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ABSTRACT

The rock cycle is a key component of geoscience education at all levels. In this paper, we report on a new guided inquiry curricular module, *Sleuthing Through the Rock Cycle*, which has a blended online/offline constructivist design with comprehensive teaching notes and has been successful in pilot use in Rhode Island middle and high school classrooms over the past 3 y. The module consists of two overarching activities: (1) SherRock Holmes and the Case of the Mystery Rock Samples, and (2) Cracking the Case of the Changing Rocks. The module encourages hands-on activities, peer collaboration, and real-time teacher review of embedded textual and reflection components. Overall, Rhode Island teachers report that the module is an outstanding teaching tool and that the associated professional development is empowering. © *2013 National Association of Geoscience Teachers*. [DOI: 10.5408/12-326.1]

Key words: rock cycle, guided inquiry, rock formation, middle school, online curriculum

INTRODUCTION

Purpose

The purpose of this work is to describe a new online, guided inquiry tool for teaching middle and high school learners about the rock cycle. This tool was built and refined through intensive collaborative effort (K. Kortz and K. Saul) in 2010 and 2011, resulting in a ready-to-run Java platform project called *Sleuthing Through the Rock Cycle*. We encourage all teachers of the rock cycle to employ this activity as a blended online/offline experience, because it has been crafted in a constructivist framework that improves science literacy in students and provides teachers with a concise module that covers material relevant in middle and high school Earth Science.

Context

Since Joseph Schwab promoted the benefits of inquiry as a teaching tool in science in the 1960s, science educators have worked to transform curricula toward a more inquiry-minded ideal. Schwab (1960) suggested that learning should occur through the active process of engaging students in inquiry because it leads to stronger development of skills and encourages the students to think like scientists. He constructed a model that describes three different levels of inquiry, ranging from guided questioning to completely open student-led exercises, where students create their own ideas and hypotheses and set up their own methods to test ideas (Schwab, 1960). Since the students are more involved in the generation of ideas and hypotheses when inquiry-based learning is applied, students have a better capability to solve problems that do not follow the usual layout and are therefore able to solve more complex problems (Schwab, 1960; National Research Council, 2000).

Guided inquiry is loosely defined as an intermediate pedagogical method fitting between open-ended, student-directed learning and traditional, direct instruction (Furtak, 2006). This now-popular teaching style encourages students to explore ideas and hypotheses, therefore fostering critical and scientific thinking (Schwab, 1960; National Research Council, 2000) while maintaining some steering on the part of the teacher. Guided inquiry has been argued to be more effective and more efficient than open inquiry to teach students new concepts (Kirschner et al., 2006).

When teaching the rock cycle concepts, for example, direct instruction might involve a teacher listing definitions, describing processes for the student, and posing questions with one right answer. Open-ended inquiry could involve student exploration of rock hand samples prior to explanation, with student-led questions coming from the student's own growing conceptualization of the rock cycle. Guided inquiry is an intermediate pedagogical style, where students are encouraged to explore materials and pursue multiple problem-solving strategies to answer thought-provoking questions introduced by the teacher.

As developed by Michael (2006), successful active learning requires student engagement in activities that integrate reflection on ideas and the ways in which those ideas are used in constructing knowledge and also invites students to control aspects of content and/or pacing, for example. The implementation of this guided inquiry teaching tool on the rock cycle embraces best practices in active and student-centered learning and tackles the problem of secondary school teachers' lack of training or comfort teaching Earth Science concepts, which otherwise has a real and negative impact on student learning. Eidietis and Jewkes (2011) articulate this problem as systemic in

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ocean science, arguing that subjects that teachers are less comfortable teaching tend to get less time in the classroom. Dahl et al. (2005) indicate that Earth Science teachers have misconceptions and are not comfortable with many geologic concepts and subsequently recommend increasing teacher's science content knowledge. Increasing content knowledge can be done through focused professional development and training in core concepts in geosciences. In addition, the development of high-quality curricular modules would enhance teacher comfort and confidence, increasing the likelihood of their dedicating more time to teaching the previously neglected content (Eidietis and Jewkes, 2011) and also increasing student learning.

The use of technology in the classroom allows for additional teaching tools and skill building for students: It allows students to devise research questions and methods and generally improves their familiarity with technology through the exploration of computer-guided modules. The use of a computer interface provides a means for students to visualize phenomena through online animations and modeling that may otherwise be difficult to explain. Students prefer online animations and refutational text because they aid in preventing or overcoming misconceptions of particular concepts (Guzzetti, 2000). Additionally, technology allows for automatic recording of student responses/work done in online modules, which may be available to teachers in real time, allowing teachers to be light on their feet in responding to student misconceptions. Online systems can also facilitate the grading process.

Diverse pedagogical strategies for teaching rock cycle concepts abound, and scrutiny of rock cycle–related unit plans/classroom observations has reflected both best practices and areas of challenge in geoscience education. The rock cycle is a fundamental concept in Earth Sciences that is often misunderstood (Kortz and Murray, 2009) and thus is an object of pedagogical comparison, such that multiple teaching styles of the rock cycle (conceptual-change teaching, didactic teaching, and microteaching) have been evaluated for successful student learning (Stofflett, 1994), and the rock cycle has been used as a topic for assessing learners' scientific inquiry skills (Orion and Kali, 2005). Concentrated content knowledge enrichment in rock cycle concepts has also been considered critical content in science teacher training, both for increasing teacher confidence and improving attitudes about science teaching (Vitale and Romance, 1992). Despite the importance of understanding how rocks form and change over time, teachers sometimes focus only on describing and classifying rocks, instead of placing them into the bigger, geologic picture (e.g., Ford, 2005).

RITES Project Overview

Here we report on the creation of a guided inquiry module and the ready audience of teachers piloting its use, which has been made possible through the Rhode Island Technology Enhanced Science (RITES) Project, funded by the National Science Foundation's Math and Science Partnership Program. RITES aims to connect with all of Rhode Island's public middle and high school teachers to improve the education of students and offer high-quality targeted professional development for teachers.

The RITES model combines the development of inquiry-based, online learning modules for students with an associated summer professional development opportunity, or short course, where in-service teachers are given hands-on time with the modules and are also taught content knowledge relevant to the module.

