Large Lecture Transformation: Adopting Evidence-Based Practices to Increase Student Engagement and Performance in an Introductory Science Course

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ABSTRACT

This study investigated students' attitudes, engagement, satisfaction, and performance in Introduction to Environmental Science after it was transformed from a typical large lecture to a student-centered learning environment. The instructors of the course collaborated with the Office of Teaching, Learning & Technology and radically redesigned the course by adopting evidence-based pedagogical methods and instructional technology to offer a rich active learning environment. Students' engagement, satisfaction, and performance in the transformed course were compared to the students in the same course that was traditionally taught in a previous semester in order to measure the effect of the transformed course on student learning. Four self-reported surveys and a focus group interview were administered during the semester, and performance scores, prior learning data, and demographic information were collected at the end of the semester. The assessment results indicate that the students in the transformed course prepared for the class significantly more, engaged in the course significantly better, and were significantly more satisfied with the course than were the students in the traditional lecture-format course. Most of all, multiple linear regression indicates that the students in the transformed course earned, on average, about three-fourths of a letter grade higher on their final grade after controlling for cumulative grade point average. The students in the transformed course reported that online learning materials and frequent formative assessments using online quizzes were helpful in their learning, and they perceived the course was relevant to real-world applications that matter to their daily life. © *2016 National Association of Geoscience Teachers*. [DOI: 10.5408/15-084.1]

Key words: large lecture, environmental science, active learning, student-centered learning

INTRODUCTION

Large lecture courses are a traditional teaching practice in most large institutions of higher education. They have historically provided an efficient way to deliver content information to a large number of students with the least amount of faculty resources. However, the traditional structure of a large lecture course adopts only one method of lecture, in which the instructor mainly delivers content knowledge. In the last a few decades, as assumptions about learning have evolved from the behaviorist perspective, in which learning is acquisition of information and routine skills (Greeno et al., 1996; Duffy and Orrill, 2001), to the constructivist view, much effort has been exerted in higher education to create environments for active learning. In particular, such effort has been intensified in science, technology, engineering, and mathematics (STEM) fields. For example, in their reported titled "Engage to Excel," the President's Council of Advisers on Science and Technology called explicitly for widening the adoption of evidence-based teaching strategies in STEM to increase the number of college graduates with a STEM degree (Olson and Riordan, 2012).

The Office of Teaching, Learning & Technology at the University of Iowa initiated the Large Lecture Transformation Project to increase the success of undergraduates. The primary goal of this project was to use technology to transform large lecture course delivery in order to provide increased student-centered learning. Most of all, through this project, sustainable models for alternative large lecture course delivery were developed to increase student engagement and satisfaction that led to greater student success. This project provides the necessary support structure to faculty members who wish to adopt new pedagogies and instructional technologies. A research study was conducted to examine the effectiveness of the project to transform traditional large lecture courses. As part of the Large Lecture Transformation Project, an Introduction to Environmental Science course was radically redesigned and transformed to offer a rich active learning environment.

According to Grabinger (1996), new assumptions about learning, which evolved from constructivist theories, are moving from a passive view of learners who study concepts in abstract forms toward a paradigm in which learners construct knowledge through rich interaction in student-centered environments. In the constructivist view, learning is

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a process of making sense of the world, which is in the activity of the learner (Duffy and Orrill, 2001). Therefore, the focus of learning has been changed from transmission of content to activities that involve learners. The constructivist approach of the optimal learning environment is to cultivate students' active construction of knowledge, which allows them to explore, discuss, and meaningfully construct concepts and relationships in contexts that involve real-world problems and projects that are relevant to the learners (Jonassen, 1999). As these new perspectives on learning have been broadly accepted by many educators, students' active engagement in the classroom has emerged as a critical factor in large lecture courses. In addition, much effort has been put into large lectures to create rich environments for active learning by leveraging a growing body of increasingly affordable instructional technologies.

Many research studies have reported various changes of large lecture courses and their effectiveness on student engagement and performance. The scale of change has varied from adopting a single technology to reforming the course structure and assessment. One of the most commonly adopted technological tools in large lecture courses is an audience response system (or "clickers"), and many studies reported its positive results on student engagement and performance (e.g., Meltzer and Manivannan, 2002; Caldwell, 2007; Mayer et al., 2009; Hoyt et al., 2010; Denker, 2013). Audience response systems promote not only student–instructor interaction but also student–student interaction and small group discussion with additional strategies. Bailey et al. (2012) indicated that adopting clickers with think–pair–share strategies promoted student–student interactions during lecture.

