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Creation and Assessment of an Active e-Learning Introductory Geology Course

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Abstract The recent emphasis in higher education on both student engagement and online learning encouraged the authors to develop an active e-learning environment for an introductory geohazards course, which enrolls 70+ undergraduate students per semester. Instructors focused on replicating the achievements and addressing the challenges within an already established face-to-face student-centered class (Brudzinski and Sikorski 2010; Sit 2013). Through the use of a learning management system (LMS) and other available technologies, a wide range of course components were developed including online homework assignments with automatic grading and tailored feedback, video tutorials of software programs like Google Earth and Microsoft Excel, and more realistic scientific investigations using authentic and freely available data downloaded from the internet. The different course components designed to engage students and improve overall student learning and development were evaluated using student surveys and instructor reflection. Each component can be used independently and intertwined into a face-to-face course. Results suggest that significant opportunities are available in an online environment including the potential for improved student performance and new datasets for educational research. Specifically, results from pre and post-semester Geoscience Concept Inventory (GCI) testing in an active e-learning course show enhanced student learning gains compared to face-to-face lecture-based and student-centered courses.

Keywords Online learning · Geoscience · Undergraduate STEM education · Course design · Google Earth · Excel

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Introduction

Despite the growing body of research that suggests the brain acquires more knowledge with more engagement (e.g., Zull 2002; Wieman 2007; Freeman et al. 2014), implementing active teaching styles can be challenging in large enrollment courses with fixed classroom setups and lack of resources. The standard hour-long lecture provides limited time to practice the necessary skills for critical thinking and problem solving, yet acquiring these abilities is why many universities require science courses to graduate. While more and more faculty recognize the benefits for student discussion groups, peer instruction, and hands-on experiences in the lab and in the field (e.g., Lasry et al. 2008; Elkins and Elkins 2007; Brownell et al. 2015), it has been difficult to come up with a model for this type of student engagement in introductory science courses.

In order to promote active student learning, educational institutions have seen a growing interest in using an inverted or flipped classroom to provide students more opportunities to apply their knowledge, guided by interactions with their peers and faculty (Lage et al. 2000; Lage and Platt 2000; Gannod et al. 2008; Berrett 2012). The use of more student engaged learning and inquiry-based techniques have begun to show significant performance gains (Koh et al. 2008; Hmelo-Silver et al. 2007; Geier et al. 2008). It is believed these new approaches will help students construct their own knowledge in more meaningful ways (Lee 2004; Taylor et al. 2010).

Along with more focus on student engagement, higher education has seen a rise in the number of hybrid and online course offerings (Allen and Seaman 2013). Hybrid learning combines face-to-face and online delivery of information, while typical online courses rarely integrate meeting face-to-face (McCray 2000; Garrison and Kanuka 2004; Bates and Poole 2003). The primary institutional motivation for online learning is to increase access to learning experiences for students who cannot, or choose not, to attend traditional face-to-face offerings, providing more opportunities to complete degrees or continue professional education (Allen and Seaman 2007). Meta-analyses have shown that students in online learning conditions performed at least as well as or modestly better than those receiving face-to-face instruction, with slightly better outcomes for hybrid courses (e.g., Wisneski et al. 2017; Means et al. 2010). It has been suggested that computer-based instruction can enhance student learning by increasing cognitive engagement and positively affecting student attitudes toward the subject and computers (e.g., Bernard et al. 2009; Kulik and Fletcher 2015). Moreover, students have been responding to online course offerings in a positive way; with nearly a third of all students enrolled in postsecondary education taking an online course (Allen and Seaman 2013).

The simultaneous efforts in higher education to improve student engagement and advance online learning led to the development of a student-centered, online version of an introductory geohazards class over the course of several semesters (Table 1). Revisions to all of the Department of Geology's introductory courses began as part of Miami University's top 25 initiative to increase inquiry-based approaches in its 25 largest enrollment courses (Hodge et al. 2011), with support for that development in a Community of Practice on Engaged Learning (COPEL) (Taylor et al. 2010). Redesigned face-to-face introductory courses were first implemented in Fall 2009 and then grew through our involvement in COPEL, which led to the realization that student development plays an important role in student adoption of active learning courses (Brudzinski and Sikorski 2010). The perception that increasing the integration of technology would create opportunities for a more authentic active learning experience led instructors to develop a fully online course, using hybrid style learning during the transition from the face-to-face version. The introductory course topically focused on geohazards was selected for the online development, but our department has sought to ensure all introductory courses have at least 70% of their content in common. So we compare the results from our active e-learning course with results from all other introductory courses in the Geology Department.

In the active e-learning environment, instructors relied heavily on a learning management system (LMS) in designing an online course structure to engage students in various outcomes-based assessments and activities (Govindasamy 2001; Powell 2003). The application of an inverted classroom model required students to do more reading and basic comprehension on their own, thus providing more time for students to think critically and solve problems. Current survey results from the Summit on the Future of Geoscience Education show that these skills and competencies are overwhelmingly important to geoscience educators (Mosher 2014). This study evaluates an option to incorporate the practice of critical thinking and problem-solving skills through the design of various online course components, including authentic scientific investigations using interactive quizzes, peer-evaluated writing assignments, and open discussion forums. At this time, Geoscience departments appear to be underutilizing blended, online, and flipped classrooms and more research needs to be done to focus on the effectiveness of each technique (Mosher et al. 2014). Here, we suggest that an active e-learning approach can provide students with more frequent opportunities to practice scientific investigations leading to overall improvements in student learning and potential gains in student development.

University and Course Setting Miami University is a public institution located in a small town in southwest Ohio with an undergraduate body of nearly 18,000 students (~15,000 undergraduate). It is a primarily residential campus with 97% full time students. It has set a goal to increase the online and hybrid credit hours to 10% of the total credit hours by 2020 to help students achieve timely and cost-effective degree completion. Typical course demographics include a majority of first and second year students of mixed genders. No specific race data was collected for this study, but overall, the undergraduate student body at Miami University is ~75% Caucasian with the remaining 25% consisting of underrepresented minorities and international students. At the beginning of the hybrid course, 70+ students were asked to bring their own laptops to class, and instructors provided laptops to the few students who were unable to do so. In continuing versions of the fully online course, enrollments range from 60 to 90 students. At Miami University, the lecture and lab portion of our introductory geoscience course are offered separately.