RITES has worked closely with teams of higher education faculty paired with in-service teachers to develop a total of 29 modules, focusing on Earth and space science, chemistry, biology, and physical science. These same pairs also developed the short courses for the teachers. The modules and corresponding short courses represent the combined expertise of higher education faculty, in-service teachers, and Concord Consortium technology specialists. Teaming of higher education faculty and in-service teachers was critical to both the design of modules and the instruction of the short courses. The higher education faculty member brought outstanding and relevant content knowledge, and the experienced in-service teacher team brought pedagogical and practical experience to the table. Teaching techniques appropriate for secondary education settings were also integrated at all phases of the project.

Each module, and supporting materials, is both a teacher-training tool and a curriculum product for students, composed of an online interface and rich supplementary material on the topic of the rock cycle. Through subcontract to the Concord Consortium (concord.org), a nonprofit organization aiming "to ignite large-scale improvements in teaching and learning through technology," the modules were designed as a Java platform product that enables students to answer questions and teachers to view student responses and monitor class performance in real time. Freestanding portable document format (PDF) versions of some modules ensure their functionality even offline.

STUDY POPULATION AND SETTING

Teachers Involved in the RITES Project

Thirty of 179 teachers that are part of RITES took the Rock Cycle Short Course in the summer of 2011. About half of the teachers that participated in RITES did not have formal training in the science, technology, engineering, or mathematics (STEM) but rather had studied in humanities, education, or other fields (Figs. 1A and 1B). Of the teachers who participated in the Rock Cycle Short Course, only one third had formal training in a STEM field, and most of those were in biology (Figs. 1C and 1D). The distribution of the highest degrees achieved by teachers involved in the Rock Cycle Short Course mimics closely that of the distribution found for all RITES teachers (Fig. 2).

Rock Cycle Short Course for Teacher Participants

The Rock Cycle Short Course was developed by the partnership of a higher education faculty (K. Kortz) and an in-service teacher (K. Saul). All RITES short courses were strongly encouraged to be led in such a way to model active, inquiry-based learning, and the Rock Cycle Short Course was exceptionally strong in doing so.

Results from all 2011 Short Courses indicate that teacher participants had very positive experiences in the professional development opportunities presented to them by RITES (Table I). Teachers teaching the rock cycle and other fundamental concepts in the geosciences are underprepared in general; thus, we have found response to this focused professional development opportunity and the careful design of the module, both of which provide training in the Earth

TABLE I: Survey results from summer 2011 short courses in all disciplines ($n = 368$) and rock cycle only ($n = 31$) showing teacher participant satisfaction and benefits ($N = 368$). Survey instrument provided by The Education Alliance at Brown University. Data courtesy of J. Caulkins, RITES Project.

Survey Items	Agreement All Short Courses (%)	Agreement Rock Cycle Short Course Only (%)
I feel more prepared to use the RITES modules in my classes.	95	95
I will probably use more inquiry activities in my classes more often as a result of this course.	91	90
I increased my knowledge of science content through participation.	96	95
I would have liked to have the opportunity to learn more science content.	67	70
I feel more comfortable using technology to teach science as a result of this course.	83	81
I feel well prepared to use activities that integrate science and mathematics as a result of this course.	86	77
I was able to share ideas with other teachers.	98	95
I would recommend this course to other teachers.	93	96
Overall, this course was a successful learning experience for me.	93	96

Sciences to the teachers, to be extremely positive. Teachers have asked for longer training sessions and more coverage in the Earth Sciences in general, which RITES is working to provide.

Development of the Module

The *Sleuthing Through the Rock Cycle* module is a curriculum for students in grades 5–12, although it focuses on the rock cycle, which is frequently taught in middle school. The module may be used in parts or as a whole, so teachers may address particular grade standard expectations (GSEs) or national teaching standards (Tables II and III). This module can also serve as an apt teacher-training tool as part of professional development events for in-service teachers trained in fields other than Earth Sciences.

RITES modules in general have been incorporated into schools throughout the state of Rhode Island, reaching teachers and students that represent the diversity of the entire state. The successful use of the Rock Cycle module, in particular, in so many different educational settings speaks to its utility and potential impact through even broader usage. Next, we describe in more detail the nuts and bolts of the module, with information on its implementation and best practice use.

METHODS

Description of the Teaching Module

The *Sleuthing Through the Rock Cycle* teaching module is set up in a way such that it can be used on a computer through Java (http://rites-investigations.concord.org) or as a hard copy worksheet. The module is divided into two overarching activities (1—SherRock Holmes and the Case of the Mystery Rock Samples; and 2—Cracking the Case of the Changing Rocks) with multiple parts in each (Fig. 3 and Table IV). Each part within the module is fairly self-contained, with its own engage, materials, explore, explain, wrap up, and assessment sections.

Both multiple-choice questions and short-answer questions are included throughout each part. Multiple-choice questions are used to help guide and narrow student responses, which help focus student energy and attention. The distractors of the multiple-choice questions were written using the expertise of the module authors with common misconceptions or misunderstanding of students incorporated. These embedded questions allow students the time to do more exploration, since the students answer the questions relatively quickly. Multiple-choice questions give quick feedback because they are automatically graded online and quickly graded by the instructor if the module is done in offline mode. Short-answer questions let the students explain responses in their own words and in more detail. Some parts direct students to fill out tables (offline) with their data, such as observations and labeled sketches (e.g., Activity 1, Parts A–C; Table IV).

The overarching theme of the first activity, SherRock Holmes and the Case of the Mystery Rock Samples, is that rocks tell information about their past, and careful examination of rocks gives clues about their history and how they formed. Throughout Activity 1, SherRock guides the students using the initial set of six mystery rock samples (which are preferably accompanied by hand samples of the rocks; see Table V). Students must then apply what they learn about those rocks to additional rocks throughout the module (Table IV). The activity encourages the students to classify the rocks based on critical visual exploration and identification of common characteristics. This application of knowledge is usually done in the "explain" and "assessment" sections.

The second activity of the module, Cracking the Case of the Changing Rocks, explores in more depth the processes involved in the rock cycle. Students learn how the three different rock types—igneous, sedimentary, and metamorphic—are tied to different Earth processes and to the larger picture of the rock cycle (Table IV).

