of the evaluation team's data sources and the number of respondents for each is shown in the Exhibit 4.

Exhibit 4: *Data Sources*

		Teams	Individual Members	Project Leaders
Written reflections	1	13	39	
	2	9	25	
	4	3	6	
Interviews		9	26	6

Materials Developers

Faculty responding to InTeGrate's call for proposals and selected to serve on development teams are, by design, exceedingly diverse. They vary on multiple attributes:

- institutional setting, instructional environment, and students served;
- educational background, discipline, and years of teaching at the undergraduate level;
- experience developing materials for use in geoscience and interdisciplinary courses;
- familiarity with and prior use of the science literacy documents to inform their work;

- knowledge of research on student learning and its application to reform-based, instructional practices.

The most important finding about the project's impact on faculty is that, for most participants, their involvement in InTeGrate's materials development process was an intensive personal and professional, collaborative learning experience. That is, it allowed most team members to start from where they were and what they knew, to contribute areas of expertise to their teams' work, and supported them to discover or deepen their knowledge in new or less familiar territory in concert with teammates. The following comments demonstrate the diversity of participants' prior teaching experiences and knowledge bases.

In the last few years, I've tried to use more interactive activities in my classes, so I jumped at the chance to work with others to develop more of those.

The way that we taught the module was in line with the way I normally teach. The content was similar, but more expanded.

[I was] doing a lot of project-based learning, having students work on activities in collaborative groups and report back. One thing I had not done a lot of was have the classroom become a learning community; have different collaborative groups wrestle with ideas, summarize their thoughts. I knew it was a good pedagogical tool, but I had not sat down and done it. I've had some growing pains. It was a learning experience for me, forced me out of my comfort zone. This work got me to do it.

I've never done formal education things. The terms and vocabulary were new to me.

[It was] an aggressive learning curve.

Some participants had been involved with programs offered by the Science Education Resources Center (SERC) in the past. They came to InTeGrate's development process with a clearer understanding of what the work was likely to entail.

I was familiar with InTeGrate's style and process. I've been a 'Cutting-edger' for a long time. I was attracted to the call for proposals. It allowed me to spend time doing what I wanted to do anyway. It was the same direction I was already going. But, I got new ideas. It forced me to try and do in a large class what I do in smaller classes -- jig saws, group discussions. I had not used those successfully in large classes before.

I modeled the design of the module on a course I taught last fall in a [general education] classroom. It's the approach I want to be heading in for all my courses. It was an opportunity to do it, in-depth.

A small number of participants found the materials development experience too far afield from their work. Others found that InTeGrate's expectations were too great a stretch and struggled to understand and/or to meet them.

My unfamiliarity with much of the pedagogical language and processes led to lengthy periods of torpor when I wasn't making any progress in materials development. Not only didn't I know where to go, I didn't even know what questions to ask.

During the development process, some expressed concerns about fully understanding feedback they received from project leaders or assessment consultants, or how to adequately revise their work in order to pass the review process.

The four of us are not pedagogy people. When we got feedback from reviewers, it was riddled with assessment terminology. It used lots of lingo, like the terms backwards design, formative and summative assessments. It's been a grand challenge.

InTeGrate project team leaders mentoring clusters of development teams were aware of the range of knowledge and skills faculty brought to the process. Some offered professional development sessions at the face-to-face meetings at Carleton and in webinar formats.

People come in with more or less experience on instructional strategies. What does it mean to work with real data? I did not want to lecture about active learning; I wanted to give them an example, how they can do it. I

hope that was useful. I wanted them to see that they should consider us resources, direct them to some online materials, and to see their fellow team members as sources for those ideas. For the teacher prep groups, this is old hat to them. It's less of an issue. They are used to doing it. For the R1s, its not what they're used to doing.

Interview, InTeGrate Team Leader

Another InTeGrate leadership team member and one of his graduate students, is conducting research on changes in module developers' beliefs about teaching and instructional practices as a result of the materials development process. He used their preliminary findings to alert him to the teams and/or team members more likely to need his support. [17]

We found out from the first time through [during the development process with cohort 1] that the team that did best got the best score on the BARSTL. Teams with difficulties, did worse on the BARSTL. Seeing that prompted us to use the BARSTL assessment earlier in the materials development process. Clearly, there is a relationship between the knowledge faculty bring to the task and the way they move through the process. In year two, the team that scored highest on the BARSTL got through the rubric review by the end of the summer.

Interview, InTeGrate Team Leader

What Faculty Learned/Gained from Developing InTeGrate Materials

It has not been possible at this time, based on existing evaluation data, to quantify faculty gains in any category of learning or practice. Rather, we have been able to document what was important or central to participants about their experiences and how their involvement in the process led to new knowledge, skills, or practices. As new materials become available, authors' case studies will hold another rich, contextualized source of evidence of the project's impact on materials developers.

In the sections that follow, we summarize what materials developers highlighted as areas of personal and professional growth. For now, many of their reflections suggest the potential for their pursuit of further research on teaching and learning; expansion of their interactions and perhaps collaboration with faculty in their home departments, programs, or institutions; and efforts to revise, refine, or create new materials for their courses. In a few instances, there are data that we consider early indicators of these changes.

The Value of Collaboration. Nearly all team members said that working cross-institutionally with other materials development collaborators was a new, productive, and valuable experience. They said they learned new ways of 'doing things' from teammates as they exchanged ideas and critiqued one another's writing.

Until now, most of what I've done in terms of developing curriculum materials, I've done on my own.

Best aspect? Hearing different ways of doing things; expanding the way that I think about things.

Best part of the development process? Collaborating in a very intentional and intense way. Bouncing things off each other, 'my way is not the best way.' I'm likely to do it again if I can find others to collaborate with.

We had a good team: respectful, communicative... But, it was a huge amount of work. It took more thought. We'd critique each other; use each other's stuff. You can't be successful without it. We got lumped into our group. We lucked out.

[17] David McConnell and Michael Pelch, North Carolina State University, are conducting research on faculty outcomes among InTeGrate team members who are developing introductory geoscience modules for general education students. 'Ongoing research at NCSU is focusing on two aspects of the InTeGrate project. The first is determining the effects of creating reformed-based teaching materials on the pedagogical beliefs of the materials developers. The second involves understanding the impacts of re-designing a traditional introductory geoscience course to fully incorporate introductory geoscience modules developed for the InTeGrate project on student's science literacy.' Researchers are using three instruments: BARSTL: Beliefs about reformed science teaching and learning, Teacher Belief Interview: TBI, RTOP: Reformed Teaching Observation Protocol (RTOP) InTeGrate website, http://serc.carleton.edu/integrate/info_team_members/research/index.html

Best aspect? Working with other institutions and faculty, learning new concepts, improving my teaching skills, forming collaboratives with new faculty.

Some said collaborative development broadened their understanding of work underway at undergraduate institutions different from their own, and about effective strategies for working with students from a range of cultural and educational backgrounds.

The best part was sharing knowledge and classroom experiences with faculty from different institutions with diverse students, likely different in cultural background and high school preparation. It was a learning process on what takes place at other institutions.

I really enjoyed working with colleagues who think different[ly] from myself and with whom I hadn't collaborated before. They helped me see different types of assignments I could write and ways I could think about my own classroom and students. I liked that I was forced to think about how an exercise would work in a classroom different from my own.

As a result of their cross-institutional collaboration, some faculty noticed they were becoming increasingly sensitive to the diverse needs of and contributions from the students they now served, regardless of where they worked.

Thinking about [teaching/developing materials for] different environments opened up my thinking--you could do it in different ways, like a gallery walk, and in different scenarios. I realized I hadn't done [that teaching approach] in some settings.

InTeGrate materials place a value on every student; to teach everyone, reach all students; use a variety of techniques to reach as many as possible.

One faculty member found that the experience of collaborating on the development team was leading him/her to thinking more deeply about what makes teams effective.

The program made me think about how to make a team work well.

A few participants did not have as positive an experience working collaboratively as most others from the materials development teams. For two teams, the process was especially challenging.

It was quite difficult to work with colleagues from an institution so far away and unlike my own.

I hate participating in group projects, and this experience did nothing to change my mindset…While I understand the benefits of developing materials as a team project, sometimes it takes a lot more time and energy, and hassle to coordinae the team members than it takes for just developing the materials.

Design of Curriculum Materials. Starting with the second cohort of materials development teams, the InTeGrate's Curriculum Development and Refinement Rubric (CDRR) served as more than a guiding hand in helping teams design their materials.[18] Teams understood that the CDRR codified InTeGrate's goals and expectations for their finished materials.

When asked to reflect on the ways in which InTeGrate's process differed from their past curriculum development work, and to consider whether and how the development process influenced what they taught or how they taught, most team members' responses, when coded, fell into rubric-item related categories. We therefore organized this section by rubric categories to show the strong connection between the design of InTeGrate's development process and team members' reports of the new

[18] Guidance: InTeGrate Curriculum Development an Refinement Rubric, Version 9 (6/6/12)
The Curriculum Development and Refinement Rubric is designed to guide InTeGrate curriculum developers as they create modules and courses to improve geoscience literacy. The rubric incorporates broad goals of the InTeGrate project and researched guidelines for best practices in curriculum development.

knowledge they gained or ways their understanding was heightened as a result of their involvement in this process. [See Appendix B for complete text of the CDRR.]

Guiding Principles

> *Materials addresses one or more geoscience-related grand challenges facing society; develops student ability to address interdisciplinary problems; improves student understanding of the nature and methods of geoscience and developing geoscientific habits of mind; makes use of authentic and credible geoscience data to learn central concepts in the context of geoscience methods of inquiry; incorporates systems thinking. [from CDRR]*

In team members' reflections and responses to interview questions, many touched on one or more of the CDRR guiding principles. While these were not new ideas to most of them, several said they had not incorporated them in their courses as often as they should or wanted to, and InTeGrate's emphasis on them was an effective reminder for them. The rubric review process required their inclusion in the materials.

> *I always had this sense that these grand challenges were a better way to teach the basic stuff. InTeGrate's structure, their guiding principles, affirmed that idea. It put it out there in a more coherent way that resonates with how I thought about it, but in a way to put that into practice better than I could have done by myself. Seeing how our module aligns with the guiding principles really helped me articulate what I mean by that.*

> *Societal applications of geoscience; it's always something I'm thinking about, but usually I run out of time; it becomes an afterthought.*

> *The module development process and InTeGrate's workshop on Teaching Methods of Geoscience influenced what I teach directly. I now provide a summary of the unique methods of geoscience in my Introduction to Geology and Sedimentary Geology courses. I have students read the Manduca and Kastens paper[19] and we discuss it in class.*

> *I have not included "geoscientific thinking" explicitly in any previous class. This is a new and valuable topical territory.*

> *We had feedback from the assessment team that we didn't use the language of systems thinking [in our module]. I thought that comment was just about semantics; we were addressing what they were looking for, but we weren't using the word. Then, after a while, I saw the importance of using the language.*

> *Another element that influenced my teaching is systems thinking. Sometimes I feel like I know systems thinking since I use in in my practice. However, I needed to develop instructional methods to foster those skills. These instructional strategies I began to learn better as a result of constructing our module.*

Alignment

> *Teaching materials, assessments, resources and learning activities align with one another; all aspects of the materials are aligned. [from CDRR]*

Developing aligned materials was an explicit aspect of the CDRR and required as part of the final review of the module or course. Faculty comments about setting explicit goals, designing course activities, and assessing student learning can not readily be uncoupled, so we have grouped materials developers' responses in terms of these additional CDRR elements in this same section.

[19] Manduca, C. A., & Kastens, K. A. (2012). Geoscience and geoscientists: Uniquely equipped to study the Earth. In K. A. Kastens & C. Manduca (Eds.), *Earth & Mind II: Synthesis of Research on Thinking and Learning in the Geosciences, Geological Society of America Special Publication* (pp. 1-12). Boulder: Geological Society of America.

Learning Objectives and Goals

> *Learning objectives describe measureable geoscience literacy goals; instructions and/or rubrics provide guidance for how students meet learning goals; learning objectives and goals are appropriate for the intended use of the course/module; are clearly stated for each module in language suitable for the level of the students; address the process and nature of science and development of scientific habits of mind. [from CDRR]*

Assessment and Measurement

> *Assessments measure the learning goals; are criterion referenced; are consistent with course activities and resources expected; are sequenced, varied and appropriate to the content; address goals at successively higher cognitive levels. [from CDRR]*

Resources and Materials

> *Instructional materials contribute to the stated learning objectives; students will recognize the link between the learning objectives, goals and the learning materials; instructional materials should be sufficiently diverse and at the depth necessary for students to achieve learning objectives and goals; materials are appropriately cited; instructional materials are current; instructional materials and the technology to support these materials are clearly stated. [from CDRR]*

Team members experienced many an 'aha' moment when working to clearly state their learning goals and objectives at the start of the development of their materials. For some, making their goals and objectives explicit was new and, they found, useful to the design process. Throughout the materials development process, faculty increasingly recognized the importance of aligning their goals, objectives, activities, materials and resources, and student assessments. Some said they were surprised to learn this; others said they had known this, but when preparing course materials in the past, they considered it in a more implicit rather than explicit way.

> *I'd think about [learning goals and objectives] more instinctively before. Before, I thought about activities [first]. Now, I'm asking will the activity really do what I want for students? Why do I want to teach that?*

> *In developing the course, we were more or less goal driven. Usually, goals are more informal, in my head, not written down. This process taught me the value of formalizing the goals and objectives and designing the materials around those.*

> *I've been trying for a long time to teach in the kind of way InTeGrate promotes. I've not always been successful. I've started to think a lot harder about what I expect students to answer, 'this is what might be a good answer, this is what I'm trying to get out of this,' making student expectations more explicit.*

> *The materials development process does force one to think more explicitly about the rationale for developing specific instructional materials and courses. In the future, I will think more explicitly about what I want students to do, why I want them to do it, and what I expect they will get from doing it.*

Some mentioned their plan to use this strategy with other courses they teach.

> *Having goals and objectives formalized forced me to think differently about the design of course. Before, it was chaotic; here's a way to put things together. No one was holding my feet to the fire. InTeGrate's process forces you to think about how to start, where are you going towards. And, it actually gives you a tangible product. I'm thinking about redoing all my classes.*

Another materials developer recognized that being clear about course goals for students helped him/her make difficult planning and instructional choices when faced with time constraints.

> *Having learning goals and objectives written and communicated, and tied back to the activities was important. When there is a time issue, it helps to have them to know what to cut. Look at the goals and objectives and decide what to cut.*

Instructional Strategies

> *Learning strategies and activities support stated learning objectives and goals; promote student engagement with the materials; develop student metacognition; provide opportunities for students to practice communicating geoscience; scaffold learning. [from CDRR]*

The faculty who are developing curriculum materials as part of the InTeGrate program identified a wide range of instructional strategies they employed in classes prior to their involvement in the project. Some had already made significant shifts in how they worked with students and they said the project helped them refine their approach or learn new techniques.

> *In the last few years, I have tried to use more interactive activities in my classes, so I jumped at the chance to work with others to develop more of those. Going through [the development] process and thinking through the requirements of InTeGrate gave me a higher standard of what those activities should be; a more specific idea of what those activities should be like and their quality.*

> *In some ways, it's not a new way of teaching. I already teach modules, although with different content. The teaching strategies are not different. [Although,] I learned how to use concept maps. I'd never thought about it. I'm still 'iffy' on the jig saw. I have to convince myself it's the way to go. I've used data in other parts of my classes. So, it's not so different. I tried out new things, new ways of delivering the content.*

> *I was well aware of active engagement of students and metacognition. This has been very important in the K-12 setting for quite some time. I started developing a more student-centered classroom in early 2000's and have been improving my instructional strategies for over a decade. I even have a very active learning classroom (other than labs) in my current science classroom. I include metacognition in many of my instructional strategies already. One area Integrate did have an influence, making metacognition more explicit.*

> *As we were revising the module, we added more student reflection. I've been adding it in throughout the semester. I need to do it throughout the whole course. I appreciate that I don't do it often enough.*

> *[Learning] new ways to assess students was helpful for me.*

> *I had to add homework to the module, give them reading and a prompt. I'm having them do problem-solving outside of class. I found I liked thinking about homework and prompts for the next period. I could link the classes nicely. It was no longer just me going at something cold. They'd had something to think about; it gave them something to talk about [in class].*

> *I was thinking about how I'd never had applied project learning. Students did individual research papers. As a result of this project, I'm having them work in groups. That's new. [They're] applying what they are learning in the classroom to understand how to develop a preparedness plan.*

Other faculty members came from a very traditional college teaching background. The instructional approach InTeGrate advocated was not how they learned in geology courses in their undergraduate years.

> *The structure of the units in the module is different than how any of us learned geology, which was lecture and lab. There are shorter-term activities, motion of the students. It's great, but different. It's not necessarily how people have been teaching. It's been a learning curve.*

> *I was learning about pedagogy, evaluation and assessment; terms I would never have cared about.*

> *Before the last InTeGrate workshop, I did straight up lecture. Some interaction, a powerpoint lecture, discussion, go away, come back. Now, it's read, test, read reflection questions, go over questions, show lecture slides, plus activity. I'm not sure [students are] learning better, but I am reaching a wider variety of people.*

> *[Involvement in developing InTeGrate materials] influenced my teaching style, even during lectures. It's more fun to teach that way. I haven't figured how to get rid of the lecture part altogether.*

> *[Instructional approach] is different from what I was doing before [InTeGrate]. I was just lecturing. I'd have discussions, post questions weekly for them to respond to. After InTeGrate, I use activities to help students apply what they are learning. It takes more time; it's more fun. Students are more engaged. The frustrating thing is some are more involved than others.*

As noted above, nearly all respondents mentioned steps they have taken or new plans they have made, whether those were adding more interactive experiences within the lecture format, or significantly changing how they engage their students and the responsibilities they give them to extend and deepen their learning. The faculty comments at this stage in the project provide both a sense of the struggle some are experiencing, but also a commitment to continuing, at least for now.

> *This way of learning was more valuable, though it took lot of time out of the course. I'll keep moving forward with active learning.*

A seemingly important factor in their determination was seeing students' responses to these changes, and recognizing what students were capable of doing.

> *Students continued to be engaged and the variety of activities helped as well as switching up the "naturally" formed groups every so often. I think it worked well that we did the module at the very beginning of the semester as I think it helped the class form a community and be more interactive with the instructor as well as each other.*

> *The instructor I worked with commented often how thrilled she was about how engaged they were throughout the module and how she didn't realize how much responsibility could be placed on the students to step up, so that indicated to me that this was different than the usual classroom for her. This is an important note as well, I think, about the activities/work provided in the module. She felt that that "good community" stayed throughout the course.*

> *The Activity 1 reading and discussions were surprisingly successful. The new reading was more accessible and the students were enthusiastic in their discussion about their naive thinking about the scientific method. Even those with some background in the philosophy of science were excited to pronounce that geoscience was a science and that they need to expand their conception of what constitutes science. The historical and model-based aspects of geoscience were especially interesting to the students.*

> *I think the materials did an excellent job of acquainting the students with the meaning of environmental justice. The materials also taught them how important science is to social justice.*

> *The visual aids, graphs, and the 'think-share-pair' activities worked extremely well. Students were very enthusiastic about discussions, especially when the local examples were used and they could then relate it to their own specific neighborhoods.*

> *The written products indicate that the students developed more sophisticated understanding of what geoscientists do, how geoscience can differ from a simple model of experimental science, and how it is relevant to many questions of human sustainability*

Summary: Status of Knowledge about InTeGrate's Impact on Faculty

The evaluation data presented to date was contributed both by teams that have completed the development process, as well as those still in-progress. The evidence from their reports show faculty have gained new insights from colleagues on their teams and from InTeGrate's ongoing support; built their understanding of InTeGrate's goals and intended purpose for the completed materials through the collaborative design and development process; and have had the rare opportunity at the undergraduate level to pilot test their materials in three distinct institutional settings, document those experiences, and use the findings to collaboratively revise and refine modules that will be accessible to a wide audience.