The progression to creating a fully online course (Table 1) took several years and was facilitated by teams of instructors. Initially in Fall 2009, a redesigned face-to-face course was developed by instructors A (senior lecturer) and B (tenured professor) and was later adopted by other departmental faculty members. Then in Fall 2012, the development of the active e-learning course was a collaborative effort between instructors B and C (senior doctoral student). Whereas, implementing one or two course changes could be more easily achieved by a single instructor, a collaborative team was needed to completely redesign the course with new assignments, written feedback, and video lectures. An estimated ~50 h per week during the 16 week semester were required between

Table 1 A timeline of our progression from a traditional face-to-face lecture to a fully online course

	Fall 2009-Spring 2012	Fall 2012	Spring 2013	Fall 2013
Instructors	A, B, others	B + C	B + C	B
Course format	Redesigned face-to-face	Partially online: transitional-hybrid	Partially online: transitional-hybrid	Fully online
Course style	Active learning	Active e-Learning	Active e-Learning	Active e-Learning
Student evaluations and assessment	W16[a] Uni Eval[b] GCI[c]	W8 survey[d] W16 Uni Eval SGID[e]	W5 survey W8 survey W16 Uni Eval SGID GCI	W5 survey W8 survey W16 Uni Eval GCI

[a] Refers to the week the evaluation was administered out of a 16-week semester

[b] University course evaluations

[c] Geoscience Concept Inventory

[d] Survey refers to informal anonymous student surveys administered through the LMS

[e] Small group instructional diagnosis

instructors B and C to complete the redesign to a transitional-hybrid course and then approximately, a third of that time commitment to convert to a fully online course. While materials available on the Science Education Resource Center website (serc.carleton.edu) were helpful as inspiration for target datasets and activities (Ledley et al. 2008), the most time consuming element of course development was the construction of assignment questions and informative feedback. Every semester instructors additionally spend time updating assignments, incorporating new content, and recording new videos. University support of the project was provided through nominal monetary summer funds to faculty for course development and through the establishment of a faculty learning community focused on online learning.

Course Design and Outcomes Through Miami University's op 25 project, which started in the summer of 2009, faculty in the Geology department created a set of student learning outcomes (SLOs) (Richlin 2006) for the redesigned face-to-face course framed around scientific analysis and a more authentic research-like experience (Brudzinski and Sikorski 2010). Ultimately, the goal was for students to develop technical and analytical skills that focused on investigating questions and understanding processes. The scientific method provides a standard procedure for students to acquire new knowledge by making careful observations, testing and modifying their original hypotheses, and sharing information in a clear manner. Emphasizing this method in science education can provide students with powerful reasoning and critical thinking skills, applicable to all types of environments and subjects of study (Wieman 2007). The specific learning outcomes identified were that students would be able to:

(a) select and/or generate possible answers (hypotheses) to key questions,
(b) collect and analyze data,
(c) place the results of data analysis in context of other experiments,
(d) evaluate hypotheses based on results,
(e) disseminate conclusions to peers, and
(f) convey the scientific information to the general public.

These skills are core components to how any geoscientist thinks. At the completion of an introductory course, students were expected to be able to understand and apply this approach in their everyday lives.

In addition to new SLOs, participation in Miami University's COPEL helped instructors to recognize that any course redesign must include not only an overhaul of how content is presented, but must also address student development outcomes (SDOs) (Brudzinski and Sikorski 2010). The following set of SDOs was developed to integrate into the existing outcomes framed around the scientific method and focus on student self-assessment and self-reflection of successful learning:

(a) Students can evaluate their abilities and have confidence to use what they learn.

(b) Students take responsibility for their learning and realize they need to continue learning to be successful in life.
(c) Students value working with others to answer questions.
(d) Students recognize the different contexts where science can be applied and can identify effective approaches in each setting.

These outcomes focus on skills that allow students to excel beyond the classroom, becoming lifelong learners and engaged citizens.

While SLOs and SDOs were originally developed for the redesigned face-to-face course, they also provided the foundation for our active e-learning course. A guidebook to the course components that were implemented as a part of our new learning environment is described in "Course Components in the Active E-Learning Environment." Additionally, "Opportunities in Active e-Learning" presents a limited dataset that suggests promising opportunities in student learning and development gains achieved in an active e-learning environment.

Evaluation of Course Components and Student Outcomes To assess the impact on students of the course and its individual components, instructors used a mixture of qualitative and quantitative approaches for evaluation, including some informal student feedback and instructor reflection. Anonymous informal surveys, university course evaluations, and small group instructional diagnosis (SGID) were used to evaluate student perspectives (Table 1). During an SGID, a trained, external facilitator uses a 50 min class period to guide small group discussion in order to articulate suggestions for improving teaching and strengthening the course (Diamond 2002). The SGIDs were held in class during a normal instruction period, yielding student participation of 60–70%. Other informal surveys and end-of-course evaluations were administered online had lower participation rates (typically 20–30%, except for the Week 5 survey which had a response rate of 52%). While student survey instruments had low participation, overall trends from multiple semesters (Fig. S1 and S2) were consistent suggesting that results from an individual semester were representative of typical viewpoints. Informal surveys were based on a 5-point Likert scale from Poor (0) to Excellent (4). By combining views from informal student surveys, end-of-course evaluations, and SGIDs, we aim to assess the class as a whole. No extra credit was offered for either the SGID or the informal student surveys.

Student learning was also evaluated through pre and post-semester student performance on a Geoscience Concept Inventory (GCI) (Libarkin and Anderson 2005), which has been administered as a timed, extra credit, online 25-question quiz in the Department of Geology and Environmental Earth Science since 2007. Students could earn extra credit up to 0.5% of a students' overall grade based on how well they performed on the GCI, but students typically earned 0.3% if they completed both the pre and post-semester GCI. Participation rates for taking both the pre and post-semester GCI was over 60% in Spring 2013 and over 80% in Fall 2013. After the conclusion of each course, instructors reflected on overall achievements related to the targeted student outcomes and opportunities for improvement within an active e-learning environment. Whereas the SGIDs, GCIs, and reflections were used as summative measures of progress in the study, the informal surveys were primarily designed to be formative tools to help motivate and guide the design of instructional approaches. A more detailed description of each evaluation tool and resulting data is available in the electronic supplementary material.

During the Fall 2012 and Spring 2013 semesters, instructors taught a transitional-hybrid course, where time working on class materials was divided equally between online and face-to-face settings. However, it should be noted that one of the primary goals for instructors was creating the necessary resources for a fully online course (Table 1). While a traditional hybrid format maximizes face-to-face meeting times with activities like in-class discussions and demonstrations, and is generally thought to be more successful than fully online courses (Young 2002), the confusion over the course style, especially in the Spring 2013 semester, may have caused the lower evaluation scores and participation seen in Tables S1–2, 4.

Course Components in the Active e-Learning Environment

Within the framework of the defined SLOs and SDOs, a series of course components were developed that could be implemented in the e-learning environment. Every course activity used a combination of technologies, including LMS automated graded assignments, YouTube, Google Earth, and Microsoft Excel. The course was developed using the open-source Moodle LMS because it provided a wide range of options (Dougiamas and Taylor 2003), including tailored answer feedback and peer review of writing assignments. Although the fully online course was run asynchronously with assignments due once a week, a course schedule was created based on meeting three times a week for 1 h increments. An example of a week's outline can be seen in Table 2. A full course schedule is available in the electronic supplemental material.