Each part within each activity lists the materials used in that activity. Within the computer module, students are directed to use these materials, including rock samples, hand lenses, and stereomicroscopes, and the rock samples in particular are strongly recommended for students to get hands-on experience in identifying rocks. The list of suggested supplementary materials is included in Table V.

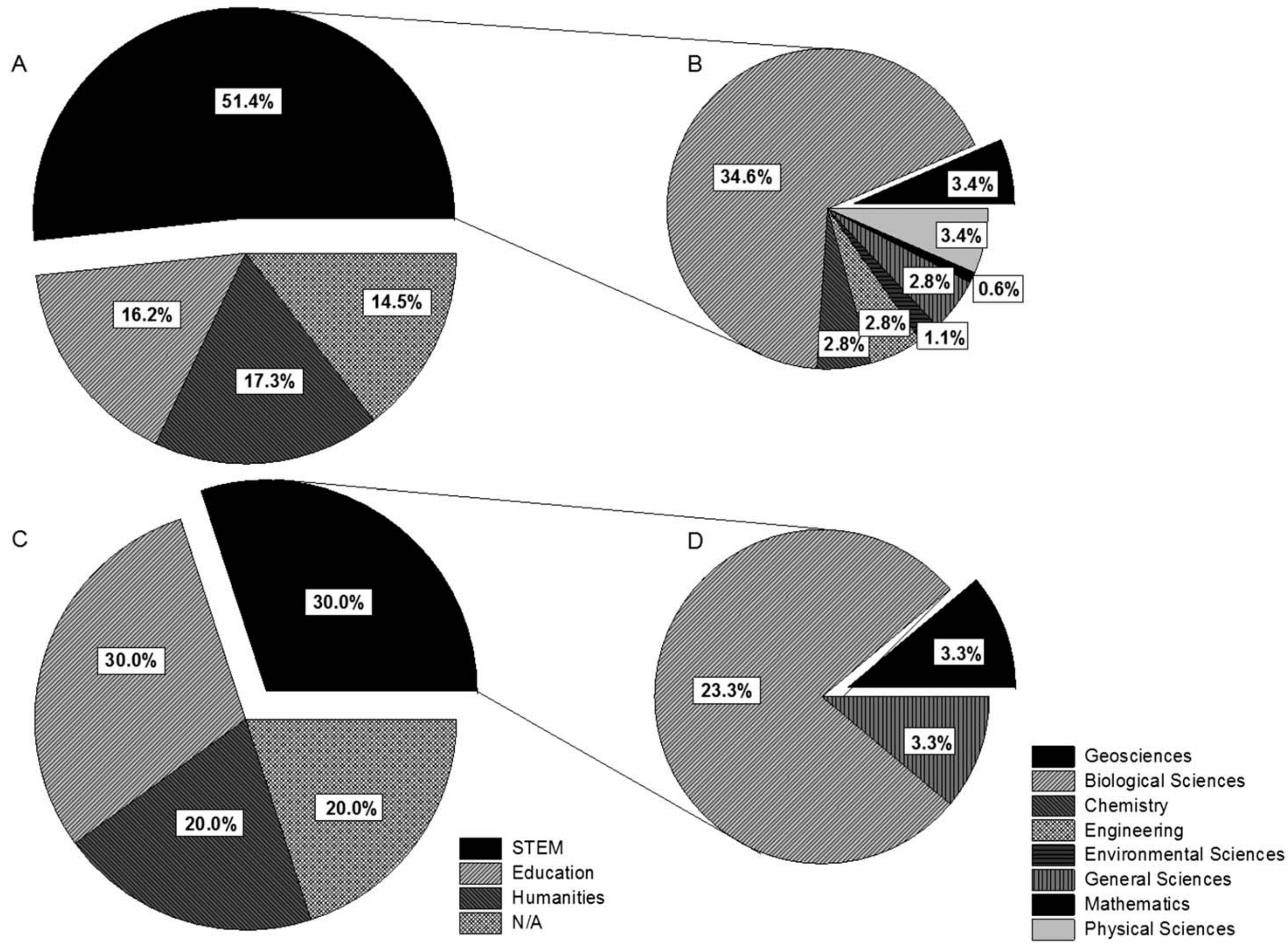

FIGURE 1: Discipline of undergraduate degrees in percentages by (A) RITES teachers ($N = 179$) and (C) teachers who attended the Rock Cycle Short Course (n = 30). (N/A indicates that the teacher did not respond to the survey question.) Breakdown of undergraduate degrees within the STEM fields by specific discipline in percentages for (B) all RITES teachers and (D) teachers enrolled in the Rock Cycle Short Course.

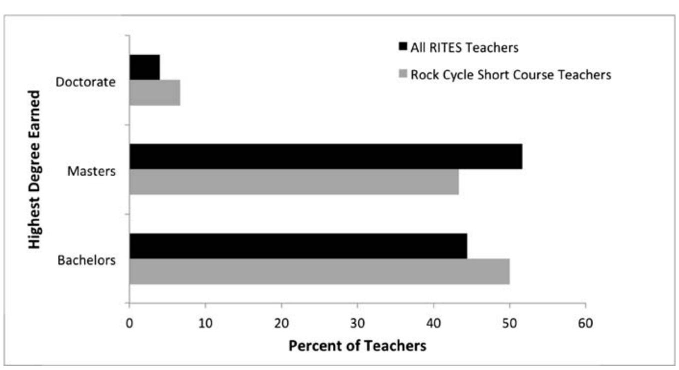

FIGURE 2: Comparison of the distributions of the highest degree earned by teachers involved in RITES ($N = 179$) and Rock Cycle Short Course ($N = 30$).

The use of this guided inquiry learning tool is very flexible, because it was designed in parts that are independent of each other, with options for blended online and offline implementation, but it can be completed either as a fully online tool or as a hard copy version. If the online version is preferred, the students require access to computers that have the ability to download the module from the Internet as well as run the teaching module through Java. A screenshot (Fig. 4) shows the layout of the module that students would see when first starting the first activity. If the hard copy version is used, teachers may choose to project the teaching module on a document camera or overhead projector for the students to view.

In both cases, the online version or the hard copy version, assessment of student learning through multiple-choice and short-answer questions is built into the teaching module. In the online version, student answers are recorded in real time, allowing immediate access to the instructor for quick identification of trends in students' understanding. Teachers with limited time can prioritize certain activities for their students, or even ask students to work at home for

TABLE II: Current Rhode Island grade span expectations that are addressed by the rock cycle teaching module for (a) middle schools and (b) high schools.