Concrete indicators of potentially more impactful and sustainable changes are just emerging. There is new evidence of faculty members on development teams doing the following:

- continuing to use their own modules in their courses,
- testing other InTeGrate modules or module components for future use,
- applying what they learned about curriculum development to redesign existing courses,
- developing labs and lab manuals that incorporate the principles, goals and instructional practices reflected in the CDRR,
- sharing the InTeGrate modules, as well as information about its development process, with colleagues at their institutions, and helping them gain access to the materials,
- working with InTeGrate project leaders to support new development teams,
- developing proposals and being selected to lead implementation programs, and
- and presenting talks or offering workshops at professional meetings (most recently at the GSA meeting this month)[20] to communicate about InTeGrate's work, to disseminate the materials, and to broaden the community.

Next Steps. The evaluation team plans to continue to monitor the development process and document its muli-leveled impacts. For InTeGrate project team leaders, providing this expanding community with new opportunities to develop, test out, use, and share additional methods for assessing student learning closely aligned with the goals of the modules and courses will continue to be important.

> *Last fall, I changed the way I teach, which was lecture based. Now I have learning objectives, have students write those down before the lecture. I do assessments after every lecture using clickers. The results have been phenomenal. The one answer I don't have is I don't know how many are getting the concepts.*

Impact on Students

To evaluate progress towards InTeGrate's student learning goals, the assessment and evaluation teams are monitoring the following impacts on students enrolled in courses that use InTeGrate instructional materials:

- students' geoscience literacy,
- students' interest in majoring in geosciences and in a career that uses geosciences, and
- students' ability and motivation to contribute to solving grand challenges of resources and environmental sustainability.

To do this, the project has developed the following instruments:

- The Geoscience Literacy Exam (GLE) for geoscience literacy
- The InTeGrate Attitudinal Instrument (IAI) for career interest and motivation to contribute to solving environmental grand challenges
- Essay questions to probe some facets of students' ability to contribute to solving grand challenges

These instruments have been widely deployed across all or nearly all InTeGrate-using courses to date.[21] In addition, materials developers are required to embed formative and summative assessments

[20] Website "Activities of Interest at the 2014 GSA Annual Meeting" [open access]: http://serc.carleton.edu/integrate/news/2014_gsa_events.html

[21] Directions from InTeGrate to instructors about how and when to administer the various assessments are on the website "Collecting Data in your Classroom" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/currdev/course_status.html

tailored to the specific learning goals of their course or module. And finally some additional assessment instruments have been deployed in more limited settings as part of research projects.

The Geoscience Literacy Exam (GLE)

InTeGrate's Geoscience Literacy Exam (GLE) is built upon recently released earth, ocean, atmosphere, and climate science literacy documents, developed by national teams of scientists and science educators.[22] Together, these documents put forth 30 big ideas that the authoring teams believe that everyone should know and understand (e.g., "Climate varies over time and space through both natural and man-made processes.") David Steer and the assessment team designed GLE to test each of these 30 big ideas. GLE has a suite of three items for each big idea, described as Level 1, Level 2, and Level 3 (essay) questions.[23] Level 1 items are multiple choice with a single answer, align with introductory geoscience course content, and target Bloom's cognitive levels of understanding and application.[24] Level 2 items can contain more than one answer, link to multiple geoscience literacy concepts, and target cognitive levels of understanding through analyzing. Level 3 GLE questions are open-ended, requiring paragraph-length responses scored with a rubric, and target cognitive levels of analyzing through creating.

Students using all InTeGrate modules developed and tested to date have been required to answer a standard set of eight GLE items, chosen by the assessment team to be representative of the full GLE array of items. The standard set include four level 1 and four level 2 items, and span across solid earth, ocean, atmosphere, and climate. Example items are shown in Exhibit 5. [25] Instructors are told that these eight questions will not necessarily correlate to material covered in the module and are encouraged to use any additional GLE items that pertain to their course. The GLE can be administered on paper bubble forms or through a learning management system; but in either case, instructors are required to administer the GLE in a controlled environment and to return the student responses to the InTeGrate office.

The eight-item GLE has been administered in courses taught by module developers from the first and second cohorts, module testers, assessment testers who are not using InTeGrate materials, and an additional control group where InTeGrate materials were not used. GLE responses from 1083 students from modules tested during 2012–14 were used to examine the reliability of the instrument and get a first indication of student learning gain[26]. Multiple-choice questions were analyzed through examination of answer distribution and through a discrimination index. Discrimination indices calculated from the data suggest that the eight tested questions provide a valid measure within the scope of the concepts covered.

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[22] Links to the literacy documents and supporting materials can be found here [open access]: http://nagt.org/nagt/teaching_resources/literacies.html

[23] Steer, D., Iverson, E., & Manduca, C. 2012. *Developing a geoscience literacy exam for assessing students' earth, ocean, atmosphere and climate literacy*. Geological Society of America Annual Meeting [open access]: https://gsa.confex.com/gsa/2012AM/webprogram/Paper208849.html

For a current list of all items, see [restricted access]: http://serc.carleton.edu/integrate/info_team_members/currdev/documents/gle/index.html

[24] Cognitive levels, see [open access]: http://www.krummefamily.org/guides/bloom.html

[25] All eight items, see [restricted access]: http://serc.carleton.edu/integrate/info_team_members/currdev/documents/gle/index.html

[26] Steer, D., Iverson, E., & Manduca, C.A. 2013. *Piloting a geoscience literacy exam for assessing students' understanding of earth, climate, atmospheric and ocean science concepts.* AGU presentation [open access]: http://abstractsearch.agu.org/meetings/2013/FM/sections/ED/sessions/ED32A/abstracts/ED32A-02.html

Exhibit 5: *Example items from the 8-item Geoscience Literacy Exam*

1. Natural hazards can be put in two major categories. Some natural hazards can be made worse by humans; others are largely independent of human activities. Select the natural hazard least likely to be affected by human activity.
   a. Forest fires
   b. Tsunami
   c. Landslides
   d. Coastal erosion
   (Level 1: Earth Science Big Idea 8: Natural hazards pose risks to humans.)

2. Which of the following geologic processes are mostly likely caused by the interactions between tectonic plates at their boundaries? Select all that apply.
   a. Earthquakes
   b. Continental Glaciation
   c. Floods
   d. Volcanic eruptions
   e. Mountains
   (Level 2: Earth Science Big Idea 4: Earth is continuously changing.)

3. Which of the following statements about the distribution of life in the oceans is most correct?
   a. Life is more abundant and diverse in some parts of the ocean than in others.
   b. Life is abundant and diverse throughout the ocean.
   c. Life is less abundant and diverse in the oceans than it is on land.
   (Level 1: Ocean Literacy—Fundamental Concept 5: The Ocean supports a great diversity of life and ecosystems.)

Analysis of GLE responses[27] to date has focused on validating the instrument more so than on measuring learning gain. However, some pre-/post- comparisons have been done on the 1083-student data set described above. This population showed an increase of 0.5 points out of 12 possible GLE points across instruction in courses with an InTeGrate module, and student normalized gains were found to average 9% (Exhibit 6). These gains were from the beginning to the end of the semester, and there is not an analysis that attempts to disambiguate gain from the InTeGrate module versus from the rest of the course.

The eventual intent is that instructors will be able to select a set of GLE items that aligns with their course content from a full array of 90 validated and reliable items.[28] To move towards this goal, the assessment team has recruited geoscience instructors to test GLE items, and has a feedback system where assessment team members record their reactions to student responses on individual GLE items outside of the core eight items.[29] The project is far from reaching this goal; it will use the core eight GLE items for project evaluation purposes for the immediate future.

[27] GLE data analysis by D. Steer.

[28] There are three levels of items for each of the 90 big ideas in the earth, atmosphere, ocean, and climate literacy documents. There is a desire among some team members to add items for energy literacy as well (http://energy.gov/eere/education/energy-literacy-essential-principles-and-fundamental-concepts-energy-education) [open access].

[29] Website "Grading Feedback" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/ assessment_team_work/ grading_feedbac.html

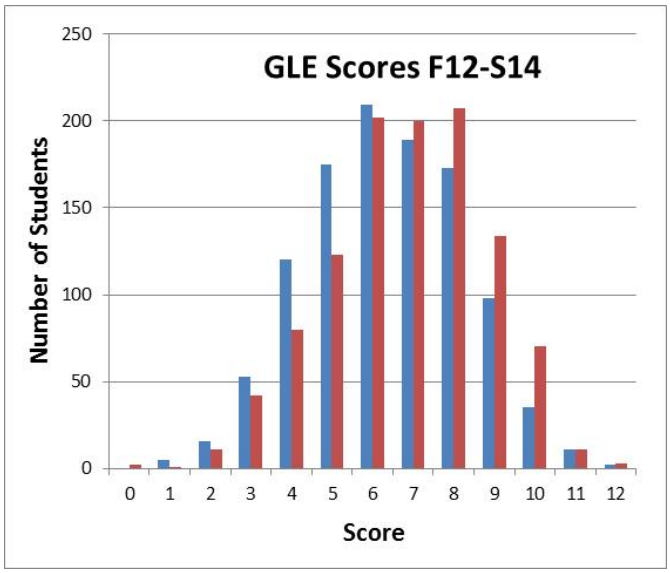


Exhibit 6: *GLE data from the first two years of testing showed that the student responses were well-centered in the range of difficulty assessed, were approximately normally distributed, and showed a significant gain from pre (blue)- to post-test (red).*[30]

InTeGrate Attitudinal Instrument (IAI)

The IAI[31] is administered as an online survey that students take outside of class at the beginning and end of a course. Instructors are told[32] that the project expects them to obtain 80% survey participation but, in fact, the response rate varies widely, from a few percent to 100%.[33] Responses are anonymized in such a way that pre- and post-instruction surveys can be matched with each other but not with the students' identities. The current version of the instrument asks about reason for taking the course (1 question, pre-instruction only), college major (1 question pre and post), career interest (2 questions pre and post; 1 additional question post), concern about various potential environmental issues (1question, pre and post), frequency of engaging in each of several listed behaviors that contribute to environmental sustainability (pre and post) and motivations for doing so (post only), and whether they can envision using what they have learned in this course to help overcome environmental/resource problems (post only, open-response). In addition, the pre-instruction survey asks for demographic information (gender, ethnicity, race, year in college, age).

Development of the IAI began with a review of sources related to assessment of students' attitudes toward sustainability and geoscience career interest (Exhibit 7). For career interest, the primary source was a survey that had been developed by M. Fuhrman for use in projects funded by the Opportunities for the Advancement of Diversity in the Geosciences. With guidance from Furhman, that long free-standing survey was slimmed down into three questions: one asking them to indicate their degree of interest in each of a list of potential college majors, one asking them to indicate their degree of interest in each of a list of potential careers or professions, and a two-part question asking them to indicate the importance that

[30] Figure from Assessment and Evaluation PowerPoint presentation to advisory board, October 2013, linked from http://serc.carleton.edu/integrate/advisory/oct_2013_agenda.html [restricted access]. Significance from file "T-Test Summary," linked from website "Data Analysis" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/assessment_team_work/analysis.html

[31] Survey instruments are linked from webpage Evaluation & Assessment Instruments [restricted access]: http://serc.carleton.edu/integrate/info_team_members/research/instruments.html

[32] Website "Collecting Data in your Classroom" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/ currdev/ course_status.html

[33] Website "InTeGrate Course Overview" [restricted access]: http://serc.carleton.edu/admin/assess/ course_overview.php?project_module_id=2244

they place on work in which they use their knowledge of the Earth and environment and on working at an organization that is committed to environmentally sustainable practices.

Exhibit 7: Sources for development of the IAI[34]

Sources for Sustainability Questions

DeWaters, J. (2009). *Energy Literacy Survey: A broad assessment of energy-related knowledge, attitudes and behaviors.* Potsdam, NY: Clarkson University. Retrieved from http://www.esf.edu/outreach/k12/solar/2011/documents/energy_survey_HS_v3.pdf

DeWaters, J. E., & Powers, S.E. (2011). Energy literacy of secondary students in New York State (USA): A measure of knowledge, affect, and behavior. *Energy Policy*, doi:10.1016/j.enpol.2010.12.049

Fieselman, L. (2011). 2011 Sustainability Literacy Survey. City, ST: Office of Research, Planning and Assessment, Meredith College.

North Carolina State University (2010, June). *Assessing student attitudes toward sustainability issues.* Office of Energy Management and Office of Sustainability. Retrieved from http://sustainability.ncsu.edu/media/pdf/StudentSustainabilityAttitudeSurvey_04_09_10.pdf

Pendarvis, S.S. (2002). *Sustainable Universities Initiative (SUI) Student Survey Preliminary Results.* University of South Carolina and Clemson University

Sinatra, G. M., Kardash, C., Taasoobshirazi, G., & Lombardi, D. (2011). Promoting attitude change and expressed willingness to take action toward climate change in college students. *Instructional Science, 40*(1), 1-17.

Washington Center (2006). *Curriculum for the Biosphere Initiative: Inquiry and planning phase 2005-06, Results of the on-line student inquiry.*

University of Colorado. (2010). Attitudes toward climate change.

Sources for Career Interest Questions

Fuhrman, M., Gonzalez R., & Levine R. (2004). *Developing short-term indicators of recruitment and retention in the geosciences.* EOS Trans. AGU 85(47), Fall Meet. Suppl., Abstract ED21D-02

Houlton, H.R. (2010). *Academic provenance: Investigation of pathways that lead students into the geosciences.* Purdue University Master's Thesis.

To probe the construct "motivation to contribute to solving grand challenges of resources and environmental sustainability," the evaluation team gathered and reviewed a large number of existing surveys and attitudinal inventory instruments around various aspects of protecting or improving the environment. Most had been developed for very specific purposes and had not been widely tested. From these, the team assembled an extensive spreadsheet of candidate items,[35] coded as to whether they probed attitudes towards environmental issues, motivation to take actions towards environmental sustainability, engagement in behaviors associated with environmental sustainability, or a combination of these. At the May 2012 Materials Development/Assessment Team meeting, a subcommittee of the assessment team worked with Kastens to narrow down the list of candidate items to best align with InTeGrate's goals and context. Those items were then tested in a think-aloud protocol with undergraduate summer interns.[36]. IAI version 1 was used in fall 2013 and spring 2013. Minor modifications were made to improve clarity and resolution, and use of IAI version 2, the currently in-use version, began in January 2014.

[34] Webpage "Evaluation and Assessment Instruments" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/research/instruments.html

[35] Spreadsheet of candidate assessment items linked from website "Evaluation & Assessment Instruments" [restricted access]: http://serc.carleton.edu/integrate/workspace/instruments.html

[36] enrolled in the Research Experience for Undergraduates program at Lamont-Doherty Earth Observatory.

Early modules: Three sets of analyses have been conducted on the IAI data to date.[37] The first analysis included pre-and post-instruction surveys from a total of 258 students from 13 instructors who had been involved in developing or testing four introductory level modules during the 2012–13 school year. There was considerable variability between instructors and modules. Across courses, the largest effect was a significant decline from pre- to post- in the proportion of students who chose "don't know enough to judge" in many career interest categories, including environmental consulting, environmental journalism, environmental law, hydrology, land use, public policy, and sustainability officer. Thirty-six percent of students self-reported movement from lower to higher interest in geo-related careers. On a composite score combining respondent's concern about several environmental issues, we saw a small but significant rise between pre and post. We respect to sustainability behaviors, there was positive movement in number of sustainable actions taken from pre- to post-instruction. When asked about their motivators for taking sustainable actions over 80% indicated that saving money was a motivator for taking sustainable action, and only 30% cited "this course or module" as an influencer. In summary, responses show small but statistically significant improvements across instruction on some but not all measures of both career interest and motivation towards environmental sustainability.

Developer versus non-developer: The second analysis contrasted the students of Climate of Change module authors with students of non-developer instructors who taught with the same version of the same module. Non-developed testers were 2 Year College (2 YC) faculty. A total of 60 students from three developer/instructors submitted both pre- and post-instruction surveys, and 150 students submitted pre- and post- from six non-developer instructors. Across items and scales, developers' students tended to have higher initial scores than non-developer students. Neither group showed a significant pre- to post-change on the career interest scales. When asked to rate the importance to them of working in an organization committed to sustainable practices, the non-developer sample showed significant growth from pre- to post- while the developer sample did not. In concern for earth issues, neither group showed significant pre-/post- gain. Finally, non-developers' students showed significant pre- to post- gains in the average number of sustainable actions reported as taken over the previous week. This analysis was undertaken to test if there might be a "developer effect," in which materials perform better in the hands of their developer/instructor than when used by instructors who might be less familiar with the content or pedagogical approach. No such developer effect was seen for these groups of students. If anything, the non-developer's students showed more pre-/post- change, perhaps because their pre-instruction responses were less inclined towards environmental sustainability than were the developers' students.

InTeGrate versus non-InTeGrate: The third analysis compares students enrolled in introductory courses taught by InTeGrate module developers and students enrolled in an introductory geoscience course that used no InTeGrate materials. The InTeGrate sample included 261 matched pre- and post-surveys from courses taught by 15 instructors who had developed five InTeGrate modules. A total of 94 students in the non-InTeGrate course submitted pre- and post-instruction surveys, comprising the comparison group. Across IAI scales and items, this analysis demonstrates mixed results. Pre- to post-changes in percent of students indicating that they were "very interested" in specific careers were small in both populations, comprising shifts of one or two students in either direction. InTeGrate students showed significant pre-/post- gain on concern for global climate change; non-InTeGrate students showed significant pre-/post- gain on concern for biodiversity loss; and neither group showed significant change on the other listed issues (population growth, energy resources, mineral resources, water resources). In terms of sustainability behaviors engaged in during the preceding week, InTeGrate students reported increases in four sustainability behaviors (Exhibit 8), while the non-InTeGrate sample showed significant differences in only one (turning off the water while brushing teeth). In summary, the effect of a one

[37] Detailed write-ups of each analysis are at website "Results from InTeGrate Attitudinal Instrument (IAI)" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/research/integrate_attit.html

semester introductory geoscience course on geoscience career interest and motivation towards environmental sustainability is small regardless of whether one InTeGrate module is included or not.