Pre-Class Reading Quizzes and Comprehension Assignments: Frequent Accountability

Innovation and Rationale In the active e-learning class, regular online assignments were introduced to hold students accountable for basic comprehension of textbook and online readings. In previous semesters of face-to-face courses, when the amount of lectures was reduced and more in-class activities were incorporated, faculty informally found students were

Table 2 Sample schedule for a week including topics, assignments, and technology used

	Topic	Pre-class "homework" assignment	"In-class" assignment	Technology
Monday	Climate introduction	Reading and 5–10 question quiz	Comprehension assignment w/ video lecture	LMS, YouTube
Wednesday	Climate change principles	Reading and 5–10 question quiz	Comprehension assignment w/ video lecture	LMS, YouTube
Friday	Climate change examples	Reading and 5–10 question quiz	Application assignment w/ video tutorial	LMS, YouTube, Google Earth, Microsoft Excel
Weekly	Discussion board: small groups of ~10 students are assigned prompts and participation points for the week			LMS
Deadline	All reading quizzes, assignments, and discussion forum posts for climate change topics are due at the end of this week Friday by 11:59 pm.			

left unsure how to best learn or how much time was actually needed to learn content material (Brudzinski and Sikorski 2010). This is consistent with literature that has routinely identified students' lack of preparation as a primary barrier to the flipped classroom strategy (Milman 2012; Herreid and Schiller 2013; Post et al., 2015). When students were assigned a reading in the redesigned face-to-face courses, it was not uncommon for them to come to class unprepared and then struggle when asked to apply new terms and content in a scientific application. Moreover, several faculties noticed that students performed worse on exam questions that were based on content that they were responsible for learning out-of-class. Brudzinski and Sikorski (2010) interpreted these as indicators that students had more difficulty learning important class content material on their own and secondarily that students lacked confidence, dedication, and/or motivation needed to learn by themselves.

After seeing students struggle with some basic comprehension in early redesigned face-to-face courses, active e-learning faculty decided to regularly utilize a 5–10 question content quiz as pre-class homework (Table 2). Low-risk assessments of this type have been shown to give students key opportunities to engage with content (Bernard et al. 2009). While the evidence that reading quizzes lead to significantly improved performance on exams is mixed, they do correlate with improved engagement with the instructor and course materials as well as improved students perceptions of preparation and motivation (Haberyan 2003; Narloch et al., 2006; Urtel et al. 2006; Angus and Watson 2009; Tune et al. 2013). Additionally, general knowledge was emphasized on designated comprehension days (discussed in "Application Assignments: Application of Knowledge Through More Authentic Science"), in which students were asked to watch a ~20 min video lecture and complete a longer 20–25 question comprehension assignment to test their understanding and mastery of content. Questions were fairly basic (Fig. 1) including vocabulary-based multiple choice questions and simple figure interpretations. By implementing the assignments through an LMS, instructors were also able to provide individual question feedback and opportunities for reattempts and partial credit, discussed in "Automated Feedback and Question Reattempts: Practicing with Immediate Evaluation."

Evaluation of Course Component Instructors perceived the online assignments as an improvement over the traditional course and face-to-face format because students were held accountable for basic understanding of reading and video lecture material. In order to complete assignments, students no longer had the option to simply copy down notes, but they instead had to engage with content material, such that they would be more prepared to apply scientific terms and content on application days. Moreover, the ease and nearly automatic grading of assignments with an LMS was critical for instructors to be able to administer and require so many assignments. Students rated the comprehension and pre-class reading assignments as slightly above average on the week 8 survey (questions 5 and 6 had mean values of 2.6 and 2.2 out of 4, respectively in Table S2). The Fall 2012 SGID, which occurred later in the semester and had a greater percentage of students participating, revealed more favorable results, with 81% of participating students agreeing that online assignments were beneficial and forced them to use concepts.

Application Assignments: Application of Knowledge Through More Authentic Science

Innovation and Rationale One of the main goals of establishing an e-learning environment was to transform classroom activities into a more modern, authentic demonstration of scientific practices to improve a student's ability to perform in more realistic, complex environments (Herrington and Oliver, 2000). By requiring students to use a computer during each class of our transitional-hybrid and fully online course, they regularly had the opportunity to practice using technology to perform scientific analysis. Activities often involved the use of authentic and multiple datasets which allowed students to be involved in more authentic research and scientific experiences (Abd-El-Khalick 2008). Throughout the semester, students worked through these scientific investigations on activities, which were termed "application assignments."

Fig. 1 Sample questions from a comprehension assignment. *Lower case letters* different answer options, while "number signs" feedback that will appear once a student submits their answer

Q	**Multiple Choice: How does the greenhouse effect relate to climate change?** a. They are the same thing. # Greenhouse effect helps moderate temperatures, while climate change is the overall average of weather conditions. b. Climate change leads to the greenhouse effect. # The relationship between climate change and greenhouse effect is not directly causative. c. The greenhouse effect leads to climate change. # The relationship between the greenhouse effect and climate change is not directly causative. d. Greenhouse gases help trap heat. # Correct - Greenhouse gases like carbon dioxide work to trap heat and energy within our atmosphere.
Q	**Multiple Answer:** What are the possible impacts of global warming/cooling? Choose all that apply. a. more deserts # 1 of many correct answers b. more subsidence # Subsidence is not directly associated with global warming/cooling c. more earthquakes # Earthquake occurrence is not associated with global warming/cooling d. more volcanic eruptions # Volcanic eruptions are not influenced by global warming/cooling e. severe weather # 1 of many correct answers f. spread of disease # 1 of many correct answers g. agricultural productivity # 1 of many correct answers h. more flooding # 1 of many correct answers

Comprehension and application assignments were alternated during each class day (Table 2). In the transitional-hybrid course, students were encouraged to come in to a physical classroom to meet face-to-face to work on application assignments. During the class period, students could work in groups and instructors were available to address software problems.

In selecting new software programs, factors such as availability, ability for regular use, and facilitation of real scientific analysis were considered. Google Earth was an obvious program to take advantage of because of it is free of cost and has the power to navigate to different locations, overlay maps, and import latitude and longitude data (Patterson 2007). Additionally, a host of activities and maps using Google Earth are readily available via the United States Geological Survey (USGS), Science Education Resource Center (SERC), and other websites (Stahley 2006). Microsoft Excel was the second software program selected. In undergraduate science education, Excel is an important program for quantitative and graphical analysis (Hansen et al. 2016). Faculty throughout the department considered that knowledge of spreadsheet software would be advantageous for students in all classes and would additionally provide skills and knowledge that could be applied to any major or career. Moreover, the majority of students already owned the Microsoft Office Suite, or could obtain a free copy through the university bookstore. Google Sheet may be considered a useful alternative in the future as more options become available, but the lack of a trendline function was a limiting factor at the time of these courses.