(a) Middle School		
Rhode Island Earth Science Grade Span Expectations		Related Activity
ESS1 (5–8) POC—3 *Explain how Earth events (abruptly and over time) can bring about changes in Earth's surface: landforms, ocean floor, rock features, or climate.*	*ESS1 (7–8)–3* **3a** Evaluating slow processes (e.g., weathering, erosion, mountain building, seafloor spreading) to determine how the earth has changed and will continue to change over time	Activity 2
ESS1 (5–8) INQ+ POC—5 *Using data about a rock's physical characteristics, make and support an inference about the rock's history and connection to rock cycle.*	*ESS1 (5–6)–5* **5a** Representing the processes of the rock cycle in words, diagrams, or models. **5b** Citing evidence and developing a logical argument to explain the formation of a rock, given its characteristics and location (e.g., classifying rock type using identification resources).	Activity 1
(b) High School		
ESS1 (9–11) SAE+ POC–3 *Explain how internal and external sources of heat (energy) fuel geologic processes (e.g., rock cycle, plate tectonics, seafloor spreading).*	*ESS1 (9–11)–3* **3a** Explaining how heat (produced by friction, radioactive decay, and pressure) affects the rock cycle. **3c** Investigating and using evidence to explain that conservation in the amount of earth materials occurs during the rock cycle.	Activity 2

some parts. In addition, the supplementary material includes pre- and post-tests that can be used to evaluate students' learning as a result of having used this module. Students can work in groups or as individuals; however, comparison and discussion of the students' findings are incorporated as part of the exercise.

Since students are actively involved in the teaching module and are asked to create a hypothesis that they must support with evidence, it is possible to spark a student's interest in science or inspire them to pursue a particular scientific concept in detail. The computer-facilitated nature of this module enables students to start building life skills in information technology, which can be important for students lacking electronic resources at home.

Design of the Teaching Module

The resource team crafted the *Sleuthing Through the Rock Cycle* teaching module based on design and content requirements set by the RITES Project, creating a pedagogically robust teaching tool. The teaching module was:

- constructed by a collaborative team of a higher education faculty and an experienced middle school teacher,
- built with an engaging narrative (high interest story),
- designed to address misconceptions about rock formation,
- framed to encourage students to think like geologists,
- paired with comprehensive teacher resources (including teacher report function),
- built flexibly on a dual-use platform (successful with paper copies or computers),
- complemented by positive comment and constructive criticism from area teachers,
- verified with evidence of learning gains and increased student understanding, and
- developed with direct relevance to Rhode Island grade span expectations (GSEs)/grade level expectations (GLEs), and also pertinent to Next Generation Science Standards (NGSS) (see Tables II and III).

The teaming of higher education faculty and in-service teachers was critical to both the design of modules and the instruction of the short courses. During the design of the module, the experienced teacher member of the design team used her knowledge of student reading level and attention span to make sure each page was readable by each student, keeping in mind special needs students. She also built in consistent, explicit mention of the overall focus of the module, so that students would not forget the direction to which they were working. The higher education faculty member of the design team used research on common student misconceptions (e.g., Kusnick, 2002; Kortz, 2009; Kortz and Murray, 2009) to help better focus the content of the module, and create the opportunity for students to confront directly their misconceptions in order to change them (e.g., Posner et al., 1982; Hewson and Hewson, 1988; Chan et al., 1997; Guzzetti, 2000), along with outstanding and relevant content knowledge.

Two large-scale and important misconceptions are addressed in the teaching module. Many students have a deep-seated conceptual barrier about the nature of bedrock (Kortz and Murray, 2009). When geologists view a hand sample, they understand that it broke off a much larger piece of bedrock, but students often see a hand sample as forming as that small piece. Having this conception barrier results in misconceptions such as a rock forms as a hand sample, granite is made from sediments coming together, and pebbles grow in streams (Happs, 1982; Kusnick, 2002; Kortz and Murray, 2009). Students also tend to view rocks as objects independent from the processes that form and change them (Kortz, 2009; Kortz and Murray, 2009). As a result, students are unable to (and do not know they can) "read rocks" to determine Earth's past. The teaching module guides students to rethink these large-scale misconceptions

TABLE III: Next Generation Science Standards elements that are addressed by the rock cycle teaching module for (a) middle schools and (b) high schools.

	Next Generation Science Standards Core Ideas	Related Activity
(a) Middle School		
ESS1. Earth's Place in the Universe	***History of Earth***	Activity 1
	ESS1. C. Earth's Place in the Universe—The History of Planet Earth	
	• The geologic time scale interpreted from rock strata provides a way to organize Earth's history. Major historical events include the formation of mountain chains and ocean basins, evolution and extinction of particular living organisms, volcanic eruptions, periods of massive glaciation, and the development of watersheds and rivers through glaciation and water erosion.	
	• Analyses of rock strata and the fossil record provide only relative dates, not an absolute scale.	
	Earth's Interior Systems	Activity 2
	ESS1. C. Earth's Place in the Universe—The History of Planet Earth	
	• Tectonic processes continually generate new ocean seafloor at ridges and destroy old seafloor at trenches.	
ESS2. Earth Systems	***Earth's Systems***	Activity 2
	ESS2. A. Earth Systems—Earth's Materials and Systems	
	• All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.	
	• The top part of the mantle, along with the crust, forms structures known as tectonic plates.	
	• Solid rocks can be formed by the cooling of molten rock, the accumulation and consolidation of sediments, or the alteration of older rocks by heat, pressure, and fluids.	
(b) High School		
ESS1. Earth's Place in the Universe	***History of Earth***	Activity 1 & 2
	ESS1. C. Earth's Place in the Universe—The History of Planet Earth	
	• Radioactive-decay lifetimes and isotopic content in rocks provide a way of dating rock formations and thereby fixing the scale of geologic time.	
	• Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old.	
	• Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.	
ESS2. Earth Systems	***Earth's Systems***	Activity 2
	ESS2. A. Earth Systems—Earth's Materials and Systems	
	• Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle, and crust.	
	• Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior.	
	• Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts.	
ESS2. Earth Systems	***Earth's Systems***	Activity 2
	ESS2. B. Earth Systems—Plate Tectonics and Large-Scale System Interactions	
	• The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection.	
	• Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding their geologic history.	
	• Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust.	