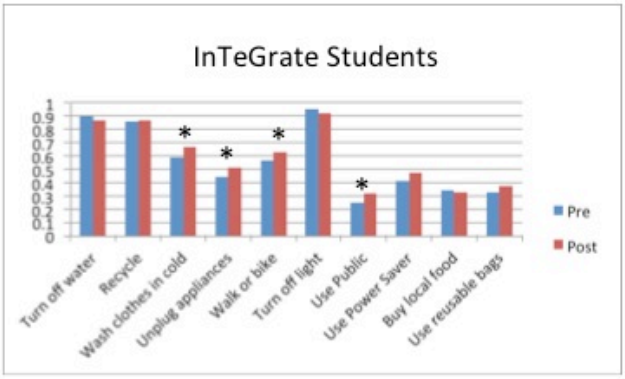
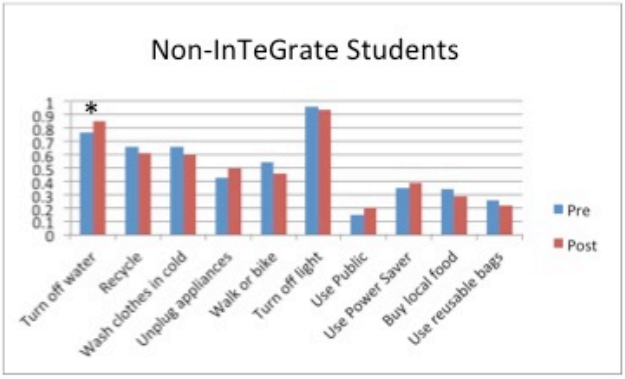


Exhibit 8: *IAI responses, comparing students who used one introductory InTeGrate module with students in an introductory geoscience course that used no InTeGrate materials. The illustrated item asked students to check which of several environmental sustainability behaviors they had performed in the previous week. Pre-/post- pairs marked with an * showed significant improvement across instruction.*

Neither population showed very much change across instruction. However, for the illustrated item, the InTeGrate population showed significant improvement on more behaviors than the non-InTeGrate population.



Essay Questions for Ability to Tackle Grand Challenges

The construct of "students' ability (as contrasted with their motivation) to tackle grand challenges of resources and environmental sustainability" poses a measurement challenge. Certainly, knowledge and understanding of earth system processes is part of this ability's toolkit, but it seems there are additional competencies as well. Early on, InTeGrate's leadership team decided to operationalize this ability by focusing on two competencies: interdisciplinary problem solving and systems thinking. These two were considered to be essential for solving problems at the interface between two complex systems—the natural earth system and human society—and thus central to the added-value that InTeGrate was seeking to bring to geoscience education, above and beyond knowledge and understanding. Although still difficult to assess, it seemed at least possible that operational measures could be developed.

"Course/module develops student ability to address interdisciplinary problems" and "Course/module incorporates systems thinking" were foregrounded as two of the five Guiding Principles of the materials development rubric.[38] The importance of guiding principles is telegraphed to materials developers by requiring that materials must earn three points in the rubric review; in other words, the rubric element must be "explicitly and/or pervasively addressed in module /course materials." To test students' mastery

[38] InTeGrate Curriculum Development and Refinement Rubric (version 9, 6/06/2013), from [restricted access]: http://d32ogoqmya1dw8.cloudfront.net/files/integrate/info_team_members/currdev/documents/integrate_currciulum_developme.v10.docx

of systems thinking and interdisciplinary problem solving, the assessment team, with input from leadership and evaluation teams, developed essay questions, one each for interdisciplinary problem solving and systems thinking. Instructors are directed to administer both essay questions at the end of the course in a proctored, summative high-stakes setting (e.g., a final exam).

The interdisciplinary-problem-solving question was originally developed in 2012 and updated in 2013, and this is still the version in use (Exhibit 9). It was a challenge to develop a single question that could be used across the breadth of courses in which InTeGrate materials are being used.

Exhibit 9: *Current Version of the Interdisciplinary-Problem-Solving Essay Question*[39]

Knowledge of earth system interactions can influence how people make decisions about global challenges. Identify and describe a global challenge that society will likely face in the next 50 years. Explain how the science related to that challenge informs economic, social, and/or political decision-making related to the global challenge you described.

Your answer will be evaluated on a 4-point scale using these criteria:

- 1 Point: Student correctly states and suitably describes a global challenge.
- 1 Point: Student correctly identifies and explains one or more scientific implications related to the problem.
- 1 Point: Student appropriately connects the science to economic, social, and/or political decisions.
- 1 Point: Student response is constructed in a coherent and logical manner.

(Note: Instructors were encouraged to include the rubric in their presentation of the essay prompt to the students, but not all did.)

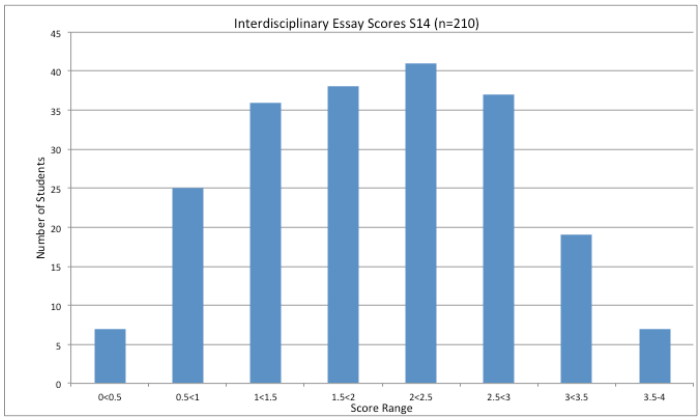
The interdisciplinary problem-solving essays from 210 students spanning a variety of materials-developer and tester contexts were scored by members of the assessment and evaluation teams. Scorers used the assessment rubric of Exhibit 9 and a project-created online scoring tool.[40] Responses fell in a normal, well-centered distribution (Exhibit 10),[41] and scorers in general felt that the students had understood the question. Further analysis of a subset of 107 students from three InTeGrate modules (Environmental Justice & Freshwater Resources, Sustainable Agriculture, and Map your Hazards) categorized each students' answer by what type of problem he/she elected to write about. Students whose course included the InTeGrate module on Environmental Justice & Freshwater Resources were more likely than the others to write about problems categorized as "water," Sustainable Agriculture students were more likely than the others to write about problems categorized as "food" or "soil"; and Map your Hazards! Students were more likely to write about problems categorized as "climate change," "volcano," or "natural disasters." Since every student was enrolled in a course that included many other topics than just that covered in the single InTeGrate module, the students' choice to write about their InTeGrate-relevant topic when asked, at the end of the semester, to "identify and describe a global challenge…" is taken as evidence that the InTeGrate module established a problem-solving orientation in the students' minds.

[39] Webpage "New Essay Questions" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/assessment_team_work/new_questions.html

[40] Website "InTeGrate Grade Sets" [restricted access]: https://serc.carleton.edu/admin/assess/manage_grade_sets.php?project_module_id=2244&view=current_user

[41] Excel spreadsheet "Interdisciplinary_essay_data-2" linked from webpage "Assessment Team Workspace" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/assessment_team_work/index.html

Exhibit 10: *Student responses to the Interdisciplinary problem solving essay* show a good distribution of scores, and the question is considered to be performing as desired.



The Complex Systems Thinking essay question has had a rockier passage. Original wording was developed and tested in 2013: "Earth consists of interacting systems which exchange energy and/or mass at different rates and scales. Describe two interacting Earth systems, emphasizing where, how, and how quickly they interact. Explain how a change in one system can drive change in the other system." Scoring of student responses from a variety of InTeGrate test classes by members of the assessment team yielded an unacceptably large number of students receiving scores of either 0 or 1 out of 4, suggesting that the question lacked face validity.[42] Further scrutiny of responses to the 2013 version on students in a non-InTeGrate intro course showed that a large fraction (78/195) of students confused "systems" versus "processes" versus "cycle."[43] Evaluation team examination of a selection of student responses also showed deep confusion, including a small number of students who thought they were being asked about computer systems, such as the learning management system used in their course.

Discussion of systems thinking among the leadership, assessment, and evaluation teams throughout late 2013 and 2014 revealed two possible interlocking problems. Clearly, many students were having trouble understanding the systems-thinking question and were responding poorly. Reasons could be either (a) that the question was poorly worded or (b) that the InTeGrate courses were not teaching systems thinking adequately. The consensus emerged that both hypotheses were probably true.

To cope with the first possibility, two new candidate essay questions[44] were developed at the joint materials development/assessment team meeting in June 2014. One question sought to remove ambiguity by specifying what earth systems and components students should consider:

> *The Earth system can be described as a set of interconnected components and interactions: atmosphere, geosphere (rocks), biosphere (living organisms), hydrosphere (oceans, rivers and lakes), cryosphere (ice), and anthroposphere (human societies). Describe (i) how a change in one component can lead to change in other components and (ii) factors(s) that cause the change(s).*

The other question seeks to be applicable across a wider range of courses, including non-geoscience courses:

[42] Caulkins, et al., 2014. Student learning in Geoscience courses incorporating societal issues and grand challenges facing society. Geological Society of America *Abstracts with Program*, 46(6), p. 50.

[43] Olson, T., & Egger, A. (2014). *Analyzing student responses from the Geoscience Literacy Exam.* Draft poster linked from website "Research Projects" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/research/index.html

[44] Webpage "New Essay Questions" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/assessment_team_work/new_questions.html

> *Using a systems perspective can help us understand many aspects of the world. Systems thinking focuses on the interactions between different parts of a system and the behavior in the system as a whole that results from these interactions. It can be productively used to understand natural systems, human systems, and their interactions in a wide range of scales, from big to small and short- to long-term. (1) Using systems thinking, describe a system that is important in addressing a specific problem or issue related to class content. (2) What advantage do you gain in understanding or addressing the problem or issues using systems thinking? Your answer should include at least one specific example.*

These two new questions are currently being tested with both intro- and upper-level undergraduates. For comparison, expert responses to these same questions are being collected from professional geoscientists attending conferences in fall 2014.

To address the possibility that the problem lay not just with the question but with the teaching, the assessment team reviewed a selection of InTeGrate instructional materials through the lens of the systems-thinking essay question. They concluded that many modules were not giving sufficient quality or quantity of emphasis to systems thinking. Three correctives were put in place: first, the scrutiny of a module's coverage of Guiding Principle #5 (Systems Thinking) will become more rigorous at the stage of rubric review; second, a webinar will be developed in the material developers' webinar series,[45] and third, a new student instructional module on systems thinking is under development,[46] with the intent that it could be included as a component in a wide range of InTeGrate-enriched courses.

Additional Student Outcome Indicators

Embedded assessments: The InTeGrate CDRR requires that each module contain embedded formative assessments and summative assessments that measure the stated learning goals, are criterion referenced, are consistent with the course activities, are appropriate to the content, and address successively higher cognitive levels.[47] All materials developers have been required to provide student responses to a subset of these assessments to the InTeGrate office. For Cohort 1, the requirement was three formative assessments, and for Cohorts 2 and subsequently, the requirement is the summative assessments. The summative responses are reviewed holistically[48] by the assessment team. Beginning with Cohort 2 (teams that began in 2013), the assessment team is providing formal written feedback to the module development team on (a) how well the assessments probe students' mastery of the module's or course's stated learning goals and InTeGrate's guiding principles for material development, and (b) how well student responses on the embedded assessments reflect progress towards meeting those goals and principles.[49] Teams that started in 2013 or after are expected to address this feedback in their materials revisions. Since the purpose of this review of these student responses is to provide feedback to be used in revising materials, and because the nature of the submitted assessment differs drastically from module to module, these data have not been considered as part of InTeGrate's evaluation program. But the data are have been archived, and could be mined at a later date to develop a more richly nuanced qualitative description of what students are learning from their InTeGrate-infused coursework.

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[45] Website InTeGrate Professional Development Webinars [open access]: http://serc.carleton.edu/integrate/workshops/webinars/index.html

[46] Webpage "InTeGrate November New Course & Module Team Meeting" [restricted access]: http://serc.carleton.edu/dev/integrate/info_team_members/meetings/nov14_participants.html

[47] InTeGrate Curriculum Development and Refinement Rubric (version 9, 6/06/2013)

[48] PowerPoint presentation "Analyzing Student Work" D. Steer, May 2014, linked from webpage "May 2014 [Assessment Team] Checkin" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/assessment_team_work/may_check_in.html

[49] Webpage "Grading feedback for June 2014 module authors" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/assessment_team_work/June_grading.html

Research measures: In addition to the data collected for purposes of program evaluation and iterative revision of instructional materials, further student impact data are being collected under the auspices of educational research projects. David McConnell and students of North Carolina State University are collecting student data before (spring 2014, fall 2014) and after (spring 2015, fall 2015) redesigning an introductory geoscience module by incorporating five complete InTeGrate modules.[50] In addition to InTeGrate assessments, students' attitudes towards science are being assessed using the Science Attitude Inventory II.[51] The degree and manner to which students find material relevant are being measured with the Changes in Attitudes about the Relevance of Science (CARS) survey.[52]

Summary: Status of Knowledge about InTeGrate's Impact on Students

In summary, InTeGrate now has in place very nearly a full suite of instruments with which it can monitor student outcomes on the dimensions of interest: (1) students' geoscience literacy, (2) students' interest in majoring in geosciences and in a career that uses geosciences, and (3) students' ability and motivation to contribute to solving the grand challenges of resources and environmental sustainability. The one exception appears to be one of the two monitored dimensions of ability to contribute to solving the grand challenges; the project is still striving to effectively measure and teach systems thinking. Although the assessment of systems thinking has absorbed a great deal of project time and energy without yet reaching resolution, we think this episode should be viewed as an evaluation/assessment success, in that evidence of student struggle with this question led to robust mid-course corrections, including the development of ambitious professional development materials and an entire new instructional module.

With developmental versions of the GLE and IAI instruments, student outcomes have been assessed on more than 1000 students enrolled in InTeGrate-influenced courses taught by both materials developers and non-developer testers. These test students had a small dosage of InTeGrate materials, only a single two- to three-week module, and most were experiencing the first enactment of not-yet-revised instructional materials. Pre- /post-instruction comparisons yielded either no change or small but significant changes in the project's desired direction—an encouraging finding. We will have opportunities to measure student gain across a larger dosage of revised materials as InTeGrate's semester-length courses are completed and implementation programs come on line.

Three nagging issues deserve more thought: First, the project has not yet established benchmarks as to what level of student gain on GLE, IAI, or essay questions would constitute "success" among groups of students who experience a larger dosage of more polished instructional materials. Second, some aspects of the process for measuring impact on students, notably the essays and embedded assessments, are very labor intensive. The project has attempted to streamline the process by building an online tool for capturing scores from a distributed team of scorers, by subsampling, by reorienting the review of embedded assessment towards a holistic review, and by experimenting with machine scoring for GLE essays. But the volume of student product remains problematic, and existing procedures would be difficult to scale up to evaluate national impact. Finally, the opportunities to measure InTeGrate's impact on students to date have been concentrated among instructors who are coupled to InTeGrate, either as materials developers or as paid materials testers. There is currently no data on impact among students whose instructors had a less intense interaction with InTeGrate, such as attending a workshop or accessing materials from the website. Since it is these less-intense forms of interactions that are

[50] Webpage "Research Projects" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/research/index.html

[51] Moore, R. W., & Foy, R. L. (1997). The Scientific Attitude Inventory: A revision (SAI II). *Journal of Research in Science Teaching, 34*(4), 327-336.

[52] Siegel, M. A., & Ranney, M. A. (2003). Developing the Changes in Attitude about the Relevance of Science (CARS) questionnaire and assessing two high school science classes. *Journal of Research in Science Teaching, 40*(8), 757–775.

conjectured to be the mechanism for InTeGrate to scale up to national impact, it would be desirable to capture a representative sample of student outcomes from such classrooms.

Program Element #2: Implementation Programs

> *Excellent materials and courses are not sufficient for the transformation we seek. Lasting change requires work at the department, program or institutional level… InTeGrate will support a series of implementation programs to develop bold approaches that incorporate geoscience into materials and programs designed to reach a diverse array of students, including those from groups underrepresented in the geosciences and students whose dominant interest or field of study lies outside the geosciences.*[53]

InTegrate's intention, at the proposal stage, was to sponsor and support the development of at least 26 implementation programs that "*make use of project materials, model innovative ways to increase the number of students developing geoscience literacy, and contribute to the preparation of a workforce equipped to bring geosciences to bear in solving societal issues.*" While the materials development component of InTeGrate's work focuses on the development of curriculum materials that address project goals for faculty and students, InTeGrate's sees the implementation programs as having a broader impact, one that fosters change at the institutional level. In the past year, as InTeGrate materials have been completed, work on the Implementation Programs has gotten underway. The following three programs were included in the InTeGrate proposal:

University of Texas-El Paso. A cluster of institutions, a dual-enrollment high school, a two-year college, and a comprehensive university are working together to interest, prepare, and support students to complete four-year degrees in geoscience, environmental science, or Earth science education. An integral piece of this collaboration is the use of InTeGrate materials across the programs. UTEP is an urban, minority-serving institution with over 60% first-generation college students. More than 80% of the students at UTEP are from the El Paso region and nearly all graduates in primary or secondary education go on to teach in the local school districts. Thus, this program provides an excellent opportunity for implementing strategies for engaging students underrepresented in the sciences and for studying the impact of the program in a relatively closed system.

Pennsylvania State University. This implementation program will demonstrate ways in which distance-learning courses can be used to enhance programming among a collaborating set of institutions. Courses, currently in the development phase, are being developed to support a new online Certificate of Excellence in Earth Science program aimed specifically at non-traditional and foreign students will be offered through the Penn State World Campus. Building on collaborations established by the Africa Array program (an NSF OEDG project), these courses will enhance the Earth Science offerings at a network of historically black colleges and universities and minority-serving partner schools including the Fort Valley State, NCA&T, Jackson State, CSU-Northridge and CSU-Bakersfield. These programs will serve as national geosciences-education distance learning models intended to increase student interest in the geosciences and, more broadly, geoscience literacy.

Stanford University. With support from InTeGrate's project leader and Diversity Coordinator at Stanford University, a new implementation program was designed this year to demonstrate the ways in which collaboration can be built between minority serving institutions (MSI), including two-year colleges, and graduate programs in the Earth sciences. The program will focus on engaging Stanford

[53] InTeGrate proposal

University School of Earth Sciences graduate students and postdocs in teaching with InTeGrate materials at targeted MSI/2YCs.[54]

In March 2014 InTeGrate issued a call for additional Implementation Program proposals from the community. Institutions, or clusters of institutions, were invited to apply for grants of up to $50,000 to develop and evaluate programs that model innovative ways of increasing the number and diversity of students developing Earth literacy, and/or preparing a diverse workforce equipped to bring geosciences to bear in addressing societal issues. Proposals were expected to involve at least five faculty members and be led by a coordinator or administrator. A list of the types of programs InTeGrate was seeking included, but was not limited to, those that proposed to:

- develop new interdisciplinary programs, majors or certificate programs with a strong geoscience component designed to prepare students for careers addressing challenges of sustainability;
- engage students with issues of sustainability and their scientific underpinnings and provide a continuous pathway from high school to a STEM degree;
- increase the enrollment and graduation of students from groups underrepresented in the geosciences;
- broaden access to science by introducing geoscience across the liberal arts curriculum;
- strengthen learning about the Earth at institutions with limited or no geoscience faculty;
- incorporate approaches to Earth literacy for all teachers at any level, elementary or middle and high school as well as preparation of earth science teachers of K-12 teachers, including but not limited to Earth science teachers;
- introduce or strengthen the role of geoscience in the preparation of STEM majors outside of the geosciences.
- facilitate the transition from college or university to the workforce for students with degrees that include a substantial geoscience component.[55]

InTeGrate established a steering committee, in association with NAGT, to review submitted proposals. The committee selected a set of four programs ready for funding, and identified two other programs that were of interest but needed additional design work. InTeGrate is helping these two teams revise and resubmit their proposals. The first four programs either started their work during summer 2014 or are planning to do so in the fall, once contracts have been negotiated. Two are liberal arts institutions; two are teacher preparation programs.