Figure 2 shows an example application assignment in the course that (1) asked students to collect and access open data through websites like the United States Geological Survey (USGS) or National Oceanic and Atmospheric Association (NOAA), (2) provided loose written instructions and more detailed video tutorials for using Google Earth and Microsoft Excel, and (3) consisted of 35–45 multiple choice questions that were implemented in the LMS. In Google Earth, students had opportunities to investigate patterns of earthquakes and volcanoes in relation to plate boundaries, look at map overlays to measure the width and elevation of a crater, or examine outcrops of rocks to understand past depositional environments. Meanwhile in Microsoft Excel, students were able to analyze large data sets to make predictions and hypotheses from current trends. The use of authentic scientific data provided students an important opportunity to make their own observations, draw their own conclusions, and compare them to current scientific results.

Evaluation of Course Component Course surveys over three semesters of teaching showed students rated the effectiveness of application assignments as slightly above average (question 4 has a mean value of 2.4 out of 4 in Table S2), similar to results of comprehension and pre-class assignments administered on the LMS. In general, students seemed to review the Google Earth activities more favorably and indicated that they felt those activities were more effective than Microsoft Excel. This is also supported by the Fall 2012 SGID (Table S3), where 72% of students agreed that Google Earth was a strength of the course. This may be due to the intuitive interface and familiarity students have with Google Earth. That early SGID also revealed that 85% of students agreed that they liked the interactive examples provided in class and wanted more background material for software programs. In response, more detailed video tutorials were developed (discussed in "Video Lectures and Tutorials: Highlighting Content and Demonstrating Software"). While there was no direct mention of Google Earth or the interactive

Fig. 2 Sample instructions and questions from an application assignment. *Lower case letters* different answer options for multiple choice questions, while "number signs" feedback that will appear once a student submits their answer

For this assignment we will investigate measurements of carbon dioxide and global temperature over the past ~150 years and the past 400,000 years from the National Oceanic and Atmospheric Administration (NOAA).

To assist you: A video demonstration that goes over Microsoft Excel instructions with sample data available for download has been provided on our course homepage in Week 13.

Recent Data Sets

1. CO2 measurements (1958-present) from Mauna Loa observatory in Hawaii: http://www.esrl.noaa.gov/gmd/ccgg/trends/index.html#mlo_growth
2. CO2 measurements from ice core bubbles (1878-1953) from Law Dome in Antarctica: https://www.ncdc.noaa.gov/paleo/study/2455
3. Annual mean global temperature (1880-present): http://data.giss.nasa.gov/gistemp/

Historical Data Sets

1. CO2 measurements over the past 400,000 years from Vostok station in Antarctica: https://www.ncdc.noaa.gov/paleo/study/2443
2. Temperature estimates over the past 400,000 years from Vostok station in Antarctica: https://www.ncdc.noaa.gov/paleo/study/2453

Additionally, you will look at glacier movement over time in Google Earth:
Map of Jakobshavn Glacier movement along the west coast of Greenland from the NASA Earth Observatory:
http://www.users.muohio.edu/brudzimr/classes/GreenlandGlacier.kmz

Q **Multiple Choice: How much larger is the percent change in the concentration of carbon dioxide from 1958 to 2011 relative to that from 1878 to 1953?**

a. 3 times larger
 # Correct
b. 3 times smaller
 # The percent change from 1958 to 2017 was larger than that from 1878 to 1953
c. 2 times larger
 # The percent change from 1958 to 2017 was more than 2 times larger than that from 1878 to 1953
d. 2 times smaller
 # The percent change from 1958 to 2017 was larger than that from 1878 to 1953

Q **Free Response Numeric Answer: Based on the answer to the previous question, what was the rate of change of the glacier edge during that time frame in km/yr? Simply, respond with a numeric answer and I will assume your units are in km/yr.**

0.26 +/- 0.02
 # Correct
<0.24
 # Too small. Remember that rate is distance divided by time.
>0.26
 # Too large. Remember that rate is distance divided by time.

nature of some of the assignments on the Spring 2013 SGID, students rated the application assignments favorably (question 5 in Table S1 and question 12 in Table S2).

Automated Feedback and Question Reattempts: Practicing with Immediate Evaluation

Innovation and Rationale Capabilities for providing immediate tailored feedback and options for reattempting assignments are available through several different LMS, including Moodle, Blackboard, and Canvas. These promote student self-assessment, an element of our course SDOs, as learning is occurring (Skinner 1954; Epstein et al. 2010; Black and Wiliam 1998). Used in the simplest manner, automated grading in an LMS allows students and instructors to immediately assess how well content is being learned (Cheang et al. 2003; Zhu et al. 2016). Moreover, interactive homework quizzes with immediate grading and individually targeted tutorial assistance have been shown to motivate undergraduates (Freasier et al. 2003). Studies have also indicated that computer-based immediate feedback has a modest effect on student learning (e.g., Azevedo and Bernard 1995).

Figures 1 and 2 illustrate example assignment questions, answers, and corresponding feedback. Providing this sort of feedback is designed to help simulate what instructors might say during a normal student-teacher interaction to guide learning and provide a new perspective. As students complete an individual question, they can submit their answer and immediately receive their score and any necessary feedback. Students are then encouraged to use feedback to reattempt answering the question for partial credit. This process turns a wrong answer into a learning opportunity and allows students to monitor their individual success. Once an entire assignment is complete, students are then allowed to attempt the assignment a second time. The two submitted scores are averaged to calculate an overall score.

Evaluation of Course Component Students evaluated the feedback and reattempt process as the strongest component of the course. On week 8 informal surveys, students rated the effectiveness of immediate feedback and retaking assignments as above average to excellent (questions 1 and 3 had mean scores of 3.4 and 3.5 out of 4, respectively in Table S2). Not surprisingly, 100% of participating students in the Fall 2012 and Spring 2013 SGID viewed reattempting assignments as a strength of the course and more specifically 96% students on the Spring 2013 SGID agreed that having immediate feedback on individual questions was helpful.

Writing Assignments: Developing Peer and Self-Assessment Skills

Innovation and Rationale To promote higher order critical thinking skills and student self-assessment, two written assignments were administered and graded through the use of a calibrated peer-reviewed process (Topping et al. 2000; Robinson 2001). Whereas writing assignments traditionally test a student's individual ability to clearly convey and defend an idea, the peer review process also promotes students' abilities to evaluate and discriminate between good and bad writing. Recent research finds peer review can enhance student performance on subsequent exams (Jhangiani 2016). Because one of the SDOs focused on students' abilities to evaluate themselves, they performed self-evaluations after completing the calibrations and peer-review process. Theoretical and empirical studies support the notion that self-assessment improves internal motivation, mastery goal orientation, and more meaningful learning (Ross 2006; McDonald and Boud 2003; McMillan and Hearn 2008). Self-assessment becomes an even more important skill as students who succeed in an online course tend toward a more self-directed learning style (Boyd 2004). Instructors additionally wanted to promote peer- and self-assessment to maximize students' ability to achieve SLOs (Magolda 2009).