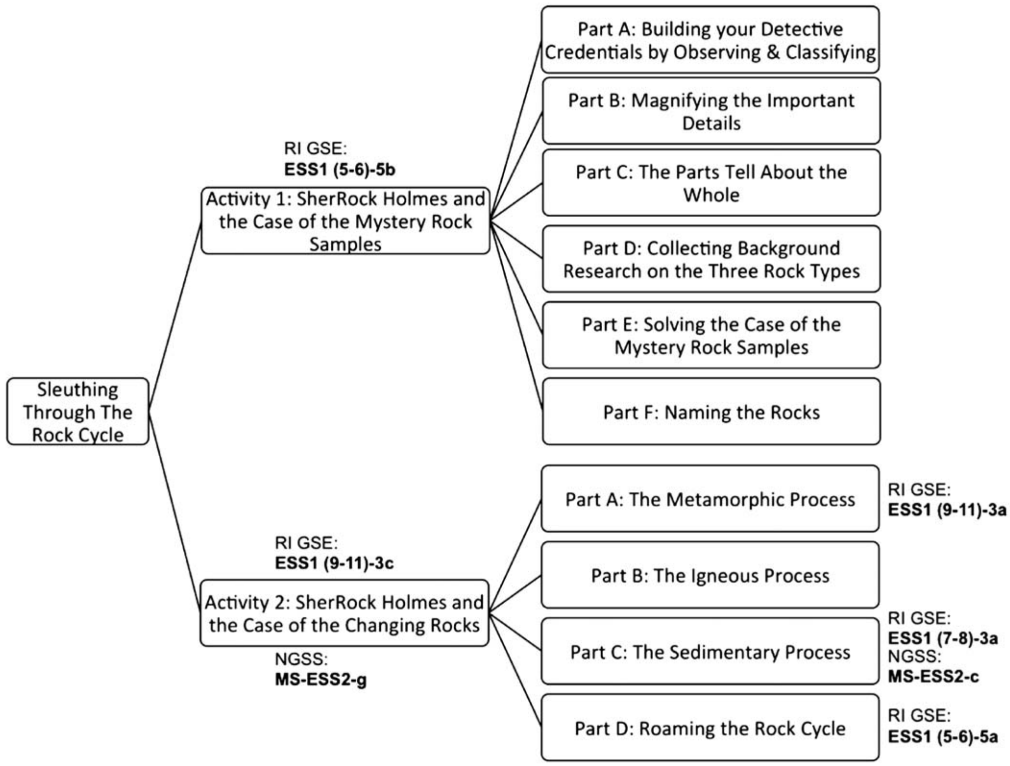

FIGURE 3: Flowchart of the *Sleuthing Through the Rock Cycle* teaching module including the individual sections that makes up both activities.

TABLE IV: Descriptions and summaries of the individual activities that *Sleuthing Through the Rock Cycle* has embedded as part of the teaching module.

Part	Summary
Activity 1—Students make observations and work with hand samples to learn how to categorize rocks into the three classifications of igneous, metamorphic, and sedimentary.	
A	Students record observations and make sketches of rocks; they classify rocks into groups of their own choosing.
B	Students figure out that shape and size of rocks are not defining characteristics; they are directed to focus their attention on the component parts (minerals or sediments) and their texture.
C	Students make new observations (using microscopes, if available) of the mystery rock samples, and divide the rocks into the three groups geologists use, even though the students have not yet learned the terms igneous, metamorphic, and sedimentary.
D	Students learn the basic concepts behind igneous, metamorphic, and sedimentary processes and what characteristics to look for in rock samples to be able to classify samples into these groups.
E	Students identify the rock types of the six mystery rock samples, determine the history of the rock, and explore the outcrops the rocks came from.
F	Using a flowchart, students discover the names of the six mystery rocks based on all the information they learned during the previous parts of the activity.
Activity 2—Students use interactive Web sites and fill out diagrams highlighting which processes drive the individual sections of the rock cycle.	
A	Students explore in-depth concepts about metamorphic processes.
B	Students explore in-depth concepts about igneous processes.
C	Students explore in-depth concepts about sedimentary processes.
D	Students investigate an interactive rock cycle simulation and develop an understanding of how the three processes are connected within the rock cycle.

TABLE V: Materials list of rock and mineral samples required for Activity 1 of the *Sleuthing Through the Rock Cycle* teaching module, including order numbers from wards.

Mystery Rock No.	Rock/Mineral Type	Wards Order Number	Investigation Part
1[1]	Basalt	47v1042	A
2[1]	Schist	47v7222	A
3[1]	Gneiss	47v3512	A
4[1]	Limestone with Fossils	47v4642	A
5[1]	Conglomerate	47v2222	A
6[1]	Granite	47v3637	A
M1[2]	Pink Granite	47v3627	A, B
S1[3]	Conglomerate	47v2222	A, B
Mineral 1	Quartz	46v6547	B
Mineral 2	Biotite	46v1192	B
Mineral 3	Microcline	46v5122	B
S2[3]	Banded Sandstone	47v0442	E
M2[2]	Diorite	47v2692	E

[1]Mystery rock samples (Activity 1, Part A).
[2]Rock samples the Mysterious Lady brought to SherRock (Activity 1, Parts A, B, and E).
[3]Rocks that belong to SherRock (Activity 1, Parts A, B, and E).

they might have, and it leads them to think about rocks more like a geologist does.

Short Course

Teacher training during the Rock Cycle Short Course covered background information on concepts in the geosciences and specific processes that are involved in the rock cycle. The training was done over 2.5 d and lasted a total of 15 h. Roughly 8 h were allotted to reinforce background knowledge in the Earth Sciences with interactive lectures covering geoscience concepts and identifying and interpreting the geologic history of rock. A field trip was included and carried out using a jigsaw method (Tewksbury, 1995), where prior to the trip, groups of participants focused on different topics related to rock identification and formation, and during the trip, the participants formed new teams, taught each other, and worked together to interpret the sequence of events to form an outcrop. Approximately, 5 h of the short course were allotted for teacher participants to explore the teaching module itself and discuss how to use it in the classroom.