Gustavus Adolphus College. Faculty at the College will work together to integrate a set of climate science modules across the liberal arts curriculum, increasing the level of climate science literacy among faculty and students and setting the stage for meaningful interdisciplinary discussions of the role of climate change.[56]

Wittenberg University. Faculty proposed to transform the University's educational model, moving from isolated general education requirements without linkages, toward a model that fosters interdisciplinary thinking and a proactive student presence in the community. The team at Wittenberg University will thread sustainability modules within existing courses, broadening participation in

[54] Website "MSI and 2YC Programs—Stanford University" [open access]: http://serc.carleton.edu/integrate/programs/implementation/program6/index.html

[55] Call for Implementation Proposals. http://serc.carleton.edu/integrate/participate/ip_call.html

[56] Webpage "Climate Science across the Curriculum at Gustavus Adolphus College" [open access]: http://serc.carleton.edu/integrate/programs/implementation/program2/index.html

sustainability curricula through recruitment and training, and creating linkages in sustainability problem solving throughout their community.[57]

Grand Valley State University. The faculty team that submitted this proposal plans to redesign three existing science methods courses for pre-service teaching students majoring or minoring in biology, chemistry, geology, and physics. The courses will incorporate Earth science content, especially climate change and energy, as overarching themes. The courses will develop shared pedagogical content skills, as well as those skills unique to each discipline, with the goal of integrated science methods courses across the curriculum.

Washington State Colleges and Universities. A coalition of state schools across the state of Washington led by Central Washington University will demonstrate how institutions can collaborate within a state to improve teacher preparation. Working through groups such as Teachers of Teachers of Science and the northwest section of the NAGT, this network will integrate geoscience methods and pedagogy modules developed through this proposal into science content courses.[58]

InTeGrate's project leaders, the evaluation team, and SERC website consultants are working with program teams to set up contracts, clarify expectations, develop the site's internal evaluation plan, and create website workspaces. Plans for supporting programs' work are still being formulated. A second call for proposals was issued in late October.

Program Element #3: Professional Development and Dissemination

> *Mirroring the project as a whole, the professional development and dissemination program has two primary goals: 1) Improving the ability of faculty to teach courses connecting geoscience to the grand challenges, and 2) Supporting the development of programs that increase the number of students developing geoscience literacy and the ability to address the grand challenges."* —InTeGrate proposal

InTeGrate's professional development and dissemination goals above are achieved through two primary vehicles—the InTeGrate workshop series and the InTeGrate website. Both are evolving resources that provide information for program participants, a recruitment mechanism for the project, a means for documentation of project ideas and activities, and a mechanism for dissemination. Although described separately below, in fact InTeGrate workshops and website are tightly intertwined: resources and insights gained from workshops form the raw material for new web areas, and conversely the website acts as a recruiting mechanism and a workspace for the workshops.

Information sources: The evaluation team reviewed the project proposal and project website, including descriptions of the goals of workshops and the website, public and private workspaces for workshops, workshop documents and products, one end-of-workshop survey report[59] (from the Systems, Society, and Sustainability workshop), data on demographics and institutions of workshop participants, and data on website usage. For workshops, end-of-day "road-checks" and end-of-workshop surveys are done by SERC's internal evaluation staff, not by the external evaluators.

[57] Webpage "Engaged sustainability: From curriculum to community—Wittenberg University" [open access]: http://serc.carleton.edu/integrate/programs/implementation/program3/index.html
[58] Webpage "STEM Teacher Preparation in Washington State" [open access]: http://serc.carleton.edu/integrate/programs/implementation/program1/index.html
[59] SERC's in-house evaluation staff does end-of-day "road-checks," and end-of-workshop surveys for every workshop.

Workshops

The project logic model distinguishes between two broad categories of workshops. In-gathering workshops (Appendix figure A-3) were the project's mode of operation for its first 2+ years, until the first InTeGrate instructional materials were published in fall of 2014. Dissemination workshops (Appendix figure A-11), the expected form of workshop for the final years of the project, spread ideas and insights to a broader community of practitioners and "… foster adoption and adaptation of InTeGrate's materials and programs."[60]

In-gathering workshops have two sets of mutually reinforcing goals: both the individual attendees and the project as a whole should benefit (Appendix fig A-3). Goals for attendees vary by workshop, and include improving pedagogical strategies and building faculty capacity around challenges such as geoscientific thinking, careers, and broadening participation. Project-building goals include recruiting new project participants who can further various aspects of the InTeGrate agenda, and gathering ideas and best practices that can be instantiated into instructional materials and implementation programs.

The workshops reflect and model InTeGrate values and ideas in that they are collaborative and interdisciplinary. They cover a range of topics, and involve participants and conveners from a variety of disciplines and institutions. Participants bring their own knowledge and experience, with time for sharing their experiences and resources both during the workshop and as part of the creation of a suite of project materials and resources

InTeGrate workshops to date have covered a broad range of topics:

- Teaching about Risk and Resilience: Sea Level Rise, Flooding and Earthquakes (May, 2014)
- Broadening Access to the Earth and Environmental Sciences (February, 2014) [IP]
- Geoscience and 21st Century Workforce (June, 2013) [IP]
- Teaching Environmental Justice: Interdisciplinary Approaches (April. 2013)
- Engineering, Sustainability and the Geosciences (March, 2013)
- Systems, Society, Sustainability and the Geosciences (July, 2012)
- Teaching the Methods of Geosciences (June, 2012)
- Programs that Bring Together Geoscience and Sustainability (May, 2012) [IP]

InTeGrate has stretched its workshop dollar and expanded its reach by offering additional workshops in partnership with other NSF-funded professional development programs.[61] Partnership workshops have been on:

- Undergraduate research in Earth Science classes: Engaging students in the first two years (August, 2014)
- Teaching Geoethics across the Geoscience curriculum (June, 2014)
- Getting the most out of your introductory courses (March, 2014)
- Teaching Oceanography (June, 2013)
- Teaching Environmental Geology (June, 2012)

Comparison of workshop topics with Module and Course topics (table 3) suggests that the plan of leveraging workshops for in-gathering towards materials development has worked. The workshop on

[60] InTeGrate proposal, p. 2

[61] Teaching Geoethics was in partnership with a grant from NSF's Ethics Education in Science and Engineering program; see http://serc.carleton.edu/geoethics/index.html. The other four were in partnership with On The Cutting Edge (http://serc.carleton.edu/NAGTWorkshops/index.html).

"Teaching the Methods of Geoscience" (June, 2012) informed the module on "Exploring Geoscience methods with secondary education students." The workshop on "Teaching Environmental Justice" informed the module on "Environmental justice and freshwater resources." An interesting future investigation would be to map in more detail how and to what extent resources, activities, and individuals gathered through workshops play a role in the as-published instructional materials.

Three of the InTeGrate workshops (designated as [IP] in the lists above) were specifically designed to lay the groundwork for Implementation Programs, by gathering materials and ideas, and catalyzing interdisciplinary collaborations. Lessons learned from these workshops are featured prominently in the area of the InTeGrate website targeted "For Program Directors and Administrators,"[62] where decision-makers can find practical guidance on workforce needs, increasing diversity, and embedding sustainability into one's local institutional context. The call for proposals for Implementation Programs was also crafted so as to bring forth proposals responsive to needs identified in the IP-groundworking workshops.

Across the eight stand-alone InTeGrate workshops (not partnership workshops), there have been a total of 276 individuals attending InTeGrate workshops (Exhibit 11). Not counting staff or members of the leadership team, 21 have attended more than one workshop and 24 have been members of curriculum development teams. The gender, race, and ethnicities of the workshop participants, as well as the type of

Exhibit 11. *Demographics of workshop participants.*[63]

	Number	%
Gender:		
Male	135	49%
Female	122	44%
No response	19	7%
Ethnicity:		
Hispanic	11	4%
Non-Hispanic	233	84%
No response	32	12%
Race:		
Asian	19	7%
Black	8	3%
White	226	82%
No response	50	18%
Institution Type:		
Associate's Colleges	32	12%
Baccalaureate Colleges	47	17%
Master's Colleges and Universities	65	24%
Doctoral/Research Universities	83	30%
Other	10	4%
Blank	39	14%
Minority Serving Institution	*15*	*5%*

[62] From InTe Grate front page, click "For Program Directors and Administrators" to reach website "Program Design: Laying the Foundation for Tomorrow's Sustainability Workforce" [open access]: http://serc.carleton.edu/integrate/programs/index.html

[63] Data from InTeGrate project database, downloaded October 24, 2014. Demographics includes every individual who attended one or more workshops (including leadership team and SERC staff.) Each individual is counted only once.

institutions that they came from, are listed in Exhibit 11. The workshop participants include a balance of males and females from a range of institution types, but they are predominately non-Hispanic and white.

In addition to the in-gathering and dissemination workshops, an additional category of professional development event has emerged: the project team has begun to offer webinars for materials developers on topics that the first cohort identified as challenges, such as dealing with copyright, rubrics, or developing student metacognition.[64] Although virtual dissemination events such as webinars for a broad audience were anticipated, in-project webinars are now offered for materials developers to support their preparation and dissemination of modules. Materials developed for participants in these webinars have been posted on the Web and have become another unanticipated vehicle for professional development for faculty engaged in materials development, whether or not they are in the InTeGrate project. The copyright webinar also serves to support project dissemination.

With the publication of the first set of InTeGrate instructional modules in fall of 2014, the workshop component is at an anticipated transition point, where the emphasis is expected to shift towards dissemination of materials. The first dissemination workshop was held at the Geological Society of America on October 18, 2014.[65] A multi-pronged program of dissemination workshops is currently being planned, including traveling workshops (held at an institution of higher learning and focusing on the needs of that institution), virtual and face-to-face workshops, plus a large scale gathering called the "Earth Educators' Rendezvous.[66] As shown in logic model figure A-11, dissemination workshops are expected to use collaborative and interactive activities, along with InTeGrate's instructional materials, to build knowledge and shift attitudes of the participants. One important output is expected to be the use of InTeGrate materials in teaching to diverse audiences in varied institutions.

Website

> *"The website is a primary vehicle for documenting and disseminating information about interdisciplinary teaching of geoscience for a sustainable future and programs that support the development of a workforce that can make use of geoscience to address the environmental and resources issues we face."*[67]

The InTeGrate website provides a second mechanism for reaching a broad audience, enabling possibilities for both recruitment and dissemination. Our review of the project website and associated materials reveals that there are actually two separate but intertwined sites: the website visible to the external world and the password-protected website used by the internal project teams.

The outward facing website reaches the public. This part of the website provides the venue for publishing InTeGrate instructional materials, recruiting for upcoming workshops, and disseminating findings and materials from completed workshops. Completed InTeGrate modules are quite elaborate, and all the materials are web-published: learning goals, student materials, embedded assessments, images, videos, and readings, plus case studies about how the module was used in at least three real instructional contexts. In addition the public website provides professional development around topics that pertain

[64] Website "InTeGrate Professional Development Webinars" [open access]: http://serc.carleton.edu/integrate/workshops/webinars/index.html
[65] GSA Short Course 517A: Teaching Geoscience in Society: Building Relevance and Interest in the Geosciences by adding InTeGrate resources to your class: https://gsa.confex.com/gsa/2014AM/webprogram/Session36278.html
[66] Webpage "2015 Workshops" [open access]: http://serc.carleton.edu/integrate/workshops/index.html

[67] Webpage: "Professional Development and Dissemination: Building Expertise" [open access]: http://serc.carleton.edu/integrate/about/engaging_community.html

across many or most InTeGrate modules and courses, such as embedded assessment or metacognition. Logic model figure A-9 depicts one conjectured future function of the outward-facing components of InTeGrate's website. Instructional materials that have emerged from InTeGrate's materials development process, as well as materials from workshops, are posted on the InTeGrate website for dissemination. Faculty without prior involvement in InTeGrate are then able to access and download InTeGrate modules and workshop materials. It is conjectured but not proven that this can to lead to changes in instructor practice [and further materials development?] and, ultimately, changes in students' geoscience literacy and ability and motivation to address grand challenges of resources and environmental sustainability.

The inward-facing, password-protected website serves the needs of the leadership team, assessment team, evaluation team, materials developers, project staff, and implementation programs. In the project proposal, the website was positioned as a dissemination vehicle. Although it is serving that purpose well, the website has also emerged as an important mechanism for project management, decision support, communication, organization of project materials, archiving of internal and interim products, and facilitation of collaborative activities. For example, the web area for development team members provides information about how to structure the module or course, how to work as an InTeGrate team, and how to work with InTeGrate's rubric.[68] Each course or module has their own workspace in which to post materials for review, agendas, and interim products. There are also designated team workspaces for implementation programs, and for the leadership, assessment, and evaluation teams. Purpose-built webpages are being used to monitor the status and progress of activities that are distributed across the complex system that is InTeGrate. For example, the Course Overview page provides a table that lists all courses where InTeGrate modules have been used or tested and the number of assessments received from those courses. This use of the website is illustrated in logic model panel (8) (Appendix figure A-10) and is further developed under "Overarching Themes," below.

The website has seen considerable activity. The website contains 1038 page and is still expanding rapidly. The site had over 35,000 visitors in the last year, of whom 40% were returning visitors.[69] Forty-two percent of the views have been on the workshop pages. An important metric going forward will be the level of Web activity around the instructional materials pages, which should begin ramping up sharply if the materials are achieving good uptake.

Remaining Questions

The logic model suggests that the trajectory of participants through the project may is an important process to monitor. For example, in-gathering workshops are shown as entry points for module developers and implementation team members (figure A-3); existing collaborations, built through InTeGrate or elsewhere, are shown as coalescing to build collaborative teams for Implementation Programs (figure A-12). Anecdotally, we know of instances where each of these pathways has been followed, but it has been difficult to get a quantitative handle on how robust and well-populated they are. This is important because movement of individuals through InTeGrate--and perhaps through related projects such as Cutting Edge, PKAL, SENCER--has the potential to develop needed leadership capacity, as motivated and competent individuals move from the periphery towards the core of the enterprise and take on added responsibilities. Our scan of available information indicated that data pertinent to these questions have been collected, but several types of data are in different formats and different places. As the volume of project participants and activities swells, it could be worth the effort to organize this data so as to facilitate compiling and perhaps visualizing the flows of people through InTeGrate.

[68] Webpage "Information for Materials Developers" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/currdev/index.html

[69] C. Manduca powerpoint presentation for Advisory Board, September 2014, "InTeGrate: Interdisciplinary teaching of Geosciences for a sustainable future: Goals, progress, priorities. Linked from webpage "Agenda: September 29, 2014 Meeting Agenda" [restricted access]: http://serc.carleton.edu/integrate/advisory/september_2014_.html

The project is not yet well positioned to understand potential changes in practice for instructors whose sole interaction with InTeGrate is via a workshop or the website. Since InTeGrate aspires to national impact, and the population whose InTeGrate contact came via workshop or website may reach large numbers, how this group is responding to InTeGrate is an important unanswered question. The only probes in place for measuring change in teaching practice (reflection surveys, evaluation interviews, BARSTL, RTOP) are being applied to instructors who are more centrally located within the InTeGrate project, either as materials developers or implementation team members, or as non-developer testers.[70] Workshop participants could be re-surveyed 6 to 12 months after the workshop to see what InTeGrate-inspired actions, if any, they have taken. Two other potential sources of insight are the NAGT survey of geoscience faculty[71] and follow-up with users who have accessed InTeGrate's password-protected "teacher stash."[72]

Overarching Themes

In this concluding section, we comment on four overarching themes that emerged and re-emerged during our observations of multiple parts of the InTeGrate venture. We think that these four themes represent core strengths of InTeGrate, and we hope that foregrounding them in this section will be of value to those trying to understand the functioning of InTeGrate, trying to draw lessons learned from InTeGrate's experiences, or planning the final years of the project.

The themes are (1) the use of a systems perspective in envisioning, planning, and evaluating InTeGrate, (2) the presence of a pervasive culture of evaluation and reflection, (3) use of technology to build community and support decision making, and (4) anticipating and planning for the traces that will be left behind when the STEP Center funding of InTeGrate sunsets.

Use of a Systems Perspective and Emergent Strategies

Drawing on previous work on complexity theory, Kania, Kramer & Russell (2014)[73] parse out societal challenges and interventions that tackle them into categories of simple, complicated, and complex. They use education to illuminate these categories, and classify improving student achievement across an education system as a *complex* problem. Such problems are dynamic, nonlinear, and counter-intuitive, characterized by the interplay of multiple independent factors that influence each other in ever-changing ways. Such problems are not amenable to solution by improving one factor. The approach Kania et al. recommend aims to improve fitness across the system as a whole by improving the knowledge, effectiveness, and resiliency of participants throughout the system, using co-created strategies to do so. Rather than pre-planning the entire intervention, complex problems require constant "sensing" of the status of the system and its environment, and then the deployment of "emergent strategies" that evolve to build upon what has been learned, respond to challenges, and take advantages of opportunities.

[70] Website "Research Projects" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/research/index.html

[71] The National Association of Geoscience Teachers (NAGT) runs national surveys of undergraduate geoscience faculty every few years in which they ask about use of various pedagogical techniques [Macdonald, R. H., Manduca, C. A., Mogk, D. W., & Tewksbury, B. J. (2005). Teaching methods in undergraduate geoscience courses: Results of the 2004 On the Cutting Edge survey of U. S. faculty. Journal of Geoscience Education, 53(3), 237-252.] The 2012 survey included several InTeGrate-relevant items. The planned 2015 survey offers the opportunity to ask about use of the InTeGrate website. The survey is confidential but not anonymous, and so survey responses can be matched against participant lists from InTeGrate workshops

[72] The password protected "teacher stash" includes portions of the InTeGrate instructional materials that are intended for-teachers'-eyes-only, such as answer keys to assessments. NAGT members and people who have a SERC account (including anyone who has attended an InTeGrate workshop) are automatically credentialed; others may apply.

[73] Kania, J., Kramer, M., & Russell, P. (2014). Strategic philanthropy for a complex world. *Stanford Social Innovations Review, 12*(3).

InTeGrate's mission is exactly this complex challenge articulated by Kania et al.: to improve student achievement across an education system. Ideas and habits of mind from the domain of complex system thinking crop up throughout the design, implementation, and evaluation of InTeGrate. Many geoscientists are accustomed to using systems thinking in their research on Earth systems, which may have helped the project team evolve towards this approach in co-designing InTeGrate.