The calibrated peer-reviewed writing assignments were implemented through a workshop feature provided in the Moodle LMS. A grading rubric was provided to guide students in their own writing. After submitting their written assignments, students were then responsible for using the rubric to evaluate three sample calibration essays, three other (anonymous) student essays, and finally their own essay. Students received a score of 75% for their submission, and 25% for their ability to accurately assess essays, including the peer- and self-assessments. Over the course of a single writing assignment, students not only worked on developing their critical evaluation skills to judge others, but also their ability to assess and improve their own work. An example of the grading rubric students used for peer and self-evaluation is available in the "Supplemental Material."

Evaluation of Course Component Compared to other course components, like pre-class reading quizzes and video lectures, the writing and peer review process received a less enthusiastic response from students. On mid-semester surveys, students were asked directly about the effectiveness of the writing assignment and peer review process, which they rated as average (question 7 and 8 had a mean value of 2 and 2.1, respectively, out of 4 in Table S2). These scores were among the lowest of all the course components that were asked about on the survey. Additionally, end-of-course evaluations revealed that students in the fully online active e-learning course rated their work on integrating ideas and information for papers and projects with a mean score of 2.53 compared to 2.86 and 2.99 out of 4 for the traditional lecture and redesigned face-to-face courses (Table S5). Overall, writing assignments in an active e-learning environment compared to face-to-face courses resulted in a large negative effect size (Table S6). This suggests that despite other components of the active e-learning course that were reviewed favorably, future writing assignments in the online course could better mirror assignments given in the traditional lecture and redesigned face-to-face courses, which may be perceived as more comprehensive and explicit about using multiple resources and synthesizing information. While the efficacy of including peer evaluation has not been formally assessed in this course, several other studies have determined that self- and peer-review of writing, particularly that which is computer-assisted, has a positive impact on overall student performance (Dochy et al. 1999; Topping 1998, 2003).

Discussion Boards and Office Hours: Social Interactions

Innovation and Rationale In order to create a more active learning environment structured on cooperation and social interactions, instructors experimented with live-chat rooms, virtual discussion boards, and held online office hours to allow for student-to-student and student-to-faculty interactions. Research suggests that students learn and understand more through discussion and peer interaction than in teacher-centered learning (e.g., Slavin 1996; Wenzel 2000) and has an important role in knowledge construction in online settings (e.g., Wozniak 2007). Moreover, social learning is an important component of students' perceived learning and satisfaction, especially in an online environment (Kennelly 2009; Susman 1998; Richardson and Swan 2003).

Several different setups for online student-faculty interactions were tested (discussed below in the Evaluation section). Instructors currently use graded asynchronous discussion boards available in the LMS. The discussion boards were implemented by breaking up students into small groups of about 10 each. In addition to grading the posts, instructors sought to facilitate discussions by posting replies to student questions, asking follow-up questions to stimulate further discussion, and providing clarification for any apparent misunderstandings. For each discussion board, students were graded on a clear 0–2 point rubric and are required to post once per class period, with one weekly deadline (typically three posts per week). At first, discussion topics were focused more on content specific and instructional questions, but were later broadened to include more informal sharing of personal experiences with course content or personal opinions about geologic hazards. While several student-to-faculty interactions occurred within the normal discussion board, online office hours via WebEx were also implemented. WebEx is an internet-based video conferencing software that was used to facilitate more direct assistance. Regular WebEx hours were held during scheduled class time and instructor office hours.

Evaluation of Course Component Several iterations of discussion boards were tested to optimize student-to-student and student-to-faculty interactions. Initially, during our first hybrid course offering in Fall 2012, a synchronous live-chat room was available during our 50 min online virtual meetings. Despite offering extra credit, only 41 of 77 students ever participated and there were on average only ~10 posts per class period. An anonymous, informal Moodle survey indicated that students felt a lack of engagement. With this feedback, the approach was shifted to using asynchronous online discussion forums in Spring 2013 to increase the opportunities for interactions. Despite grading for participation, the average score was 39% per discussion board with an average of 30 of 70 students participating, and many students only posted once. An SGID revealed that many students perceived the discussion forum as busy work and through end-of-semester course evaluations a few students specifically reported they felt disconnected from the class (Table S4 and S5). Due to the low participation rates on discussion boards in Spring 2013, the next iteration of asynchronous discussion boards focused on students' personal experiences and opinions. This increased average student scores to 79% per discussion board with an average of 77 of 90 students participating. It has also become more common to see students posting more often than required and engaging in helpful discussions with one another.

While most student-to-faculty interactions occurred within the normal discussion board, occasionally students sought direct assistance from instructors via WebEx. Video conferencing was especially helpful for resolving computer issues or difficult to explain concepts. The most common issue to resolve was the installation and use of Safe Exam Browser software that was used to prevent students from using other parts of their computer during the exam.

Video Lectures and Tutorials: Highlighting Content and Demonstrating Software

Innovation and Rationale Many have recognized how multimedia can be used to improve student learning (Mayer 2005; Day and Foley 2006; Stelzer et al. 2009). Video lectures and video demonstrations were provided to assist students with the redesigned classroom. The lectures, which were about 20–25 min, were designed to help students transition from a traditional classroom to a more active e-learning environment. This allotment of time aligns with studies that suggest optimal learning occurs in time frames shorter than a standard hour-long face-to-face lecture (Stuart and Rutherford 1978; Medina 2008; Johnstone and Percival 1976). Instructors used Microsoft Expression Encoder and Quicktime to screen capture the lecture materials (primarily PowerPoint) and then posted the videos on YouTube for students to access.

Video was also a useful way to introduce and train students on new software. Early iterations of using new software, like Microsoft Excel, included assigning homework, writing out explicit directions, and in-class demonstrations all of which ended up frustrating either faculty or students. Studies using video tutorials show that students reviewed these positively and performed as well as or better than with demonstrations used in face-to-face environments (DeVaney 2009; He et al., 2012). The video tutorials that were developed demonstrated different techniques using a sample data set that was also available to students to download and manipulate as they watched the video. Then the subsequent activity would have students apply their newly acquired skills to a new set of data. Student feedback indicated this approach was successful, but also highlighted opportunities for improvement such as inclusion of written text that pops up during key instructions.