Overall, during the interactive lecture portion of the short course, many teaching techniques were used to help teachers understand the underlying geologic concepts: Gallery walk; ConcepTests (conceptual multiple-choice questions using clickers); Lecture Tutorials (worksheets specifically targeting misconceptions); think-pair-share questions; skits; group discussion; demonstrations of classroom activities; and moving questions, where participants answered spatial questions by moving to particular locations around the classroom (Science Education Research Center Carlton College, 2012). These techniques were used because it has been shown that active participation is a more effective teaching strategy than lecture alone (Pratton and Hales, 1986). Teachers were encouraged to use similar methods in the classroom when they introduced material related to the rock cycle, and they were given time during the short course to reflect on how they might do so.

As part of the Rock Cycle Short Course, teachers were provided with a binder with the material presented during the workshop and extensive supplemental resource materials. These resources included scientific background information, reliable Web sites for more information, Grad Span Expectations (GSEs) addressed, learning goals, prior knowledge necessary, materials needed, answer keys with example student work, and additional activities teachers can do to supplement the teaching module. These resource materials are also available online in the Teachers Resources section of the module, so teachers who did not participate in the short course can still receive some of the information.

VALIDITY, RELIABILITY, AND TRUSTWORTHINESS

Given limited time available for fundamental Earth Science learning in K–12 classrooms presently, we prioritize clear teaching of the rock cycle concept through this guided inquiry tool, focusing on correcting common misconceptions in geosciences.

Validity and Reliability: How Is the Teaching Module a Valid and Reliable, Guided Inquiry Teaching Tool?

The material and academic approach of this teaching module are grounded on research on teaching and learning and directly confront student misconceptions as identified by the experts in middle school pedagogy who created it. This module was created to purposefully implement best practices of student learning. Kirschner et al. (2006) showed that guided inquiry is a stronger pedagogical approach compared to other methods of teaching, which is why this module was built to follow this model. Furthermore, the fact that the module is written as a synergy of connected parts directly addressing misconceptions allows the students to actively construct their own knowledge to learn deeply (National Research Council, Committee on Development of

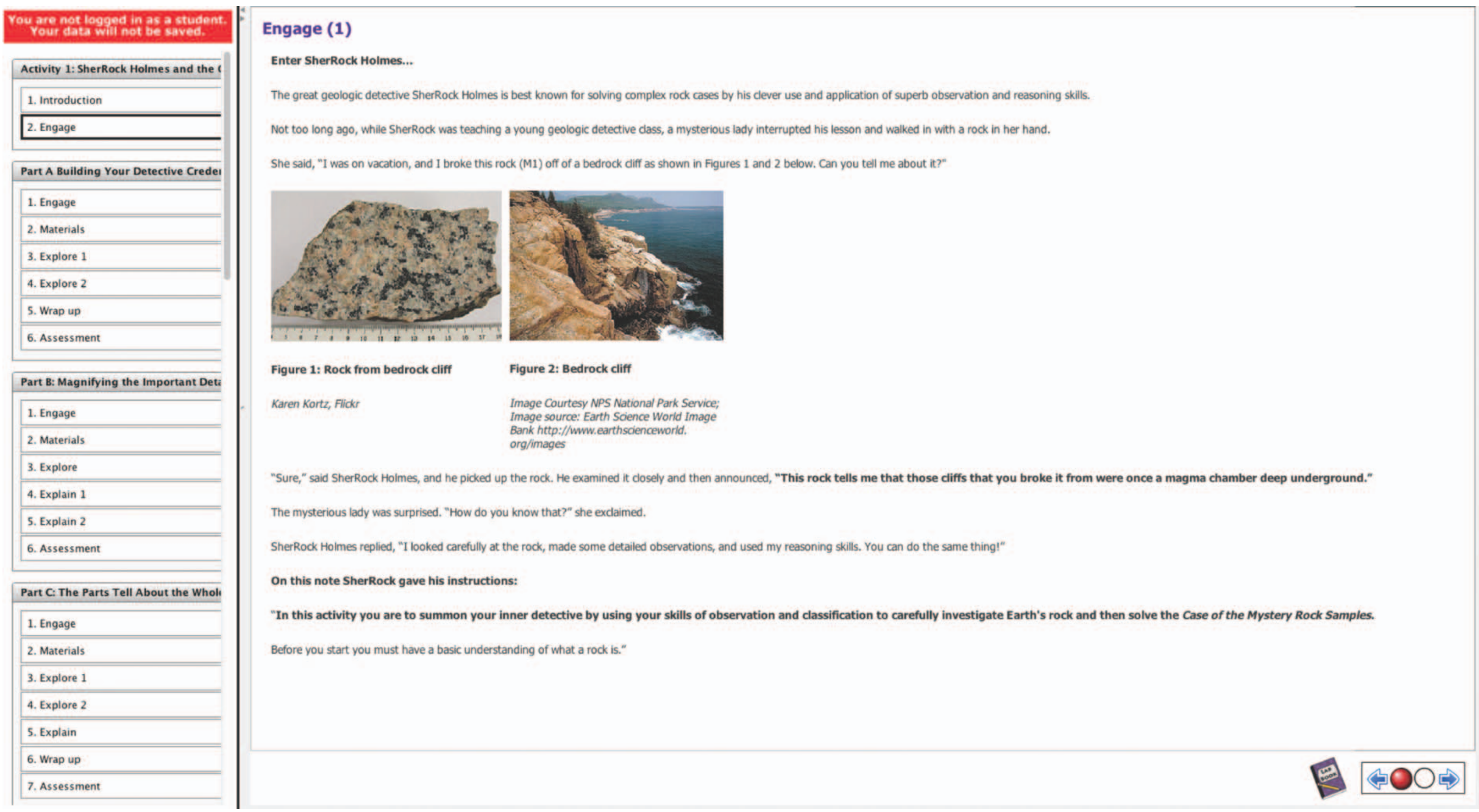

FIGURE 4: Screenshot of the online *Sleuthing Through the Rock Cycle* module, displaying how the activity is framed and presented.

an Addendum to the National Science Education Standards on Scientific Inquiry, 2000).