Online learning components are often incorporated into large lecture courses to provide extensive learning materials to students and to allow students to build self-regulated learning skills (e.g., Letassy et al., 2008; McKenzie et al., 2013). Multiple studies reported that video lectures improve students' initial learning (Brecht, 2012), keep students' attention, generate interest in science, and clarify understanding (Eick and King, 2012). In particular, video lectures are more likely to benefit low-achieving than high-achieving students (Owston et al., 2011). Along with video lectures, online quizzes have been adopted in large lecture courses to prepare students for in-class activities. Commonly, quiz questions are based on assigned readings for each class and are due prior to the class. Because students can take online quizzes anywhere, they are not viewed as a valid assessing tool but rather as an incentive to have students read the materials prior to coming to the class (Aiken, 2005). Providing online self-tests without grading may also contribute to the substantial increase in student test scores (Bongey et al., 2005).

Beyond these strategies, Persky and Pollack (2010) reported on the reform of a pharmacokinetics course by adding e-book and Web-based multimedia learning modules to facilitate students' independent learning, which reduced face-to-face time. The majority of face-to-face lecture times were replaced with learning activities, including discussion, problem solving, and case studies, to encourage higher-order learning. Bailey et al. (2012) also reported on the reform of a large lecture course by including a process-oriented guided inquiry learning approach to create active learning environments in biochemistry.

The effort to reform teaching practices by using interactive teaching pedagogies has been made specifically in the geosciences as well (e.g., Arthurs and Templeton, 2009; Budd et al., 2013; Kennedy et al., 2013). Researchers observed 26 introductory geology courses at 11 institutions using the Reformed Teaching Observation Protocol. They found that 35% of them were student-centered classrooms with more active learning and 35% of them implemented some elements of active learning (Budd et al., 2013). This research also found that of observed courses, most large classes at research universities were traditional lecture-dominated classrooms with little student talk and minimal student activity beyond listening and note taking (Budd et al., 2013). The strategies that instructors adopted to create a student-centered learning environment in geoscience courses were varied, including coupled in-class small group activities and individual follow-up homework in a lecture-based environmental geology course (Arthurs and Templeton, 2009) and inquiry-based activities in a laboratory section in an introductory Earth Science course (Forcino, 2013).

Most studies reported that redesigned large lecture courses showed relatively positive results compared to traditional lecture-format courses. Students achieved higher grades (Aitken, 2005; Walker et al., 2008), they preferred the redesigned course over the traditional lecture format, and their overall rating of the course was increased (e.g., Persky and Pollack, 2010). A recent meta-analysis of the impact of active learning on undergraduate student learning in STEM emphasized the importance of using evidence-based teaching strategies (Freeman et al., 2014).

In contrast, a number of studies revealed no significant improvements in learner outcomes of redesigned large lecture courses even though a portion of the results indicated that overall, students valued their learning experience under the redesign (e.g., Kapp et al., 2011). Kahl's study (2008) pointed out a misalignment of interactive teaching methods and measures of student performance, in which the adopted assessment might not properly identify the degree to which students achieved the course goals. Rutledge (2008) examined the effects of a diversified instructional approach on students' attitudes and reported that students in an instructor-centered large lecture course perceived it more effective than student-centered instruction in fostering knowledge of biological content, while student-centered instruction was perceived to be more effective in engaging students in the learning process and helping students construct their understanding. In addition, communication strategies have become an important factor in student success in redesigned courses, because students often do not see the purposes or values of activities on their own. Majerich and Schmuckler's study (2007) revealed that more positive student perceptions of the benefits of the adopted pedagogical methods resulted in greater content mastery for students in a modified course than for those in a traditional course.

The current study investigated students' perceptions of the course and learning outcomes in the Introduction to Environmental Science course after it was transformed from a typical large lecture to a student-centered learning environment. In particular, students' attitudes, engagement, satisfaction, and performance in the transformed course were compared to those of students in the same course that was traditionally taught in order to measure the effect of the