Evaluation of Course Component Instructors observed that students liked the familiarity of learning content through a traditional lecture while also being able to take advantage of a video's flexibility over the pace and environment in which they learn (Simpson 2006). Informal midterm surveys showed that students rated the video lectures and video tutorials (questions 9 and 10) slightly above average (2.5 and 2.3 out of 4, respectively; Table S2). Moreover, the Fall 2012 SGID (Table S3) revealed that 85% of students viewed the short and concise lectures as a strength of the course and 75% agreed that video lectures were a good way to get information. In an anonymous online questionnaire, one student wrote, "I feel like I absorb and understand so much more information through the podcasts (video lectures) because I can watch them at my own pace." Specific student feedback from the Spring 2013 SGID did not mention the video lectures or tutorials, except to say that they were difficult to use when reviewing, presumably to search for a specific piece of information. Previous studies have found a majority of students utilize and review videos frequently (Kay and Kletskin, 2012), indicating that video lectures should be well organized and close captioning should be used to allow students to search for specific content. Close captioning was implemented by implementing the videos through YouTube, but breaking the videos into shorter components to improve navigation remains a goal for the instructors. Additional examples of effective video lectures are given by Wiggens and McConnell (https://geosciencevideos.wordpress.com/) who have shown short videos (5–7 min) have improved student performance over traditional paper-based resources.

Online Exams: Rigor and Cheating Prevention

Innovation and Rationale There is a general perception that online courses present more opportunities for students to cheat, but previous studies (Sindre and Vegendla 2015; Sessink et al. 2004) found that even though digital environments may provide more possibilities for cheating, they also create more methods to mitigate cheating. Specifically, in our course, we found that the digital database of student actions collected by the LMS provided us with a means to review student actions in much greater detail than in a traditional face-to-face course. Through the LMS database we could regularly look for evidence of cheating such as similar patterns in student answers, unusually high scores over short amounts of time, and multiple student accounts using the same IP address. To ensure academic integrity, we also looked for any of our course material posted on websites created for sharing assignments and gaining unfair advantage (e.g., Coursehero, Cramster, Koofers, Quizlet, StudyBlue, and StudyMode). Although a detailed discussion of our efforts to identify all possible areas of academic dishonesty is beyond the scope of this study, we present a short description of efforts to identify possible cheating on exams below.

A primary focus of our course design was to implement rigorous exams, which were designed to be taken through our LMS. For the initial transitional-hybrid offerings in Fall 2012 and Spring 2013, students met in a physical classroom to take proctored exams. The first exam in Fall 2012 was given on paper, while the remaining exams given in Fall 2012 and Spring 2013 were given in-class within our LMS. Then in Fall 2013, for the fully online course, exams were taken online, in a controlled but unproctored environment (proctoring software was not implemented until 2016). Exams taken online followed procedures to prevent cheating from Cluskey Jr., et al. (2011) which included implementing the exam synchronously, setting a time limit for the overall exam, randomizing questions and answers, restricting the number of questions viewed at a single time, preventing backtracking, not allowing retakes, using a restricted web browser, and developing a pool of questions. Our unproctored exams were administered through a software program called Safe Exam Browser (www.safeexambroswer.org), which prevents the use of any other browser windows until the exam is completed (Frankl et al. 2012), although it cannot prevent students from using other devices. A specific time period was set up when all students would take an exam of 50 questions synchronously. Each of the 50 questions was pulled from question banks, which were made up of multiple equivalent questions on each topic to be evaluated. The LMS would then randomize questions from each topic question bank to make a unique exam for each student. Within the exam, parameters were set to have two questions appear at a time and prevented backtracking to previous questions, so students would not be tempted to use extra time at the end of an exam to seek outside help for improving their answers. It is also important to note that by changing the nature of the course to be more focused on scientific analysis, rather than facts and memorization, exam questions were aimed at the application of different scientific concepts, analysis and interpretation of figures, and describing physical processes. The more in-depth nature of these questions may make it more difficult for an answer to be easily found through an internet search. To ensure the integrity of the exam, instructors plan to continue making new versions of exam questions each year.

Evaluation of Course Component Course exams were evaluated based on student feedback, rating, and overall performance. Student feedback on the exams revealed they wanted more preparation, such as study guides (Table S3 and S4). Upon receiving this feedback, more extensive study guides were built that help students to review content, concepts, and skills covered in the comprehension and application assignments. Moreover, early in the course, student attention is drawn to the benefits of taking notes during assignments, as they may be more accustomed to taking notes during a lecture than during a set of interactive questions. Overall, students felt the exams were average, rating them a score of 2.5 out of 4 (question 16 on Table S2). While instructors did not specifically ask about exam questions or structure, the neutral student responses led to the perception that the exams were adequate and fair.

To identify possible occurrences of cheating on exams, for example students searching the internet or working with each other, we investigated exam scores between proctored and unproctored environments and looked at the amount of time taken for students to complete the exam. Student performance on proctored exams compared to synchronous, unproctored exams did not vary greatly (Fig. S4). Average scores ranged from 68 to 78% from the three semesters of exams and the average unproctored exam scores were within the standard deviation of proctored exams. Scatter plots (Fig. S4) show very little correlation between time spent to complete the exam and exam score, suggesting that students are not successfully using additional time to find or share answers, even though exams may be unproctored. While there may be other ways students are gaining unfair advantages on unproctored exams, data indicates that unproctored exams can be as rigorous as those given in class and that if any cheating is occurring, it is balanced by disadvantages associated with an online testing environment (Fask et al. 2014). Our course data is also consistent with results from a rigorous randomized experimental design study that found online, unproctored exams are not more vulnerable to student cheating (Hollister and Berenson 2009) than proctored exams. Nevertheless, fully online proctoring solutions utilizing webcams have become available and will be investigated in future work.

Opportunities in Active e-Learning

In the previous sections, we described the instructional design process and justification for different course components that were developed in the transition from a face-to-face to online course. In the current section, we present results from the Geoscience Concept Inventory, SGID reports, informal surveys, and end-of-course evaluations to provide a first order attempt to evaluate overall student learning and development. We will discuss unique opportunities in active e-learning for student gains and identify a new means for educational research.

Improved Student Learning

To help evaluate changes in student learning as a result of the course revisions, the Miami University Department of Geology and Environmental Earth Science began employing the Geoscience Concept Inventory (GCI), an already established assessment used to assist instructors to evaluate overall student learning, in introductory courses in 2007. The GCI is a set of conceptually based questions geared toward fundamental concepts in the earth sciences, including foundational concepts in physics and chemistry. It was developed by geoscience education researchers (Libarkin and Anderson 2005) and has been evaluated and validated using item analysis techniques from both classical test theory and item response theory.

The impact on student performance can be estimated through comparisons of GCI scores (out of 100%) at the start of a course (GCI_{PRE}) and the end of a course (GCI_{POST}). The same 25 questions selected via the GCI category guidelines were used in all cases since there is a large content overlap in the various introductory courses. The same set of GCI questions was administered pre and post as a timed 50-min multiple choice quiz through the LMS regardless of class format (face-to-face, transitional-hybrid, online). So even for the classroom-based courses, the GCI was completed online and was not proctored. Given these conditions, students may have been tempted to take unfair advantages by looking up questions online or copying from a student who may have recorded their answers. We envision that these strategies would either result in students having higher scores and longer completion times (e.g., looking up online), or higher scores and shorter completion times (e.g., copying from another student). However, we do not see evidence for either trend in the LMS data (Fig. S5), giving us some confidence that if any cheating occurred it was minimal. Furthermore, students received a score upon completion but could not review the questions or their responses as we sought to preserve the integrity of the GCI over time. Based on their performance on the pre and post-semester GCI, students received up to half a percentage point of extra credit. Response rates were comparable across the different types of classes. In the fully online version of the course, the Safe Exam Browser software was required for the GCI, which prevented students from using other parts of their computer during the assessment.