The module was written by expert teachers using research-based pedagogic approaches keeping students in mind and resulting in materials that are clear to all students. Students can easily maneuver their way through the module and can logically develop their understanding of the rock cycle as a process. Embedded animations of Earth processes with a combination of media (e.g. text, visuals, and rock samples) allow students to more readily understand these difficult processes because students learn more effectively this way (Mayer, 2003). The virtual resources available in the module support student learning and understanding when coupled with concrete, hands-on mini-lessons on the processes involved in the rock cycle.

Focus groups for teachers to provide feedback after implementing the *Sleuthing Through the Rock Cycle* module were set up, and teachers provided consistent and generally positive feedback for the quality and utility of this module, detailing situation-specific concerns about the way in which the guided inquiry module could be actualized in classes. Analysis of the focus group transcriptions will be the subject of a separate article and is beyond the scope of this paper. However, representative comments from teachers supporting the validity and reliability of the module include:

''[The module allowed] …that the kids could move at their own pace, and so they were able to ask questions amongst themselves; then because it allowed the kid to go to a particular Web site. 'What is this question', and then they would go there—then if they still didn't get it, they would go ask other kids, then come and ask me, then go from there. So it did allow for a lot of in-depth study as much as their ability would allow them to.''

''I think I don't have [a high] confidence level in geosciences, but because it is so thoroughly outlined [in the module and associated materials], what knowledge I have, I keep learning more of course, I was able to take kids further. [My students]…were able to take themselves to a point based on how well it was organized. And that made me more confident….So I felt I was an effective facilitator given my background knowledge in this area, and that is important. I did feel confident because of your program.''

In addition, the module was classroom-tested several times. Feedback provided from testing the module in the classroom resulted in a revised, clearer presentation. Finally, during the short course, participant in-service teachers provided input for possible revisions of questions and material, which was used to make the module more clear and concise.

Effectiveness: What Evidence Demonstrates that This Teaching Module Is Effective?

To determine the effectiveness of the Rock Cycle teaching module in Rhode Island classrooms, short pre- and postassessments were given to 54 eighth-grade and 35 sixth-grade students from two separate middle schools to assess learning gains in a preliminary study. Based on known misconceptions, this assessment combined open-ended and multiple-choice questions addressing topics covered in the module. The open-ended questions were scored by two of the authors as correct or incorrect using a simple rubric.

Significant learning gains in student comprehension were found in all cases. Student scores increased from 36% correct on pretests to 77% correct on post-tests. Of the 89 students assessed, 74 (83%) had positive learning gains, and only 4 (5%) showed negative learning gains (Fig. 5). These results indicate that the Rock Cycle teaching module is effective in reaching the majority of students and increasing their knowledge and decreasing their misconceptions.

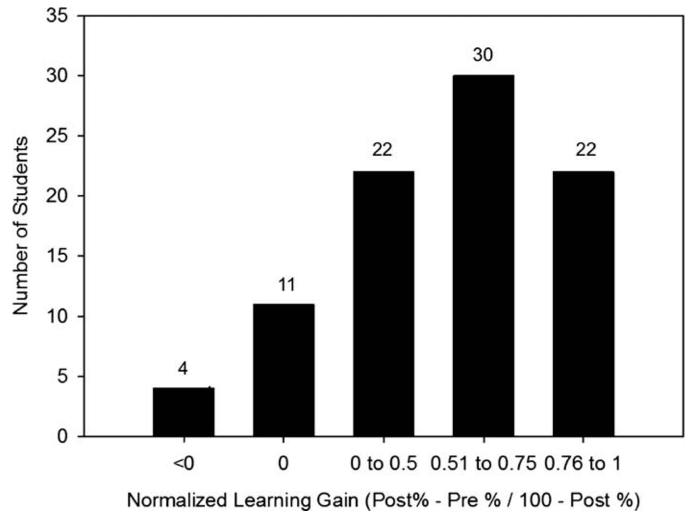

FIGURE 5: Normalized learning gains of middle school students ($n = 89$) that explored the Rock Cycle module. Pre- and postassessment data were analyzed using normalized learning gain, where gain is measured by the following equation: (Post-test % − Pre-test %)/(100 − Post-test %). Note that a value of zero indicates that pre- and post-test scores were the same. The number of students in each bin is labeled above each column.

Classroom observations and reflection periods with RITES teachers who have taught the Rock Cycle module demonstrate that student enthusiasm for learning about rocks has increased and that students get excited about the information that can be learned by studying rocks. Students enjoy working on computers and are enthusiastic about the narrative and engaging scenarios that are presented in each section of the module because each gives a succinct and clear focus of the goal for the day(s). As one of the authors (K. Saul) introduced the process of the rock cycle as part of the curriculum in her middle school classroom, a student expressed boredom towards studying rocks ''because they cannot talk.'' She explained that rocks do in fact give clues about Earth's history, not through spoken words, but rather the understanding of their composition and origin, similar to a mystery story, and that is the strategy presented in the module. This sparked interest in studying and learning about the stories of rocks in the entire class.

Constraints: What Are Constraints on the Effectiveness of This Teaching Module?

Since the module has been designed for use in both online and offline modes, it is possible to conduct the module in any classroom, with the caveat that some questions within Activity 2, *Cracking the Case of the Changing Rocks*, were developed for use on computers with access to the Internet, making it hard to adapt to hard-copy materials. If students or groups of students do not have access to computers, teachers may choose to project the linked animations. If no Internet or computers are available, students are not able to view the links to animations that visually describe different processes driving and influencing the rock cycle, such as erosion and weathering. During one of the focus groups on the module for teachers, a common constraint was:

"I think we all are hampered by the fact that we don't have enough technology. I mean we live in 21st century world. But our classrooms look like 19th century. We have four computers in our room, and sometimes all four don't work, and a computer lab—there's not even enough chairs, and some computers are busted. And only one cart for an entire school. We have almost 600 kids and 1 cart; the competition for computer time is fierce, so that's the only thing concerned [us]..."

Since it has been shown that visual aids are beneficial in student learning across media (Mayer, 2003), this lack of access to supporting visual aids may present a limitation or constraint on effectiveness of this part of the module if run without a computer.

RESULTS AND IMPLICATIONS

The *Sleuthing Through the Rock Cycle* teaching module offers an accessible, teacher-friendly, student-friendly learning opportunity for middle and high school student and is meant to be used by anyone who is learning about or teaching the rock cycle. It may be especially useful for teachers who have not had training in geosciences or Earth Sciences because of the extensive teacher support provided.