The systems flowcharts (Appendix A), co-developed by the evaluation team and project leadership, are intended to depict some of the more important flows of influence and information within and between the components of the InTeGrate system. The flowcharts are best viewed as a hybrid of conjectures[74] about how InTeGrate is intended to work and empirically grounded observations of how InTeGrate is in fact working. Additional empirical evidence is accruing as the project proceeds and the conjectures are tested, with the flowcharts helping to pinpoint where evaluative empirical observation is most needed.

Rather than a linear cause→effect chain, InTeGrate's design conjectures that any given action will have multiple outcomes or consequences. This attribute of a complex system is purposefully leveraged throughout the InTeGrate design. For example, in-gathering workshops (Appendix fig. A-3) are designed to achieve at least four outcomes simultaneously: increased fitness of the instructor/attendees, increased knowledge base for the project as a whole, a more robust community of practice, and recruitment of new allies and new leaders into the InTeGrate effort. Co-development of instructional materials by 3- to 4-person teams from different institution types (fig. A-5) is designed to result in both materials that are not specifically tied to a context and in an enduring collegial relationship within a growing community of practice. When materials developers complete version 1 of their course or module, and again when they finish testing their materials, they complete online reflection surveys; this process provides insights that they draw in revising their materials and also provides information for the evaluation team on the functioning of the development process. Many, if not most, InTeGrate activities are undertaken to achieve multiple desired outcomes simultaneously.

Likewise, InTeGrate's design conjectures that any given desirable outcome will require multiple nudges or influencers. For example, to create "instructors who have internalized InTeGrate values and methods" (fig. A-6), InTeGrate has put in place face-to-face and virtual interactions with a team of materials co-developers, with an assessment team consultant, and with a team leader; has provided webinars and Web materials; requires individual and group reflection on the development process; all in addition to developing and deploying a rubric that articulates and reinforces InTeGrate's pedagogical values and priorities (fig. A-4). There is no effort to disambiguate the individual impact of these support structures; rather the aggregate package of supports is viewed as interactively generating a set of influences and feedbacks that collectively shift the system towards the desired outcome.

The systems thinking perspective helps InTeGrate to capitalize on unexpected opportunities. For example, when it was discovered that some geoscience curriculum development projects were using the InTeGrate materials development rubric outside of InTeGrate, that was not merely filed away as an interesting factoid or a dissemination success, but rather was recognized as a potentially important—and unanticipated—flow pathway to spread InTeGrate-endorsed pedagogical values widely beyond the community of individuals directly funded by InTeGrate.

Similarly, InTeGrate has shown resilience in the face of challenges. For example, the first cohort of materials developers struggled with several aspects of the InTeGrate's requirements, including use of the CMS to share materials, fostering student metacognition, and use of formative assessments. InTeGrate

[74] Sandoval, W. (2013). Conjecture mapping: An approach to systematic educational design research. *Journal of the Learning Sciences*. doi: 10.1080/10508406.2013.778204

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responded by developing purpose-built webinars on these topics. The first effort to foster and assess students' mastery of systems thinking showed that instructors were not sure how to teach this topic and that the systems-thinking assessment essay question was yielding only superficial answers. The project responded with a major collaborative effort to revise and test new essay questions, and is now recruiting developers for a special, separate systems-thinking module. The first Implementation Program solicitation did not yield strong proposals that would bring substantial numbers of underrepresented minorities into the geoscience education pipeline. The project responded by inviting two proposing teams with the desired goals but immature work plans to engage in a mentoring process to improve their proposals, under the guidance of an advisory board member. These fairly substantial changes and additions to the plan could be viewed as jury-rigged patches over system components that are broken. Kania et al.'s work would encourage us instead to regard them as emergent solutions, redeploying resources after learning by doing, an essential way of working when tackling a complex problem. Note that all of these invented-in-real-time solutions to emerging challenges have an evolutionary feel in that— like the solutions arrived at by biological evolution—they re-purpose structures and processes that were already in place and adapt them to new purposes. Webinars, module development procedures, skilled advisory board members, and collaborative development of assessment items were already in the InTeGrate toolkit, and one or more such tools were pulled forth to address an emerging challenge.

Attempts to understand education as a complex system do not yet benefit from computational models like those used in trying to understand the climate system. Instead, our efforts to understand InTeGrate as a complex system have led us to think metaphorically (exhibit 12). Several metaphors seem useful, although each is imperfect. The first metaphor is an orchestra. InTeGrate has a strong leader, the conductor/PI Cathy Manduca, who has a vision of the collaborative sound she wishes to create. But creating that sound requires a large team of talented individuals, each of whom is focused and attentive, and each of whom brings years of learning and practice to the orchestra. The effort is deeply collaborative, yet firmly directed. The second metaphor is an organic farm. This metaphor positions InTeGrate as a purposefully managed subsystem within a larger unmanaged system: the biosphere in the case of the farm, and the nation's higher education system in the case of InTeGrate. Within the boundaries of the farm, the farm family and staff are planting, weeding, enriching the soil, and setting up circumstances in which desired life forms will grow and thrive. Rather than a monoculture, InTeGrate's farm grows a wide range of different crops. This was conspicuous in the selection process for the Implementation programs, which was aptly described as trying to compare apples and oranges; InTeGrate

Exhibit 12: *In trying to understand how InTeGrate works and is intended to work, it may be helpful to think about comparisons to other systems, including an orchestra and an organic farm.*[75]

[75] Orchestra photo from http://commons.wikimedia.org/w/index.php?title=Category:Orchestras&fileuntil=DSC+0384+%285413465459%29.jpg#mediaviewer/File:100th_2.jpg Farm produce photo from http://commons.wikimedia.org/wiki/Category:Permaculture#mediaviewer/File:Courges_permaculture.jpg

chose some of each. The two metaphors overlap in several ways: a large number of different things must be "gotten right" to get the desired effect; in each case, there is a guiding hand; and in each case, the person with the guiding hand can't get the desired effect without the collaboration of other dedicated and talented individuals.

The systems approach does present some difficulties in implementation. Outside of the leadership team, most rank-and-file participants see only a small sliver of the InTeGrate system, as is typical of participants in complex social systems. If participants are unaware of the multiple functions of an activity or structure, they may make decisions that are locally advantageous but that inadvertently undermine some other component of the larger system. For example, some materials development teams began their collaborative work by sharing plans and drafts through Google docs or as email attachments, instead of via the Web-based templates provided by the project.[76] This served the activity "Materials are collaboratively developed and tested by 3- to 4-person teams from differing institutions" (fig. A-5), and did so with a minimum of start-up friction and learning curve. But it inadvertently cut off the essential input into another activity: "Assessment consultant and team leader review materials against rubric" (fig. A-4). This, in turn, cut off information that needed to flow to "'Dashboard' allowing near-real-time monitoring by leadership of InTeGrate's system status and progress, across distributed components" (fig. A-10). The team members who chose to share their draft materials through an ad hoc mechanism that worked well for their local corner of the project probably did not envision the project-provided Web templates as a component of the project leadership's system-monitoring and decision-support system. As the workings of InTeGrate's complex system become better understood and more clearly articulated, it may be both possible and desirable to be more explicit about sharing the system perspective and design more broadly.

Culture of Reflection/Review/Evaluation Throughout the InTeGrate Ecosystem

We external evaluators are not the only people undertaking evaluative types of activities within InTeGrate. SERC has substantial in-house evaluation expertise and, in fact, InTeGrate is permeated with instances in which individuals are engaged in reflection or peer review or evaluation or assessment or other purposeful activities whose goal is to figure out what is working well and what is working less well. Examples include the following:

- Because InTeGrate instructional materials are collaboratively developed by 3- to 4-person teams with different backgrounds, and opportunities are provided for the teams to interact virtually and face-to-face, in well-functioning teams the members are constantly trying out their ideas on each other and providing feedback on each other's work.
- The assessment team and materials developers engage in rounds of propose>critique>revise in which plans and drafts are compared against the rubric.
- Materials developers provide individual or collective written reflections on their experience four times during the materials development process: when their materials pass the rubric, when they finish testing their materials in the classroom, when they agree upon a revision plan, and at the end of the entire process.
- The materials development rubric requires that students engage in metacognition, which includes monitoring one's own learning processes and making adjustments to one's learning processes when appropriate.[77]

[76] Example of materials developers' templates for a fake course are provided at http://serc.carleton.edu/dev/integrate/teaching_materials/fake_course/index.html

[77] Webpage "The Role of Metacognition in Teaching Geoscience" [open access]: http://serc.carleton.edu/NAGTWorkshops/metacognition/ introduction.html

- Students take pre- and post-instruction tests of their geoscience knowledge and understanding (GLE).
- Students take pre- and post-instruction surveys of their interest in Earth-related careers and their behaviors and attitudes around resource issues and environmental sustainability.
- Students write post-instruction essay questions designed to probe their skill at interdisciplinary problem solving and systems thinking.
- GLE question scorers provide input on how well students seemed to understand individual questions and how well each question brings out student understanding and differentiating among students.
- All InTeGrate workshops have brief "road checks" at the end of each day plus a longer survey at the end of multi-day workshops, administered and synthesized by the SERC internal evaluation staff.
- Advisory board meetings limit the agenda time spent on reporting out-of-project accomplishments, and devote half or more of each meeting to interactive problem solving, and seeking feedback and recommendations.
- The internal/external evaluation program itself had an evaluation, by engaging Frances Lawrence as an evaluation consultant.[78]

Seen from a systems perspective, this culture of reflection/review/evaluation can be seen as an effort to manufacture innumerable small and large virtuous feedback loops. Reinforcing (positive) feedback loops nudge project participants towards actions that align with InTeGrate's values and priorities or that are observed to be effective. Countervailing (negative) feedback loops rein in departures from InTeGrate's values before they escalate. It is important to note that many of InTeGrate's feedback loops do not pass through the principal investigator or even through the leadership team. Individuals in the farthest reaches of the InTeGrate domain have been empowered to take part in the process of figuring out what is working and what is not working and to nudge their local part of the system towards doing more of that which is working.

InTeGrate's cultural norm of reflection/review/evaluation has been achieved partly by social engineering, for example, the use of 3-person development teams from different types of schools. It has been achieved partly by policy tools: for example, the rubric requires that materials shall have students engage in metacognition. And finally, it has been supported by technology, for example, tools for scoring essay questions, for critiquing individual GLE questions, for administering workshop road checks and evaluations and compiling results, and for keeping track of workshop participants and re-participants.

Use of Technology to Build Community and Support Decision Making

In the project proposal, the InTeGrate website was positioned primarily as a dissemination vehicle. As the project has matured, additional functions for the website and associated technology-based tools have been developed with a different purpose: to support the internal workings of the InTeGrate team rather than to communicate with the outside world (Appendix fig. A-10).

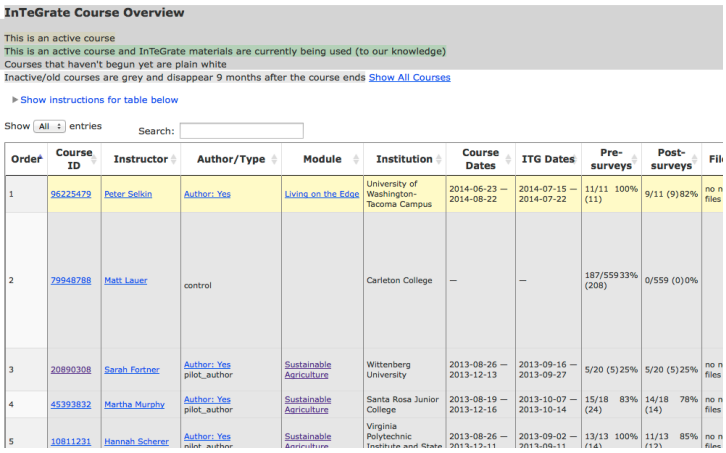
Building on the existing SERC Content Management System (CMS) and the expertise that had accumulated in developing that system, InTeGrate has built a suite of Web-based tools, archives, databases, and workspaces (fig. A-10) for use by those actively engaged in building InTeGrate (the leadership team, materials developers, assessment team, evaluation team, implementation programs.) Most of these are accessed via password-protected, inward-facing regions of the InTeGrate website. For

[78] Evaluation summit materials and outcome are here: http://serc.carleton.edu/integrate/info_team_members/research/evaluation_summ.html

example, materials development team members accumulate their plans and draft materials into Web templates that are monitored by assessment team members. Most meetings and conference calls generate a Web-accessed archive, in which notes, agendas, and presentations endure and are findable. Purpose-build, web-accessed tools allow team members to work collaboratively and keep track of what is going on elsewhere in the system: for example, allow evaluation team members to keep track of how many IAI surveys have been received from each enactment of an InTeGrate course or module,[79] and allow assessment team members to keep track of the suggested changes in each GLE question.[80]

InTeGrate leadership is trying to manage a complex distributed system with many moving parts. These technology-based tools are being used to create a kind of a dashboard, comprising webpages that record and update the status of different parts of the system. This dashboard can be used to spot problems and support decision making, somewhat analogous to the dashboard of a car or the control panel of a power plant (exhibit 13). Different parts of the InTeGrate team have access to different parts of the dashboard. For example, materials development team members see the progress of their own module or course through the template fields and checkpoints, and can use that information to prioritize what to do next—but they do not see the status page for all materials in development.

Exhibit 13: *InTeGrate has created a series of webpages and web-accessed tools that provide information on the status and progress of various components of the complex system that is InTeGrate, somewhat analogous to the dashboard of a car or control panel of a power plant[81].*



InTeGrate Course Overview

This is an active course
This is an active course and InTeGrate materials are currently being used (to our knowledge)
Courses that haven't begun yet are plain white
Inactive/old courses are grey and disappear 9 months after the course ends Show All Courses

Show instructions for table below

Show All entries Search:

Order	Course ID	Instructor	Author/Type	Module	Institution	Course Dates	ITG Dates	Pre-surveys	Post-surveys	Fil
1	96225479	Peter Selkin	Author: Yes	Living on the Edge	University of Washington-Tacoma Campus	2014-06-23 — 2014-08-22	2014-07-15 — 2014-07-22	11/11 100% (11)	9/11 (9) 82%	no n files
2	79948788	Matt Lauer	control		Carleton College	—	—	187/559 33% (208)	0/559 (0) 0%	
3	20890308	Sarah Fortner	Author: Yes pilot_author	Sustainable Agriculture	Wittenberg University	2013-08-26 — 2013-12-13	2013-09-16 — 2013-09-27	5/20 (5) 25%	5/20 (5) 25%	no n files
4	45393832	Martha Murphy	Author: Yes pilot_author	Sustainable Agriculture	Santa Rosa Junior College	2013-08-19 — 2013-12-16	2013-10-07 — 2013-10-14	15/18 83% (24)	14/18 78% (14)	no n files
5	10811231	Hannah Scherer	Author: Yes pilot_author	Sustainable Agriculture	Virginia Polytechnic Institute and State	2013-08-26 — 2013-12-11	2013-09-02 — 2013-09-11	13/13 100% (14)	11/13 85% (12)	no n files

The power plant metaphor is strong in that it foregrounds the complexity of the enterprise that the InTeGrate leadership is trying to orchestrate, and the importance of carefully-designed, near-real-time information displays in so doing. But the metaphor shouldn't be carried too far. InTeGrate's dashboard serves a monitoring function rather than a control function. Once a decision is taken, that decision is executed by actions of leadership team members rather than by manipulating switches and buttons on the dashboard: in fig. A-10, "Information from the 'dashboard' informs team members' decisions and actions."

Nor is the information in the InTeGrate dashboard provided automatically from the electromechanical sensors that would be found in a power plant. Instead, most of InTeGrate's dashboard is fed by hard-working human beings uploading data, reflections, segments of instructional materials, etc. The

[79] http://serc.carleton.edu/admin/assess/course_overview.php?project_module_id=2244 (restricted access)
[80] Website "Grading Feedback" [restricted access]: http://serc.carleton.edu/integrate/info_team_members/assessment_team_work/grading_feedbac.html
[81] Power plant control room from http://faculty.cs.byu.edu/~mike/mikeg/WORKSHOP/panel.html. Webpage "InTeGrate Course Overview": http://serc.carleton.edu/admin/assess/course_overview.php?project_module_id=2244 (restricted access)

effectiveness of InTeGrate's status-monitoring and decision-making thus depends on many people in the far reaches of the InTeGrate domain having both the skill and the propensity to engage with the InTeGrate website regularly and in fairly complex ways: "Team capacity and inclination to use SERC CMS and webtools" of fig. A-10. The project began with a reservoir of "GeoEd community experience using SERC CMS" as an input, from the many Geoscience faculty who had attended Cutting Edge or Starting Point workshops at which they were required to use the CMS, but found it necessary to add capacity through "Team webinars and face-to-face professional development" for materials development teams (fig. A-10).

For the geographically distributed builders of InTeGrate, the website supports the development of a collaborative team by providing a "place" to "convene" and share ideas, plus a visible artifact depicting and showcasing shared progress. The actual thing that the InTeGrate team are co-designing and co-constructing is largely invisible: a gossamer veil of subtle nudges and influencers and feedbacks and affordances overlain upon the existing fabric of American higher education, which is supposed to influence millions of micro-decisions taken invisibly in the prefrontal cortex of millions of individuals: What should I emphasize? What should I leave out? What will I ask next? What will I study? What shall I choose for my major? How shall I lead my life? Collectively, integrated over the tens of millions of students, teachers and administrators engaged in undergraduate education in America, the network of influencers is supposed to shift the entire nation towards solutions to the grand challenges of resources and environmental sustainability. In a project where the network of influencers is difficult to see and individuals' decision-making apparatuses are impossible to see, the website provides a tangible, visible depiction of what the team is accomplishing together.

What beneficial impacts are likely to remain in place after the end of the grant?

As practitioners of an historical science, geoscientists know that events in the world leave traces. It is appropriate at this point to consider what will be the traces left by the event called InTeGrate. From a systems perspective, this is similar to asking what are the flows of information or influence that may carry InTeGrate's impact outward beyond activities that are directly funded by the project and that may persist after the award period ends. Identifying what such pathways are and finding ways to maximize their effectiveness is essential if InTeGrate is to achieve national and enduring impact. Some candidates:

Instructional materials developed by the project and adopted by schools outside the development team are the most obvious and in some ways the concrete legacy of a project like InTeGrate. But they are less enduring than they seem at first glance. Web-based instructional materials decay quickly in the absence of paid maintenance and updates. Links break. Science makes new discoveries. Real world vignettes and problem-based applications come to feel dated.

A culture of evaluation, as discussed above, may take root in individual departments or spread to entire universities, and could inform the culture of future science education projects proposed and implemented by InTeGrate team members. For example, two other curriculum development projects[82] have adopted the InTeGrate materials development rubric.[83]

Vision of education as a complex system and education reform as a complex challenge, can influence the project planning and implementation of future projects. It appears that most of the InTeGrate leadership team and Advisory Board are seeing this big picture and sharing this vision, which they will carry on to future projects. Spreading this vision further, documented with concrete evidence of success and mechanism, is an opportunity for the second half of the project.