In the geosciences, it has been common for studies to report the raw gain in GCI scores to estimate the improvement in student performance, which is calculated as:

$$GCI_{GAIN-\mathrm{RAW}} = GCI_{POST} - GCI_{\mathrm{PRE}}$$

However, results for the comparable Force Concept Inventory are often analyzed by normalizing the scores relative to the student's initial score (Hake, 1998). Compared to raw gain, normalized gain is believed to better account for variations in initial knowledge and thus potential for improvement. The normalized improvement for each student on the GCI is calculated as:

$$GCI_{GAIN-NORM} = \left[GCI_{POST} - GCI_{\mathrm{PRE}}\right] \Big/ \left[100\% - GCI_{\mathrm{PRE}}\right]$$

We have decided to report both types of gain calculations for completeness. In addition, we are reporting the scores and gains for courses that were taught by the directors of the active learning redesign (instructors A + B) and e-learning redesign (instructors B + C) separate from courses that were not. This should serve to illustrate whether those directly responsible for the redesigns had a different impact on student performance.

For each subset of students evaluated, the average GCI_{GAIN} was calculated and 95% confidence interval uncertainties were estimated by using a simple jackknife subset resampling algorithm (Kunsch 1989). For this approach, 10% of the dataset is removed repeatedly and the GCI_{GAIN} recalculated many times, taking the second standard deviation of the resulting variability to represent the variance of the measurement. While the true uncertainty based on variability in the student population could be higher for our smallest subset

(N = 116), the calculated uncertainties provide an indication when the different average GCI_{GAIN} values are statistically significant.

Table 3 shows the average GCI_{GAIN} across three subsets of introductory courses in the department: courses with the traditional lecture-based approach, courses with an active learning revision, and courses with an active e-learning approach (either hybrid or fully online). The table includes data collected from Fall 2007 to Fall 2013 from multiple instructors in the department. Instructors A and B were primarily involved in the design and development of the face-to-face active learning course, while instructors B and C were responsible for the active e-learning course. Unfortunately, no instructor has taught all three formats of the course, so it is difficult to make definitive determinations about the exact cause of GCI scores. However, if we take a closer look at both the raw and normalized gains for the traditional lecture and redesigned active learning courses, GCI_{GAINS} appear to be more closely influenced with course style and not due to variations in instructors. The more specific development of SLOs and SDOs may have helped the consistency in GCI scores observed in the redesigned face-to-face courses.

The most prominent trend in raw and normalized GCI_{GAINS} appears to be linked to the styles of instruction. Raw GCI gains, ~10–11.4%, in the active learning and e-learning courses are larger than those observed in traditional lecture-based courses, which had an average gain of ~6–8%. Specifically, the raw gains in the active e-learning course are encouraging because many introductory geology courses nationally do not see significant increases in GCI scores (Libarkin and Anderson 2005) and our results are similar to gains of 8–15% reported from other interventions of active learning (e.g., McConnell et al. 2006; Petcovic and Ruhf 2008; Elkins and Elkins 2007). These results indicate that similar academic rigor can be achieved in both a face-to-face and online environment. Furthermore, if we take a closer look at normalized GCI_{GAINS}, we can better separate the impacts of face-to-face and online courses. Active e-learning shows significantly larger normalized gains compared to the classroom-based traditional lecture and active learning courses. This data is promising and provides support that an active e-learning environment provides opportunities for improvements in student conceptual learning.

Here, we have combined scores for the transitional-hybrid and fully online courses to represent learning gains from active e-learning as a whole. Even though a hybrid course offers opportunities to meet face-to-face, materials were developed with the end goal of producing a fully online course and did not necessarily take full advantage of the benefits of hybrid courses design. The GCI_{GAIN} from the transitional-hybrid course did show slight improvements in student learning when compared to results from the fully online course (Table S7). The improved student learning gains of our transitional-hybrid course are in line with previous results of increased student learning outcomes from other studies of hybrid and blended courses (e.g., Baepler et al. 2014; Kiviniemi 2014; López-Pérez et al. 2011; Taradi et al. 2005); however, based on our current results, it is difficult for us to distinguish the outcomes of partially and fully online courses.

Since the GCI is constructed to assess the understanding of fundamental geologic concepts, the results demonstrate evidence for content mastery. The improved learning outcomes could be a consequence of a more deliberate and interactive learning environment that focuses on active learning strategies, including case studies, open-ended questioning, and self-assessment rubrics. In previous studies (e.g., Bernard et al. 2009; Kanuka 2011) researchers concluded that higher levels of learning were dependent on the amount of interaction students have with each other, the instructor, and with the content. Furthermore, GCI results have been shown to have a positive correlation with other critical thinking assessment tools (McConnell et al. 2006), so these results also suggest improvements in students' critical thinking abilities.

Promising Student Development

Another primary goal of the active e-learning course was to focus on improving student development. SDOs defined during the course redesign process focused on self-reflection and self-assessment to help student adoption of active learning styles. Despite a limited dataset, we attempt a preliminarily assessment of SDOs using qualitative analysis of SGID reports, informal surveys, and end-of-course evaluations.

Specifically, SGID reports indicate positive trends that align with SDOs focused on student autonomy and ownership. In the Spring 2013 SGID, 77% of students agreed with the statement "We like that the class is less structured because it is what you make of it." Moreover, students overwhelmingly agreed on SGID reports (Tables S3-S4) that strengths of the course included retaking assignments, longer time limits on assignments, and flexibility on assignments. Students appear to recognize the importance of practicing to learn in this course by highlighting the aspect of redoing and reviewing. The positive response about these course components indicates that many of the students have embraced a self-regulated learning model, as described by Zimmerman (2000). The structure of the course, like some other blended or online courses, provides the flexibility to create a more student-centered learning environment (Knowlton 2000). These survey results suggest the possibility that students are becoming more responsible and increasing their ability to self-assess over the course of the semester (Lee et al. 2011).