A pragmatic and important aspect of this module is that it provides teachers who do not have a background in Earth Science a way to teach the rock cycle in an interactive and hands-on manner. We have received direct comments from teachers who are using the Rock Cycle module and building their geoscience content knowledge through targeted professional development opportunities; they say that they are now excited and more comfortable about teaching the rock cycle to their students (Table I). Instead of traditional rock identification, which may have been puzzling to teachers and students alike, this module is now an engaging, inquiry-based, hands-on unit in the curriculum. In the case of the *Sleuthing Through the Rock Cycle* module, teachers receive background information on the rock cycle, such as Web site links, PowerPoint presentations, and images from local rock outcrops in the field. This additional information makes it easier for teachers to adapt the module to students' individual needs.

Feedback teachers gave during focus groups has also indicated that there is an interest in more Earth Sciences training in general because there are often content knowledge gaps for teachers. As shown in Figure 1, about half of the RITES teachers/participants hold degrees in STEM fields, and of those STEM-trained teachers, only 7% are trained in Earth Sciences (Figs. 1A and 1B); this trend is also apparent when only teachers enrolled in the Rock Cycle Short Course are considered (Figs. 1C and 1D). The Rock Cycle Short Course is designed to overcome these limitations by teaching geoscience concepts to the teacher participants.

We anticipate that using guided inquiry exercises in the classroom, such as this module, will enable students to learn more about the rock cycle due to the versatility of this teaching tool. In addition, this module will prepare the students better for state-based standardized tests, because science problems in these standardized tests are often inquiry based and require students to analyze experimental data. Preparation for such standardized tests using this module may lead to higher test scores in the future and warrants future investigations.

We strongly recommend use of the Rock Cycle module in diverse classrooms, given its measured success in the classroom, as presented in Figure 5 and discussed previously herein. This teaching module serves as a quality curricular tool, buttressed by the (1) collaborative design process (higher education faculty working side by side with experienced teachers; revision following teacher comments and learning gain data), (2) useful teacher's guide to complement the module, (3) attention to content and pedagogy, (4) flexibility of use via offline or online platforms, and (5) direct relevance to existing state and new national science standards. Overall, this guided inquiry module is a learning tool that embeds pedagogic and cognitive qualities that can have a positive impact on student confidence, while it promotes science literacy and encourages students to think critically about their responses.

Overall, the RITES model of a guided inquiry module, whether used online or offline, is a useful tool for teachers and students. It has been designed to enhance student's understanding of scientific concepts through the use a mix of approaches centered on engaging students in critical thinking.

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REFERENCES

Chan, C., Burtis, J., and Bereiter, C. 1997. Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction*, 15:1–40.

Dahl, J., Anderson, S.W., and Libarkin, J.C. 2005. Digging into Earth Science: Alternative conceptions held by K–12 teachers. *Journal of Science Education*, 12:65–68.

Eidietis, L., and Jewkes, A.M. 2011. Making curriculum decisions in K–8 science: The relationship between teacher dispositions and curriculum content. *Journal of Geoscience Education*, 59(4):242.

Ford, D.J. 2005. The challenges of observing geologically: Third graders' descriptions of rock and mineral properties. *Science Education*, 89:276–295.

Furtak, E.M. 2006. The problem with answers: An exploration of guided scientific inquiry teaching. *Science Education*, 90(3):453–467.

Guzzetti, B.J. 2000. Learning counter-intuitive science concepts: What have we learned from over a decade of research? *Reading & Writing Quarterly*, 16(2):89–98.

Happs, J.C. 1982. Rocks and minerals. Science Education Research Unit Working Paper No. 204. Waikato, New Zealand: University of Waikato, p. 31.

Hewson, P.W., and Hewson, M.G.A.B. 1988. An appropriate conception of teaching science: A view from studies of science learning. *Science Education*, 72:597–614.

Kirschner, P.A., Sweller, J., and Clark, R.E. 2006. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41:75–86.

Kortz, K.M. 2009. Alternative conceptions of introductory geoscience students and a method to decrease them [Ph.D. dissertation]. Kingston: University of Rhode Island.

Kortz, K.M., and Murray, D.P. 2009. Barriers to college students learning how rocks form. *Journal of Geoscience Education*, 57(4):300–315.

Kusnick, J. 2002. Growing pebbles and conceptual prisms—Understanding the source of student misconceptions about rock formation. *Journal of Geoscience Education*, 50:31–39.

Mayer, R.E. 2003. The promise of multimedia learning: Using the same instructional design methods across different media. *Learning and Instruction*, 13:125–139.

Michael, J. 2006. Where's the evidence that active learning works? *AJP: Advances in Physiology Education*, 30(4):159–167.

National Research Council, Committee on Development of an Addendum to the National Science Education Standards on Scientific Inquiry. 2000. Inquiry and the National Science Education Standards: A guide for teaching and learning. Washington, D.C.: National Academy Press. p. 202.

Orion, N., and Kali, Y. 2005. The effect of an Earth-Science learning program on students' scientific thinking skills. *Journal of Geoscience Education*, 53(4):377–393.

Posner, G.J., Strike, K.A., Hewson, P.W., and Gertzog, W.A. 1982. Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66:211–227.

Pratton, J., and Hales, L.W. 1986. The effects of active participation on student learning. *The Journal of Educational Research*, 79(4):210–215.

Schwab, J.J. 1960. Inquiry, the science teacher, and the educator. *The School Review*, 68(2):176–195.

Science Education Research Center, Carlton College. 2012. Interactive lectures. Available at: http://serc.carleton.edu/introgeo/interactive/index.html (accessed 8 February 2013).

Stofflett, R.T. 1994. Conceptual change in elementary school teacher candidate knowledge of rock-cycle processes. *Journal of Geological Education*, 42(5):494–500.

Tewksbury, B.J. 1995. Specific strategies for using the jigsaw technique for working in groups in non-lecture-based courses. *Journal of Geological Education*, 43:322–326.

Vitale, M.R., and Romance, N.R. 1992. Using videodisk instruction in an elementary science methods course: Remediating science knowledge deficiencies and facilitating science teaching attitudes. *Journal of Research in Science Teaching*, 29:915–928.