[82]. University NAVSTAR Consortium (UNAVCO): http://serc.carleton.edu/getsi/teaching_materials/index.html. Geoprisms: http://serc.carleton.edu/margins/mini_lesson_authors/index.html

[83] The rubric alone may not be enough, however. Within InTeGrate, additional structures, including checkpoints enforced by the assessment team, were in place to nudge developers towards alignment with the rubric. See flowchart (2).

Friendships and collegial relationships from previous projects were essential in developing the very-complicated InTeGrate proposal and project plan. InTeGrate is building friendships and colleagial relationships, reservoirs of trust upon which future endeavors can be built. This is apparent at the leadership team level, and also farther down into the tendrils of the InTeGrate system, where we note that some of the materials development teams express a desire to continue to work together. It seems plausible that some student teams, tackling project-based challenges in InTeGrate classrooms, may also be building relationships that could incubate into organizations or companies that tackle interdisciplinary environmental challenges—but we have no way to track that.

Faculty members who have changed their teaching practice to a more student-centered, active-learning pedagogy, and/or towards more societally relevant orientation within geo, and/or more geo-rich content outside geo departments. And, they like these changes so much they extend them across the rest of their teaching, and perhaps even try to influence the colleagues to do the same. We have some evidence in faculty reflections that instructors involved in InTeGrate materials development are moving, or at least report that they intend to move, in this direction.

Students who have experienced learning that is more systems-based, data-rich, problem-and-solution focused. In theory, such students could insist on this approach in their future courses, and vote with their feet for instructors, departments, and universities who offer such an approach. The extent to which this happens may be wrapped up in the effectiveness of the metacognitive component[84] of that InTeGrate requires in all instructional materials, which may help students to see such activities as supportive of desirable learning rather than an annoying lot of extra work.

A cohort of *geoscience graduates with the skills and propensity to address societal problems.* Attitudes and priorities established as undergraduates can influence decisions for a lifetime.

An Earth-literate cohort of non-geoscientists--lawyers and business people and engineers and congress people--who consider the Earth in their decision-making, voting and consuming, and the consequences of their decisions upon natural and human systems. Students influenced by InTeGrate can impact the Earth not just through their own decisions and actions, but also through their roles as opinion-shapers in their own person and professional communities.

From an evaluation perspective, measuring the effectiveness with which InTeGrate is establishing enduring traces will be difficult. We can note the degree of attention or inattention paid to these flows of information and influence by the leadership team. And we can document specific instances or cases in which early signs of the establishment of a trace seem to be happening, as for example an uptick in students' stated desire for an employer who considers environmental sustainability in their business practices. Compiling this list, and follow-up discussion that may grow from it, has revealed and may continue to reveal additional opportunities to monitor early indicators of these traces[85].

Note that this idea of focusing on and enhancing traces or legacy left behind by the InTeGrate event is separate from the effort to develop ongoing funding streams that would enable the InTeGrate team to continue some of the activities that they are currently carrying out. The Advisory Board has encouraged InTeGrate to begin early and vigorous efforts towards this latter kind of project economic sustainability.

[84] Metacognition is required by the materials development rubric for all materials. Advice to materials developers on how to foster metacognition and self-regulated learning is here: http://serc.carleton.edu/integrate/info_team_members/currdev/effective_materials/metacog.html Fostering metacognition has been one of the more difficult aspects of InTeGrate's pedagogical model for materials developers to work with.

[85] For example, we are not currently attempting to measure either students' metacognitive reflection nor their desire to seek out additional courses that use InTeGrate-like pedagogy.

Appendix A: Logic Models

The design and evaluation of InTeGrate have been aided by the development of a series of flow-chart style logic models that depict the flows of influence and information among various components of the InTeGrate system. These have been developed through collaboration between the Evaluation Team and project leadership. The logic models are used to think about how the pieces of InTeGrate interact, to communicate about the workings of InTeGrate, to identify leverage points for interventions, and to identify where evaluative probes would be most illuminating.

The logic models are an evolving document. [86] The earliest draft, created in first months of the project from the proposal alone, was pure conjecture in the terminology of Sandoval:[87] a set of conjectures about what interventions ["activities"] would help move the undergraduate education system of America towards InTeGrate's goals, and a related set of conjectures about what observable phenomena ["outputs"] would provide evidence that the system was moving in that direction. As the project has matured, the logic models have become more detailed, more observation-based, and less conjectural. At this snapshot in time, they are a hybrid of conjectures about how the leadership team and evaluation team think that InTeGrate is supposed to be working and observation of how InTeGrate is in fact working.

On the pages that follow, the boxes are color coded to indicate:

- Inputs (blue): phenomena that existed prior to or outside of InTeGrate, which InTeGrate uses or leverages
- Activities (orange): actions undertaken by members of the InTeGrate community,
- Outputs (brown): observable or measurable products or phenomena resulting from InTeGrate activities, and
- Outcomes (green): longer term desirable consequences of InTeGrate's existence, not necessarily observable within the term of the funded project.

The *cursive text* attached to some of the boxes indicates sources of information by which we can monitor or evaluate that activity or outcome. Black font indicates information sources used primarily by the external evaluation team, and grey indicates information sources used for review/evaluation/quality control by other parts of the InTeGrate system, mostly the SERC Internal Evaluation Team and the Assessment Team.

In general, the arrows can be read as "leads to" or "contributes to" or "influences" or "enables." In order to draw an arrow, we require a plausible mechanism by which A should lead to or influence or enable B. Some arrows are annotated to suggest what that mechanism might be. As the project matures, we seek evidence that each arrow is not only plausible, but is also veridical: that when A happens B follows.

[86] Earlier versions of the logic model are at website "InTeGrate Logic Models" [restricted access]: http://serc.carleton.edu/integrate/workspace/logic_model.html

[87] Sandoval, W. (2013). Conjecture mapping: An approach to systematic educational design research. *Journal of the Learning Sciences*. doi: 10.1080/10508406.2013.778204

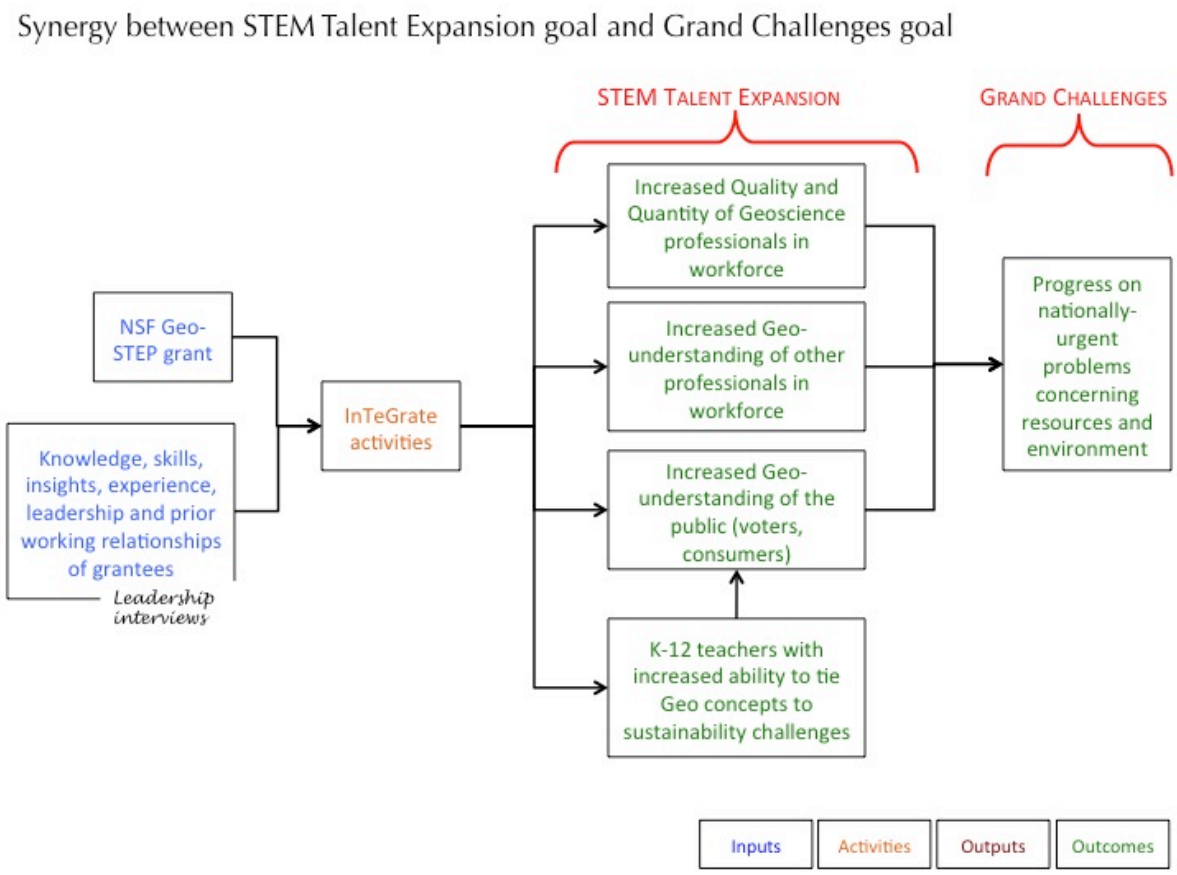


Figure A-1: *NSF's STEM Talent Expansion Program asks each STEP Center to accomplish two things simultaneously: expand the talent flowing into the STEM education and career pipeline and make progress on tackling a major challenge facing the nation. In InTeGrate's theory of change, these two goal are intertwined, as shown in this figure. To make progress on the grand challenges of limited natural resources and environmental sustainability, InTeGrate seeks to increase the quality and quantity of geoscience professionals entering the STEM pipeline. This is considered necessary but not sufficient to tackle the identified grand challenges, so InTeGrate also seeks to increase the geo-understanding of other professions in the workforce, the geoliteracy of the general public, and the capacity of K-12 teachers to tie Geo concepts to sustainability challenges.*

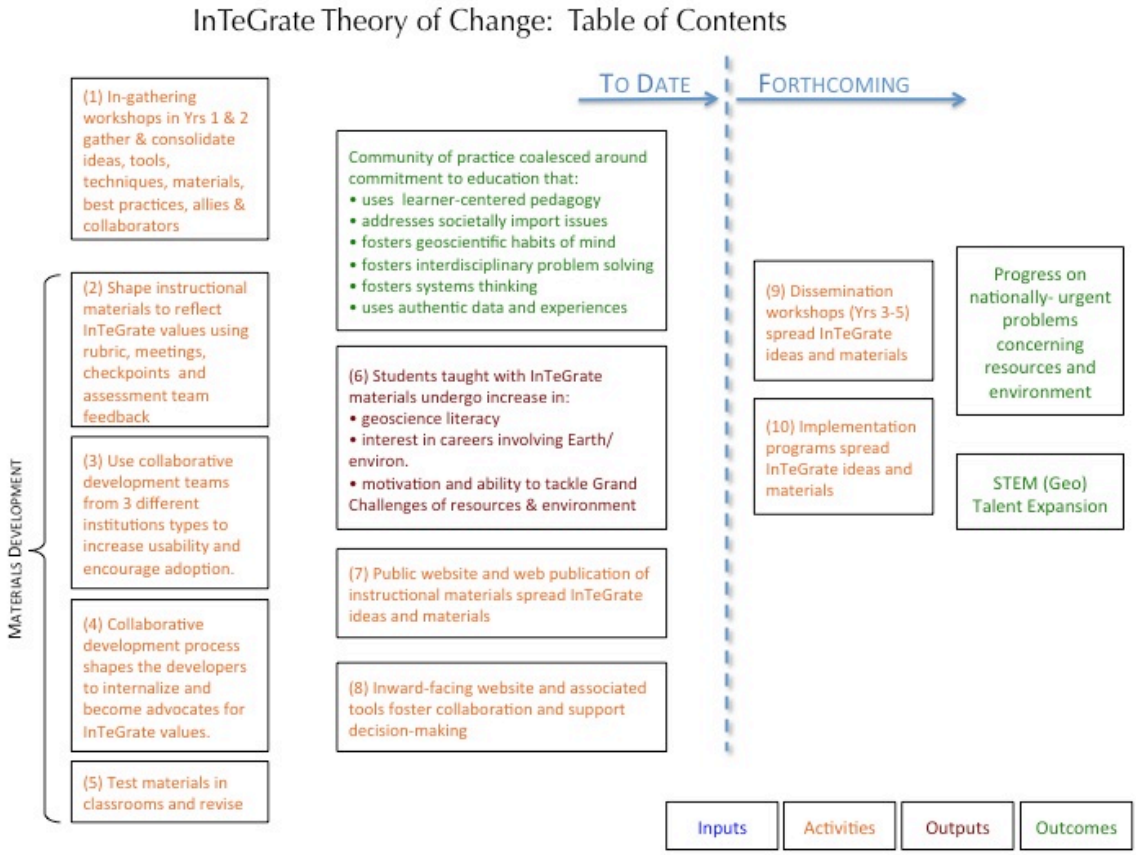


Figure A-2: *Each box on this page is expanded into a flowchart on a subsequent page. InTeGrate Program Element #1, Materials Development, has had the lion's share of effort in the first three years of the project, and so the logic model for that aspect of the project is best developed.*

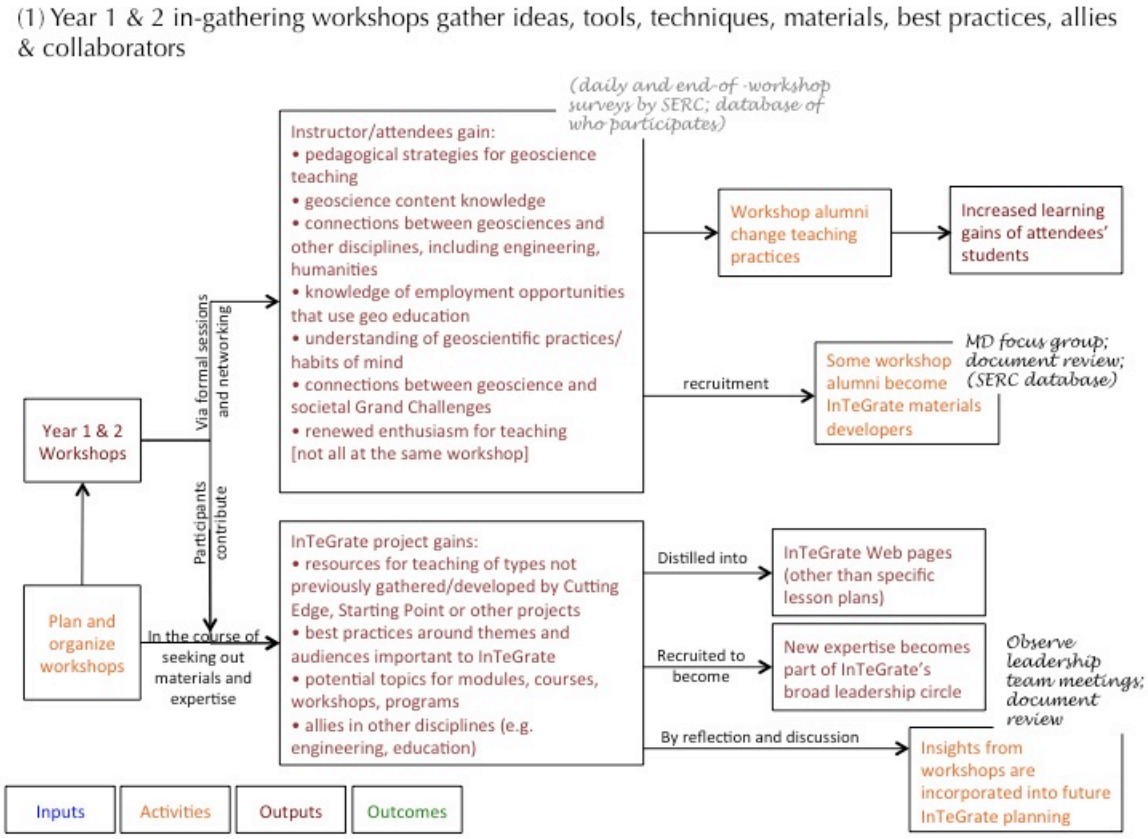


Figure A-3: *Because the leadership team views InTeGrate as a complex system, they tend not to plan for linear cause-effect chains in which one activity results in one outcome. Here we see an example of how one type of activity (in-gathering workshops) is expected to yield two families of outputs: benefits to the attendees, who will leave as better-equipped instructors, and benefits to the project, which will gain resources, ideas, and allies.*

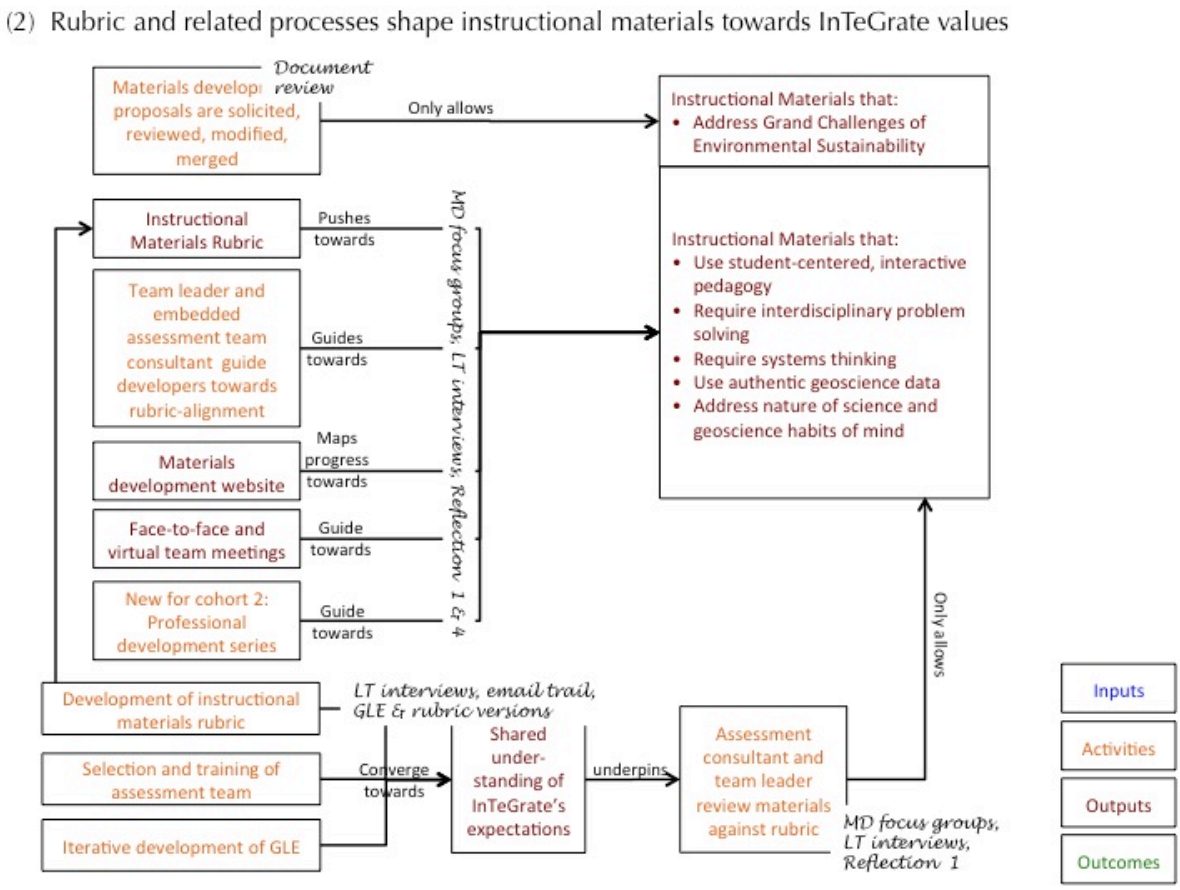


Figure A-4: *In the previous panel, we saw how InTeGrate's complex system has a single activity leading to multiple outputs. In this panel, we see that the converse is also true: multiple activities acting simultaneously are required to nudge the system towards a single desired output. In this case, multiple activities and entities (rubric, website) combine to nudge the materials development process in such a way as to end up with instructional materials that align with InTeGrate's pedagogical guiding principles. There is no effort to disambiguate the individual impact of each of these activities and entities; the output is viewed as a result of the cluster of influencers, acting synergistically.*