In addition to student ownership, students in the active e-learning course showed the potential for more engagement in learning compared to a traditional lecture setting. On end-of-course evaluations, students were surveyed using a variety of

Table 3 Student gains on the Geoscience Concept Inventory in introductory courses in the Miami University Geology and Environmental Earth Science Department

	Traditional face-to-face lecture		Redesigned face-to-face active learning		Transitional hybrid and fully online active e-learning
Instructors	A	Others	A + B	Others	B + C
Average pre-GCI	43.8	48.9	46.2	50.2	55.7
Average post-GCI	49.8	56.9	57.2	60.2	67.1
Raw GCI gain	6.0 ± 0.7%	8.0 ± 0.8%	10.9 ± 0.7%	10.0 ± 0.5%	11.4 ± 1.2%
Normalized GCI gain	7.3 ± 1.4%	11.2 ± 1.7%	16.7 ± 1.5%	17.5 ± 1.1%	22.0 ± 2.7%
Number of students	229	212	481	640	116

questions, including several from the National Survey on Student Engagement (Table S5). Participation was relatively low ($n = 20$) for the transitional-hybrid course and some of the lower evaluation scores, especially on questions related to participation in class discussion and integration of ideas on papers or projects, may reflect the overall growing pains associated with the development of the course. If we look more closely at results from the fully online course, which had greater student participation ($n = 43$) we may gain a better perspective on how students are perceiving the overall active e-learning environment. When a fully online active e-learning environment was compared to a traditional lecture setting, students self-reported more frequent contributions to course discussion, analysis of basic ideas, applications of concepts to practical problems, and put more importance on becoming an independent learner (Table S5). Effect sizes (0.31–0.78) suggest small to moderate practical significance (Table S6) in these results. The fully online active e-learning results were also comparable and typically within one standard deviation of evaluation results from the redesigned face-to-face active learning course and marked by noticeably smaller effect sizes, suggesting students' perception of learning and engagement in these courses was similar. Other results from the student evaluations show students felt they worked on papers and projects less than in the traditional course and there was an overall decrease in student satisfaction with the fully online course. It is also important to note, students report spending more time on preparing for the active e-learning course compared to other learning environments (Table S5). While this result may be somewhat distorted because students are confusing class time with preparation time, there is a strong indication that students are spending at least the same amount of time engaging with course material as they would in a traditional lecture and potentially even more.

While our dataset is somewhat limited, our analysis suggests active e-learning environments may help promote improvements in student development. Results indicate that the regular course assignments and course discussion forums increased student engagement and potentially provided important opportunities for students to assess their own learning. In the active e-learning course structure, multiple types of assignments (reading quizzes, comprehension assignments, and application assignments) provided formative assessment opportunities for students. The relatively low-risk nature of the assignments may have allowed students to interact more with the content and receive constructive feedback. Within this type of course design, it is the student's responsibility to decide whether their understanding and study methods are sufficient. The results of this study support previous findings that the use of Web-based technology promotes student engagement (e.g., Hu and Kuh 2001; Robinson and Hullinger 2008; Chen et al. 2010) and can achieve similar results as face-to-face courses (e.g., McCutcheon et al. 2015; Reece and Butler 2017). Moreover, stronger student engagement along with asynchronous learning has been suggested to allow learners more opportunity to develop critical thinking skills (Robinson and Hullinger 2008; Bernard et al. 2009). The deliberate design of the e-learning course likely influenced the positive trends toward student development outcomes; however, further studies are needed to evaluate the SDOs more fully.

Improved Educational Dataset

An additional outcome researchers discovered is that online learning environments build an educational database of student actions that could be investigated to improve student learning. The database presents an opportunity to see the frequency at which students log in to the LMS, the amount of time and the number of reattempts students use on assignments, and the interaction between students. In the future, the intention is to use data collected in the LMS to assess the individualized SLOs that were established at the beginning of the course design. In particular, individual questions were designed in each assignment that target key aspects of the scientific method (e.g., observation, analysis, interpretation), so that changes in performance could be investigated on individual SLOs throughout the course.

By recording thousands of student actions and performances in Moodle, an educational database has been built that provides a new opportunity to investigate student learning pathways as opposed to individual question content (Romero et al. 2008). Envisioning the LMS as a research tool was a primary reason we decided to invest the time and effort in developing a Moodle instance specifically for the department with a server maintained and secured by our university's IT Services. Data mining, the efficient discovery of non-obvious valuable patterns from a large collection of data, is commonly used throughout business, engineering, and science, but has been applied only recently to educational research (Romero and Ventura 2007). The database of student actions and traits collected by the LMS can be examined to look for less obvious or unexpected trends, beyond the overall student performance results presented in Table 2. For instance, there is additional capacity to breakdown results by students according to declared major, time spent on an activity, or course resources utilized. The intent is to pursue future analysis of student performance with data mining to improve the assessment of SLOs and SDOs.

Summary

The two major educational movements being discussed today are student engagement and online learning. This case study describes efforts to merge both movements into an active e-learning environment that is designed for enhanced student engagement through effective use of technology. While the transition into active learning began as part of a university initiative, including a geology department effort to generate key course resources (e.g., assignments, orientation letter) for face-to-face classes (Brudzinski and Sikorski 2010), this study examines additional developments for online classes. The components developed for the active e-learning environment include: (1) regular online assignments, (2) application assignments, (3) tailored feedback and multiple reattempts, (4) written assignments, (5) social interaction, (6) video lectures and tutorials, and (7) online exam implementation. The rationale and effectiveness of each course component were evaluated through formal student evaluations, informal student surveys, SGIDs, and instructor reflection. The most successful components were the immediate informative feedback and options for assignment reattempts. Students rated these aspects of the course highly and instructors found that while initially time consuming, implementing feedback and reattempts through the LMS will be efficient and effective in the long term. Other successful components with strong ratings were online assignments including pre-reading quizzes, comprehension assignments, and application assignments. Students indicated these assignments were beneficial, providing important practice of conceptual understanding in an interactive manner. Video lectures and tutorials were also rated as useful course components and instructors found creating the tutorials reduced the number of questions students had about the use of software. While students rated the writing assignments as average, instructors felt they successfully incorporated writing instruction and peer-/self-assessment that is typically difficult in a large enrollment introductory course. Other successes included implementing social interaction and effective exams in an online environment. As content learning, critical thinking, and problem-solving skills are improved through interactive assignments, the newly created educational setting requires students to spend about half of their course time practicing realistic geoscience skills.

The progress made to develop an active e-learning geoscience course is encouraging. Opportunities within this setting for increased student learning and development outcomes, as well as for educational research are evident. The implementation of active learning through online environments has shown students are able to achieve similar raw GCI_{GAIN} as face-to-face active learning courses and normalized GCI_{GAIN} suggest that active e-learning may promote even further improvements in student learning. While there are many factors that may impact student performance on the GCI, gains observed in the active e-learning course may be a result of overall improvements in student development, specifically learner autonomy and engagement. The autonomous nature of e-learning (as students control the time and location of their work) has the potential to further the independent, self-directed learning processes, producing greater engagement and resulting skill development than in a classroom environment. The structure of an active e-learning course can encourage students to spend more time on learning activities than in the inquiry-based face-to-face version, producing greater mastery. Furthermore, an e-learning environment contains many educational research opportunities that are not possible in a traditional classroom. The ability to analyze thousands of student actions in an LMS creates the potential to data mine for unexpected patterns and potential learning pathways for different types of students in order to create more effective and efficient student learning.

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