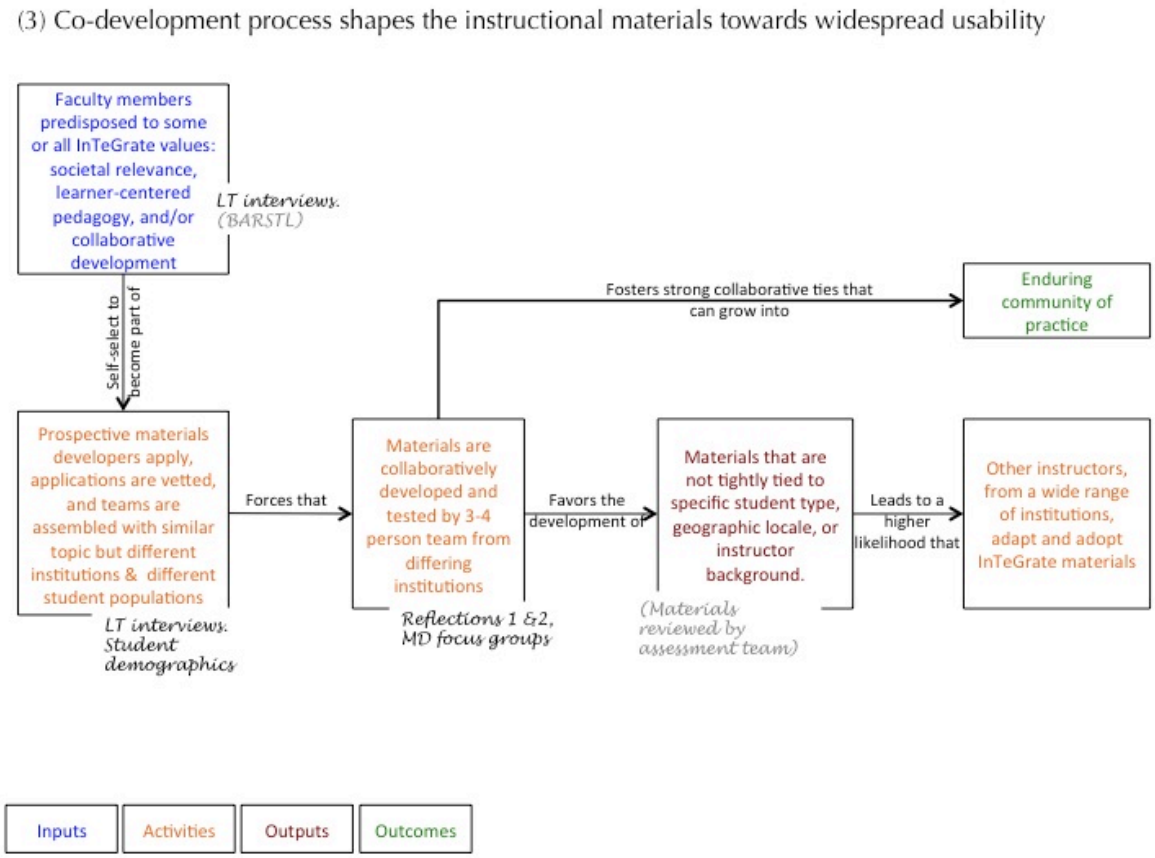


Figure A-5: *In this panel, we see the first green-colored "Outcome." As practitioners of an historical science, geoscientists are accustomed thinking about how events in the world leave traces, traces that can endure long after the causal forces are over. An "Enduring community of practice" is conjectured to be one of the beneficial traces that the InTeGrate event may leave behind. Even after the STEP Center funding sunsets, the community of practice built by InTeGrate could continue to catalyze new collaborations and new initiatives that continue to nudge America's higher education system towards InTeGrate's goals.*

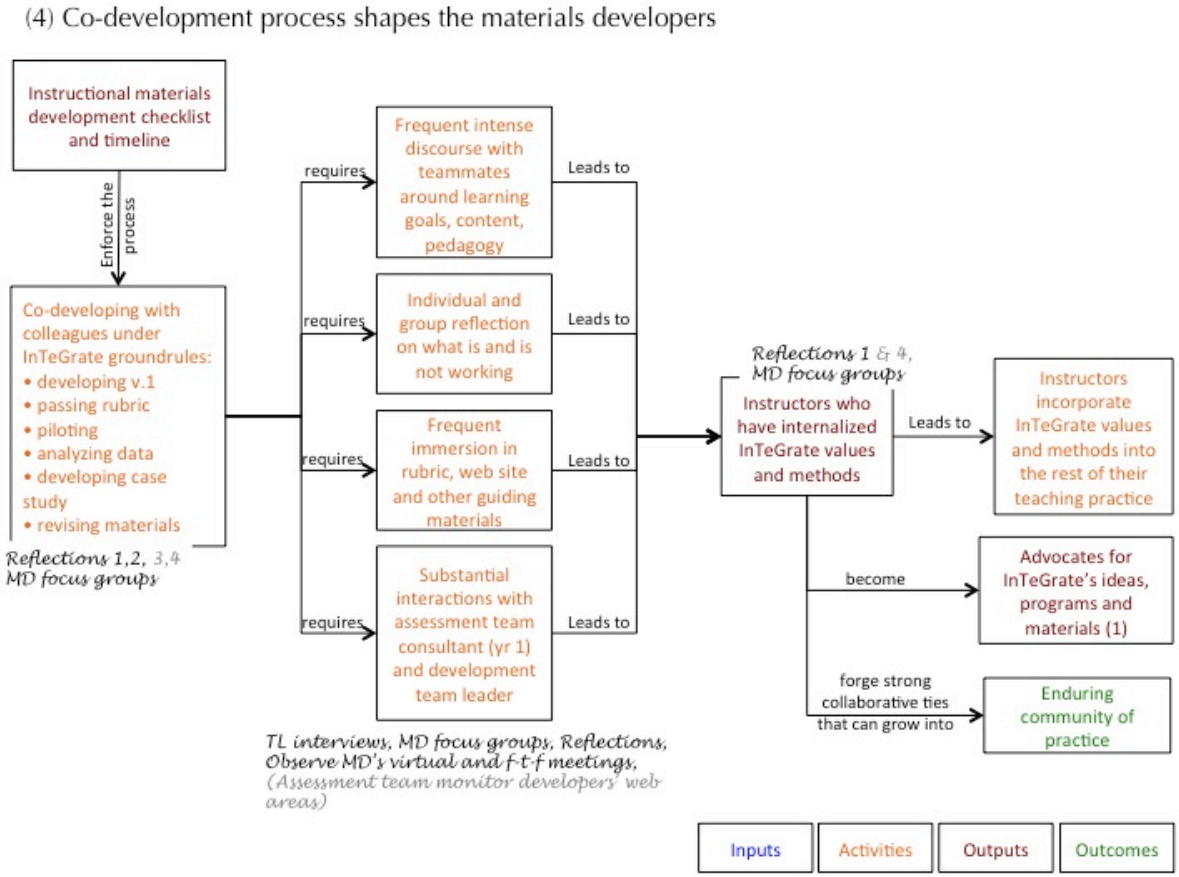


Figure A-6: *On the surface, InTeGrate's elaborate materials development process appears to be designed to shape the instructional materials into alignment with the pedagogical values embodied in the Instructional Materials Rubric. That set of influences, depicted in logic model panel (3) [figure A-5] is true, but it's not the whole story. This panel shows that the same set of processes is also supposed to be shaping the materials developers themselves, into instructors who have internalized InTeGrate's values. This could turn out to be a more profound and longer lasting impact. Long after InTeGrate's instructional materials have become infested by broken links and obsolete factoids, the instructors impacted by their involvement in InTeGrate may still be incorporating InTeGrate's values into the their teaching and advocating InTeGrate's values among their professional circles.*

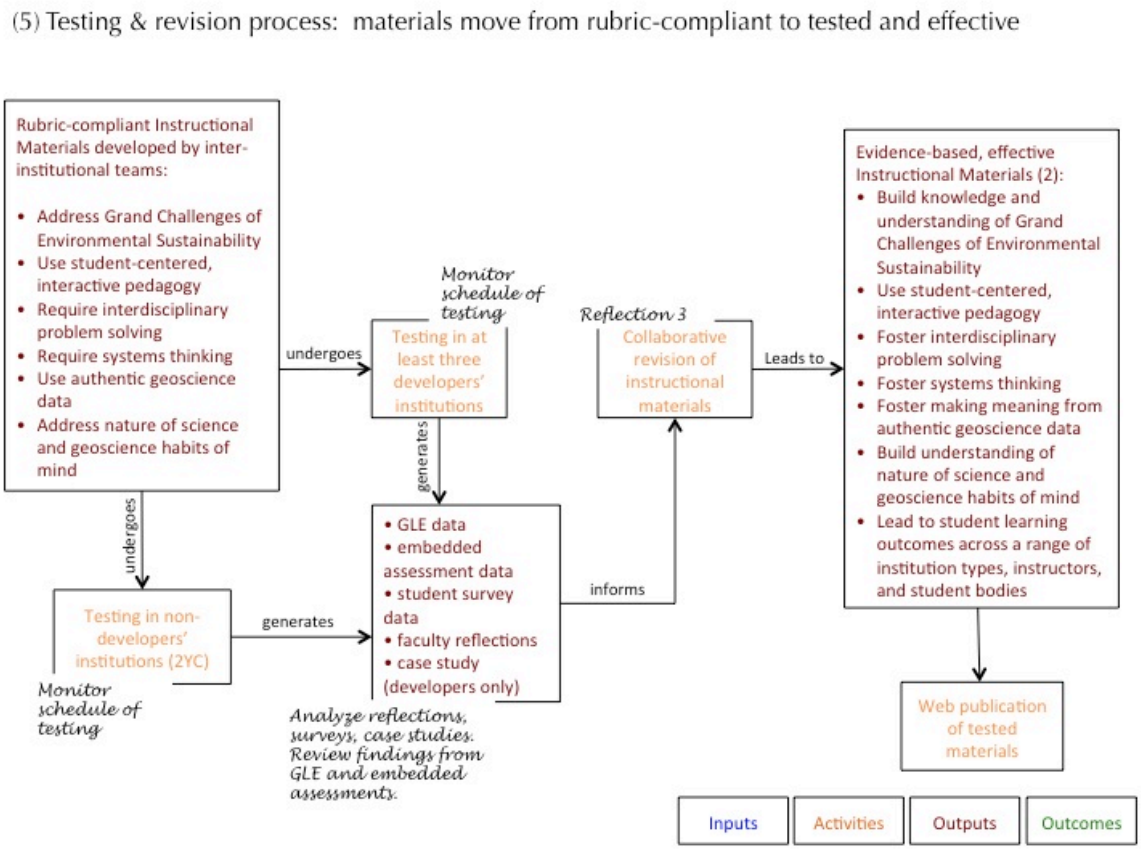


Figure A-7: *In InTeGrate, evaluation is not only the responsibility of the external evaluation team. Opportunities for evaluation, reflection, peer-review, assessment, quality control, and data-informed revision permeate the system. This panel depicts the process of testing and collaborative revision that lies between rubric-compliant instructional materials and materials that have been shown to be useable and effective in classrooms.*

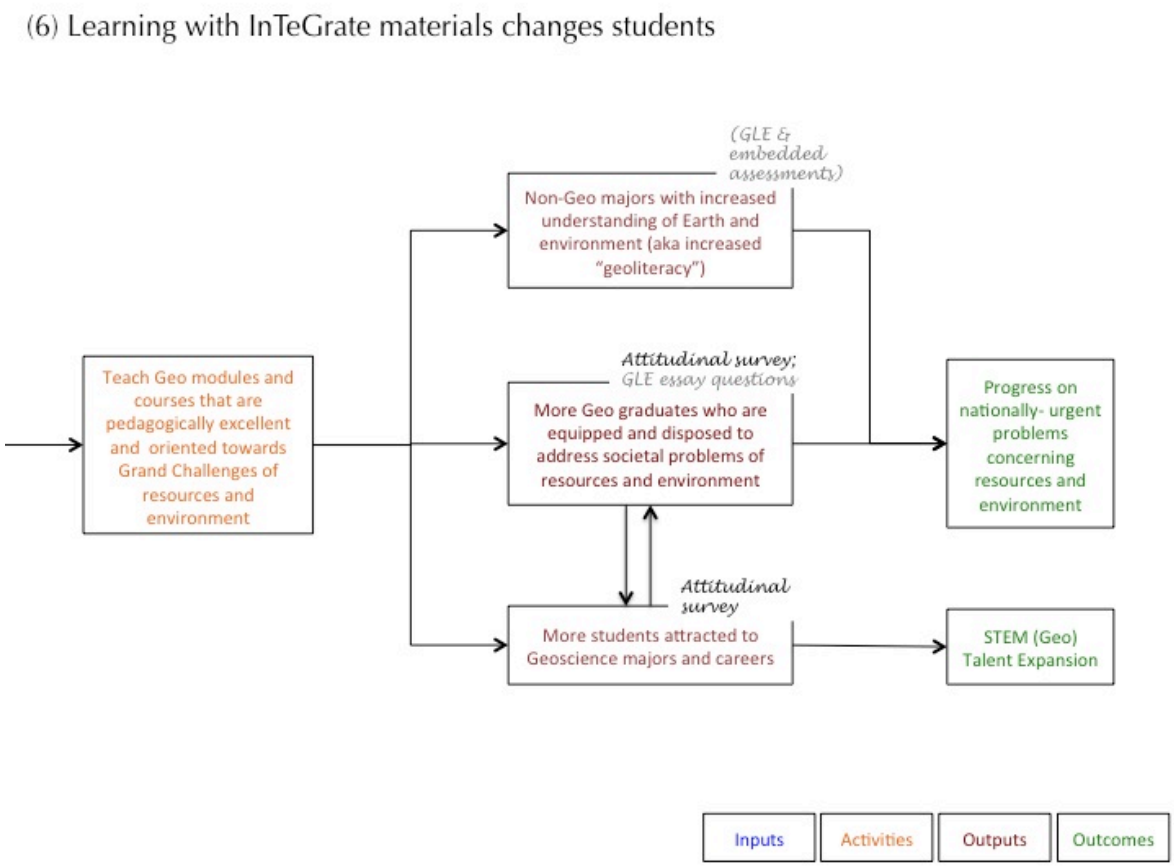


Figure A-8: *Here we see laid out most starkly the set of giant conjectures that lie at the center of InTeGrate's theory of action: If InTeGrate manages to offer modules and courses that are pedagogically excellent and are oriented towards societally relevant Grand Challenges, then hearts and minds will be won, and students will be better equipped and more disposed to seek out Geoscience major and careers and to address societal problems of resources and environment, and they will change their choices and behaviors in such ways that the world will make progress on some of its most pressing and intractable problems. InTeGrate now has a set of instruments in place [the Geoscience Literacy Exam (GLE), embedded assessments, essay questions about systems thinking and interdisciplinary problem solving, and the InTeGrate Attitudinal Instrument (IAI)] to detect whether these changes to heart and mind are happening.*

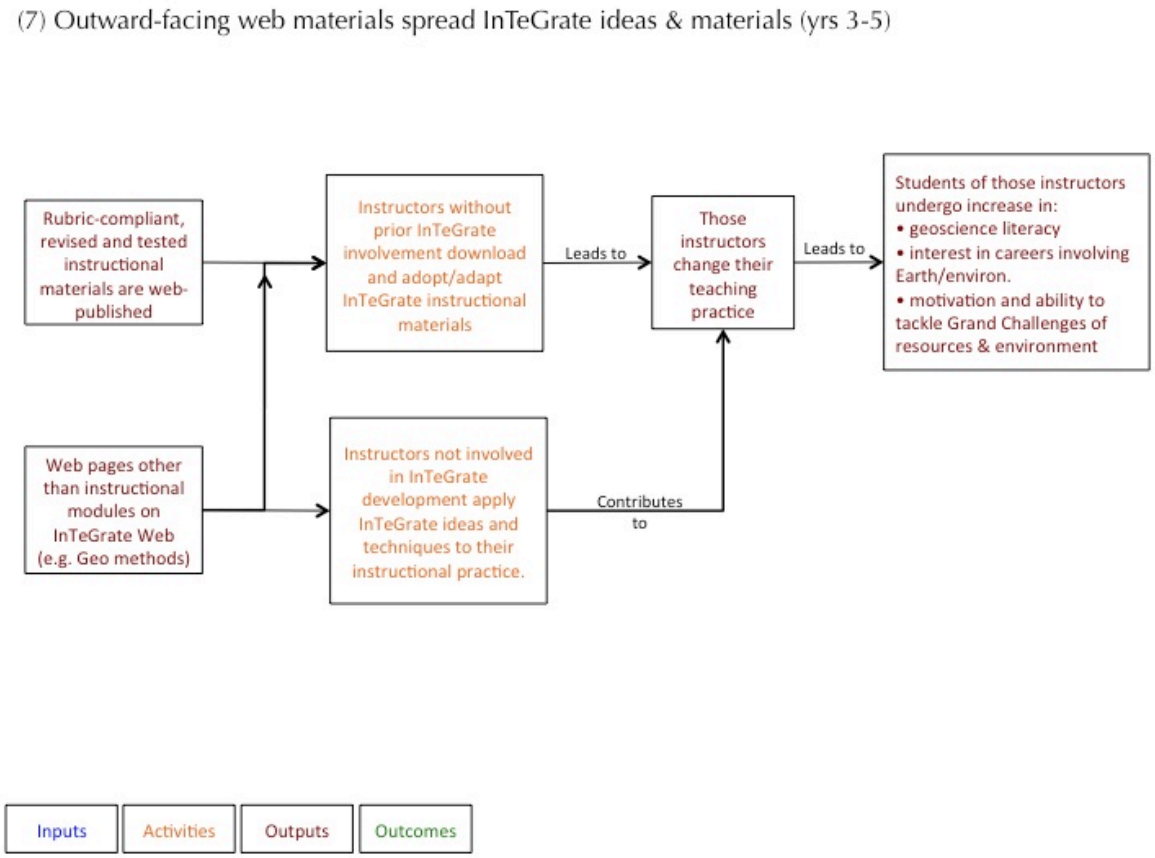


Figure A-9: *This panel of the logic model is mostly conjecture, as the first of InTeGrate's instructional materials were made available on InTeGrate's public website only a few weeks ago. It is an evaluation challenge for the remainder of the project to know how to evaluate whether instructors do indeed "change their teaching practice" or whether students do indeed "undergo increase[s] in geoscience literacy" etc, when the only contact with InTeGrate has been via the website.*

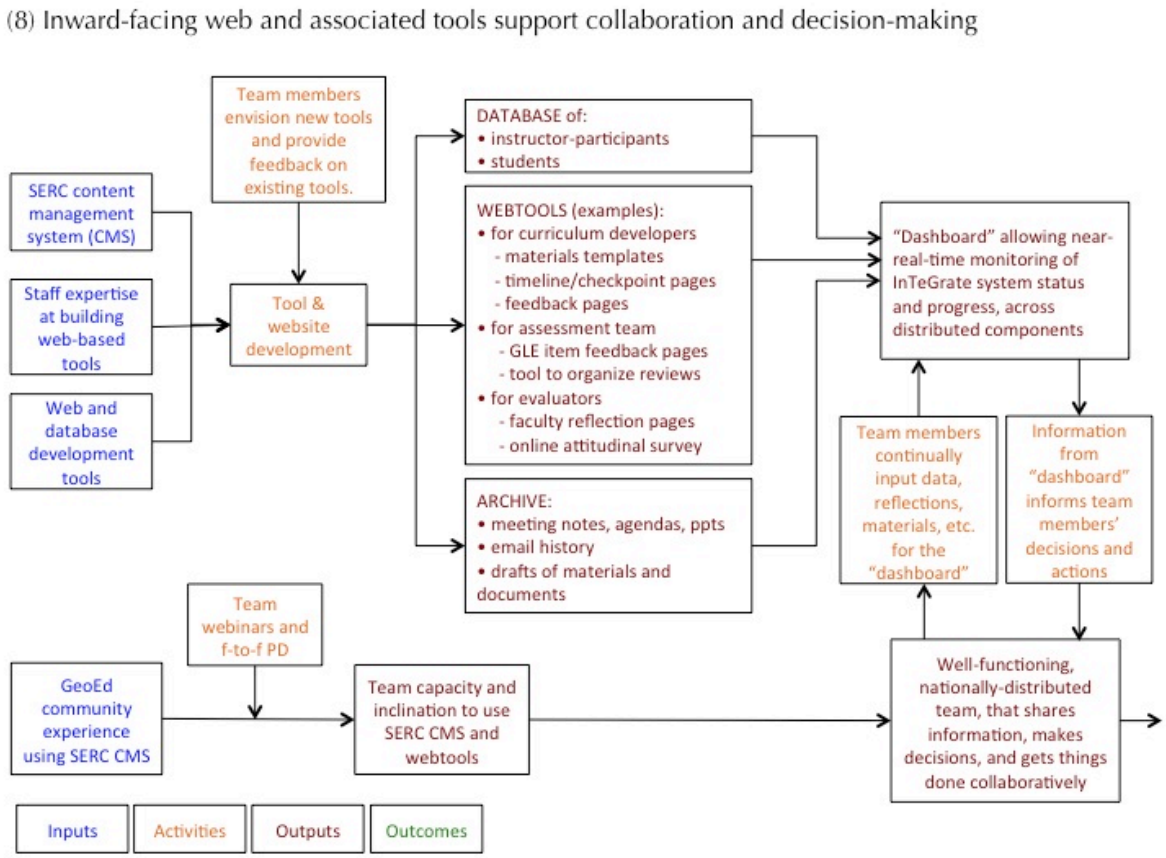


Figure A-10: *Educational reform efforts that consider education as a complex system cannot pre-plan every detail of their intervention in advance. Instead, they need to be continually "sensing" the status of the system and its environment and deploying "emergent strategies" that evolve to build upon what has been learned, respond to challenges, and take advantage of opportunities.88 This panel outlines how InTeGrate is using web-based technology to create a "dashboard" that supports the process of continuously monitoring the InTeGrate system.*

[88] Kania, J., Kramer, M., & Russell, P. (2014). Strategic philanthropy for a complex world. *Stanford Social Innovations Review, 12*(3).

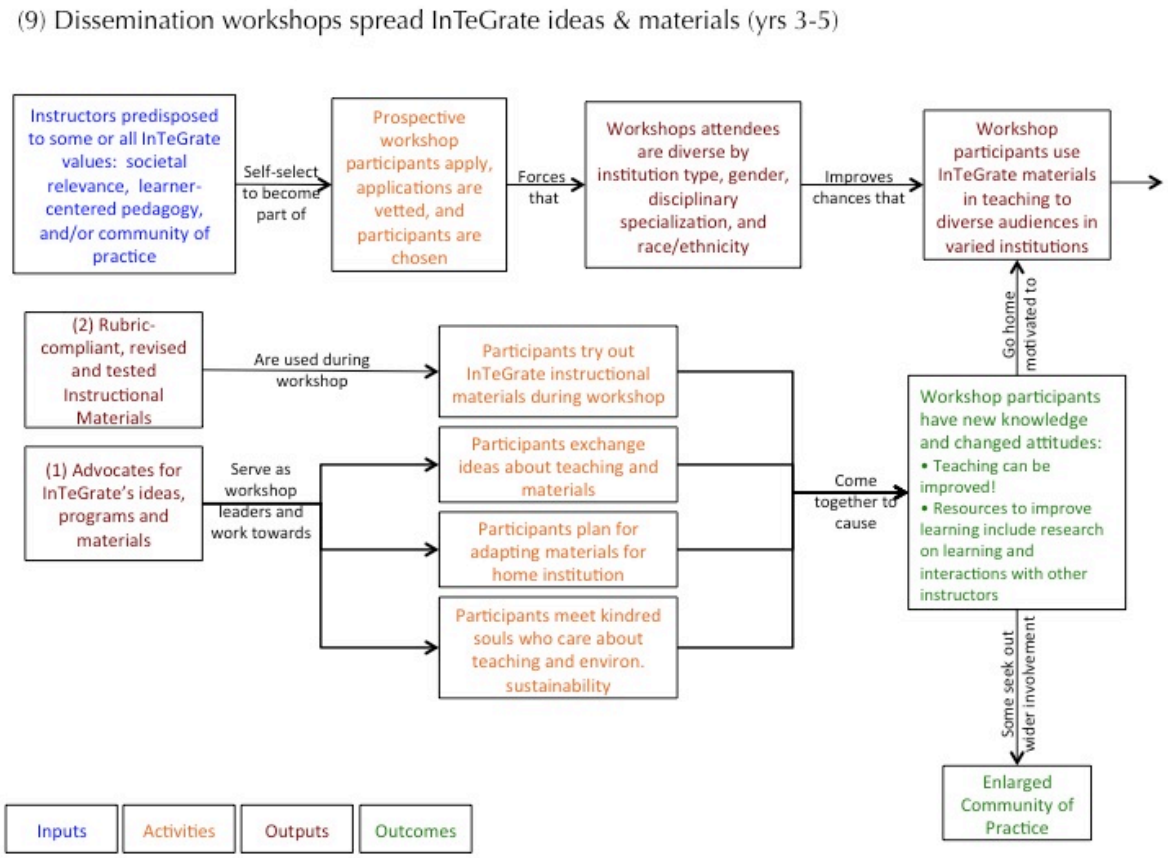


Figure A-11: *This is another panel that is mostly conjecture, as dissemination workshops had to wait until materials were published. The first such workshop happen in October 2014, at the Geological Society of America meeting. These conjectures are more firmly grounded than some others in InTeGrate's theory of action, as they are based on long experience with Cutting Edge and Starting Point professional development workshops.89*

[89] On the Cutting Edge: Strong Undergraduate Geoscience Teaching website [open access]: http://serc.carleton.edu/NAGTWorkshops/index.html; Starting Point: Teaching Entry Level Geoscience website [open access]: http://serc.carleton.edu/introgeo/index.html

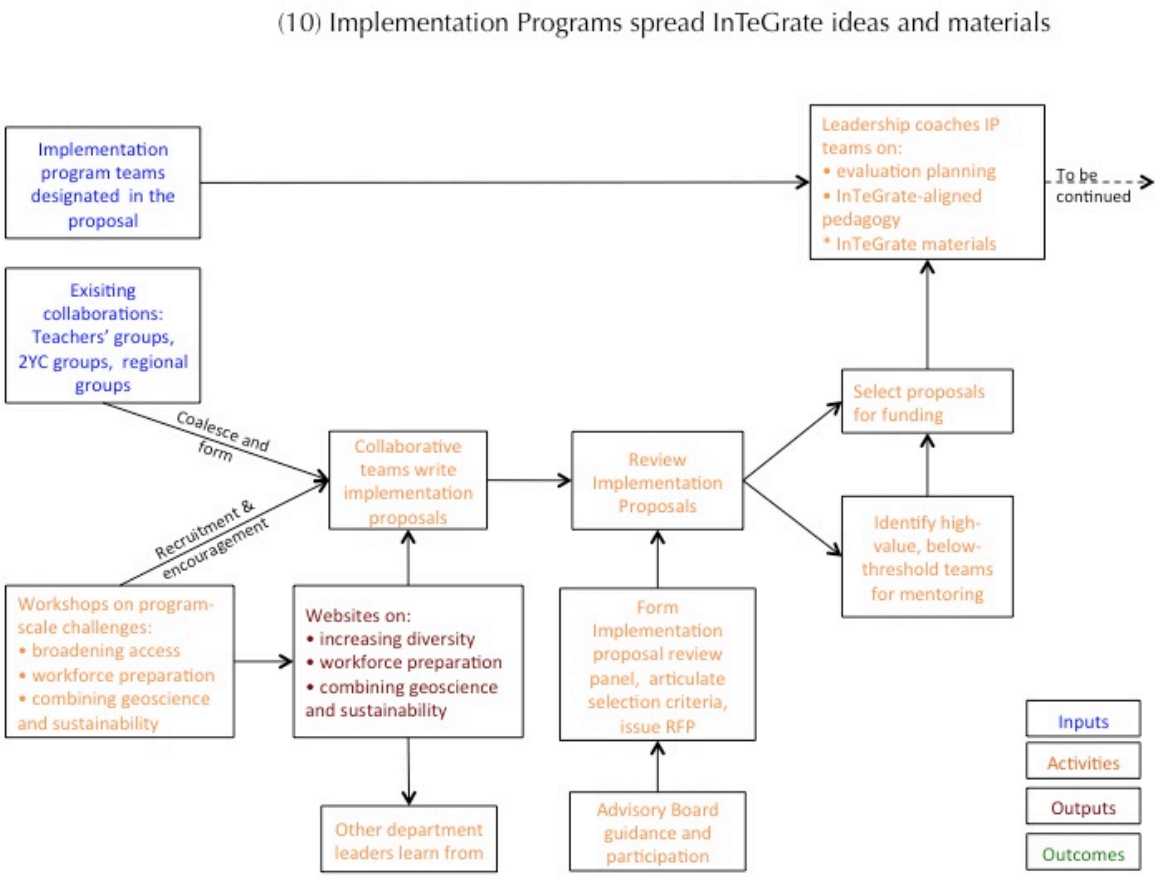


Figure A-12: *Initial activities in the development of Implementation Programs have happened, and are mapped here by solid arrows. This logic model panel will need to be fleshed out as the programs mature. The arrow from "Review Implementation Proposals" to "Identify high-value, below threshold proposals for mentoring" represents a pathway that was not anticipated. When the proposals were reviewed, two were identified as tackling a very important problem but below the threshold for funding. Rather than reject these outright, the leadership team created an alternative pathway to bring these teams into the system via a high-level mentoring process.*

Appendix B:

InTeGrate Curriculum Development and Refinement Rubric (CDRR)

Geoscience literacy involves context that includes recognizing life situations involving geosciences and knowledge, and which encompasses understanding of both scientific concepts and the nature of science. It also includes competencies related to identifying scientific issues, explaining phenomena, and drawing scientific conclusions. Another component of literacy is associated with citizen attitudes related to indicating an interest and motivation to act responsibly toward the Earth.

This rubric is designed to guide InTeGrate curriculum developers as they create modules and courses to improve geoscience literacy. The rubric incorporates broad goals of the InTeGrate project and researched guidelines for best practices in curriculum development. 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 guiding principles 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.

Guiding Principles (must score 15/15)

1 **Course/module addresses one or more geoscience-related grand challenges facing society**: Grand challenges listed in the original InTeGrate proposal include resource issues (e.g., minerals, energy, water, food, sustainability) and environmental issues (e.g., climate change, hazards, waste disposal, environmental degradation, environmental health). Other Grand Challenges include those listed in the National Academy's "Grand Challenges in Environmental Science." Those include challenges related to biogeochemical cycles, biologic diversity and ecosystem functioning, climate variability, hydrologic forecasting, environmental change impact on pathogens, resource extraction, land use and land cover, and recycling.

2 **Course/module develops student ability to address interdisciplinary problems**: Interdisciplinary problems require diverse perspectives that promote understanding of the interactions between Earth science and economic, societal and policy issues. Such materials integrate robust geoscience with trans-disciplinary knowledge from other disciplines such as geography, social sciences and humanities.

3 **Course/module improves student understanding of the nature and methods of geoscience and developing 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: comparing modern processes to those found in the geologic record; comparison of cases to understand commonalities and differences attributable to process, history, and context; developing converging lines of evidence; and testing through prediction. Geoscientific habits of mind include: recognition of the fundamental role of observation and of a spatial and temporal organizational scheme in understanding the Earth, recognition of the Earth as a long-lived, dynamic, complex system whose history is shaped by a continuum of long-lived low impact processes and short-duration high impact processes, and valuing collaboration as a strategy for effectively moving forward understanding of the Earth.

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. For instance, geoscientists use such data to derive and inform knowledge, to develop hazard assessments, to provide early warning to citizens and as inputs to models. References to updated data sources will be provided as available.

5 **Course/module incorporates systems thinking**: Course/module develops students' ability and propensity to use systems thinking in considering natural systems, human systems, and their interactions. A systems thinker understands basic interactions among the spheres (atmo-, hydro-, geo-, cryo, anthropo-, bio-) and the difference between open and closed systems. In addition, a systems thinker habitually anticipates that a perturbation in one sphere may have effects throughout Earth's system, and is able to identify multiple causal factors that could influence a single observation or outcome. They may also have the ability to use the concepts of positive (reinforcing) and negative (countervailing) feedback loops, flux, reservoir, residence time, lag (delay), and limit (threshold), in explaining the behavior of natural systems, human systems, and linked human/environment systems.

Learning objectives and Goals (must score 13/15)

6 **Learning objectives describe measureable geoscience literacy goals**: Learning objectives are clear statements that describe the desired goals of the instruction. Learning goals are directly stated specific competencies, skills and/or knowledge that students are to master or demonstrate. The objectives

and goals are 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 where appropriate.

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

8 **Learning objectives and goals 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.

9 **Learning objectives and goals are clearly stated for each module in language suitable for the level of the students**: Learning objectives and goals should avoid jargon and highly technical language unless required.

10 **Learning objectives and goals address the process and nature of science and development of scientific habits of mind**: According to the AAAS, 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. The nature of science includes such attributes as: the world is understandable, recognizing the difference between credible and non-credible scientific arguments, scientific ideas are subject to change, scientific knowledge is long-lasting or durable but subject to change and science cannot answer all questions. Scientific habits of mind include recognition that science is a complex social activity, science is organized by disciplines and carried out at multiple institutions, there are accepted ethical principles related to the conduct of science, scientists participate in public affairs as specialists and citizens, scientists communicate their understanding of the world to multiple audiences, and that there are accepted criteria for evaluating the credibility of scientific interpretations and scientific claims.

Assessment and Measurement (must score 13/15)

11 **Assessments measure the learning goals**: Embedded formative assessments and summative assessments and assignments will provide logical tools to determine the extent to which students have met the course and module goals. These activities must match course content such that they help the student achieve the goals (and thus be able do the assignments).

12 **Assessments are criterion referenced**: Assessments include a clear and meaningful list of criteria used to evaluate student work and participation including all the information students need to know how a grade will be calculated. This could be accomplished with a formal rubric or with a more informally structured description of what each grade looks like. 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 such as examples of excellent or poor papers or projects.

13 **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 goals. Every assignment should link directly to the goals assessed. Resources needed for activities and assessments are clearly stated.

14 **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.

15 **Assessments address goals 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 creation. Feedback from these assessments informs the student of their level of learning.

Resources and Materials (must score 15/18)

16 **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 guiding principles, literacy goals or core concepts embedded in learning objectives and goals.

17 **Students will recognize the link between the learning objectives, goals 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 goals; and which materials are required and which are recommended resources. Reviewers will assess whether they believe the students will understand how to use the materials provided.

18 **Instructional materials should be sufficiently diverse and at the depth necessary for students to achieve learning objectives and goals**: Instructors should provide meaningful content using a variety of sources (e.g., text, articles, presentations, websites, lecture notes, outlines, and multimedia). The course materials are robust and create a rich learning environment for students. 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 goals. For example, an upper-level capstone course should include significantly deeper materials than those required for an introductory general education course.

19 **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.

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

21 **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.

Instructional Strategies (must score 13/15)

22 **Learning strategies and activities support stated learning objectives and goals**: The learning activities promote the achievement of the stated learning objectives and goals. Students should be able to meet the stated objectives and goals using the learning activities provided. They should actively engage students with the course content using a variety of different types of activities. Activities should be designed to support reinforcement and mastery in multiple ways.

23 **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 provide multiple opportunities that foster interactions designed to facilitate students' understanding and mastery of the learning objectives and goals. Activities should foster instructor-student, content-student and student-student interactions where appropriate. Examples include group discussions or blogs, small-group projects, peer critiques or rotating assigned communication roles such as moderator or summarizer.

24 **Learning activities develop student metacognition**: The activities should provide opportunities for students to iterate and improve their understanding incrementally. Activities should include an appropriate balance of guidance versus exploration and opportunities for reflection, discussion, and synthesis. Students should be able to assess their own learning and confirm they are on the right track.

25 **Learning strategies and activities provide opportunities for students to practice communicating geoscience**: It should be clear that the students 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 where appropriate.

26 **Learning strategies and activities scaffold learning**: Activities should promote deep learning by stimulating student intellectual growth from novice to advanced levels, considering the needs of non-traditional students, as appropriate. Activities should be structured to allow students to first note obvious connections and then grasp the significance of those connections. 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.

Alignment (must score 5/6)

27 **Teaching materials, assessments, resources and learning activities align with one another**: A constructive alignment approach suggests that goals, learning activities and assessments within each section of the module/course align with one another and directly with stated learning objectives and goals. A curriculum map that identifies core skills and content, learning strategies and resources can be used as an effective way to ensure alignment.

28 **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.