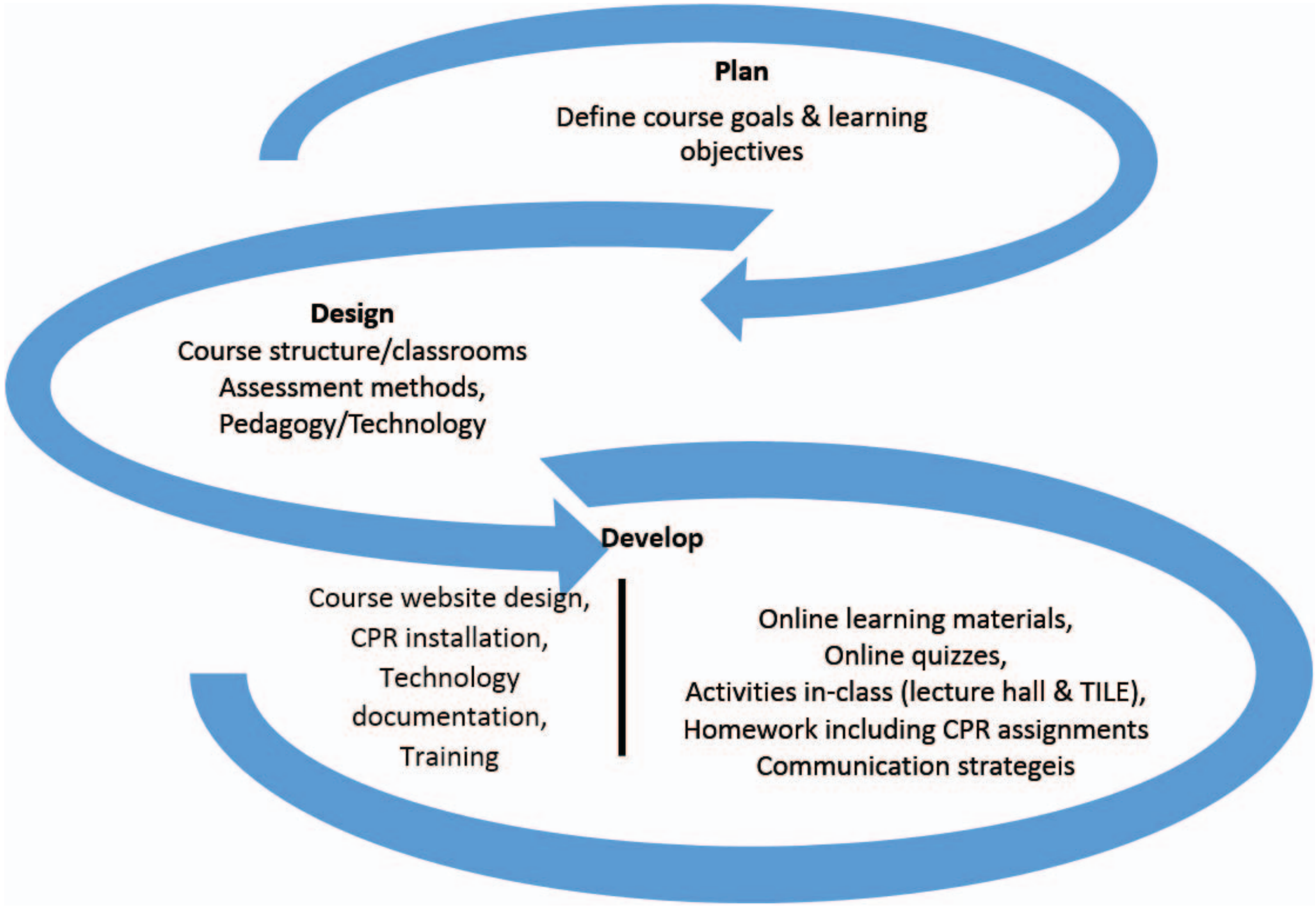

FIGURE 1: Transformed process.

transformed course on student learning. The same instructors taught the course in the traditional lecture-centered course format a year before the transformed course was offered.

SETTING

University and Course Description

The University of Iowa is a large public institution located in the Midwest. It is a research university and has more than 31,000 students. Introduction to Environmental Science is an introductory science course that fulfills the Natural Sciences General Education requirement at the University of Iowa. Prior to the course transformation discussed in this paper, this course was a traditional large lecture course: one instructor taught the first half of the course, and a second instructor taught the course for the second half of the semester. Class time was heavily focused on delivering content knowledge to about 200 to 250 students in a large lecture hall. Lectures typically covered about two-thirds of a popular textbook at a pace of about one chapter per lecture, and instructors generally followed the order of content of the textbook. Students were assessed using two exams during the semester and a final comprehensive exam. All exams consisted of multiple-choice questions. Writing is an important component of the General Education requirement at the University of Iowa. Prior to the course transformation, the writing component was a 250-word abstract associated with a service-learning experience. Due to the time required for assessing the writing assignments for a large population of students, no peer review or revision was incorporated into this assignment.

Transformed Process

The project team consisted of an instructional designer and an assessment researcher from the Office of Teaching, Learning & Technology and the course instructors and a senior teaching assistant from the Department of Earth & Environmental Sciences. The team had about 8 mo of preparation time before the transformed course was scheduled for implementation. The major motivations of instructors to participate in this project were to (1) increase students' engagement with course topics, (2) incorporate more meaningful writing projects, and (3) save students' cost by replacing a textbook with digital interactive learning materials.

The process involved three stages: planning, design, and development (Fig. 1). First, at the planning stage, the instructors defined course goals for students in the course: (1) be able to critically evaluate popular media articles related to environmental science; (2) be able to locate and

TABLE I: Course structure and assessment comparison.

	Traditional Course	Transformed Course
Course Structure	Two 75-min lectures per week	Online learning One 50-min lecture by instructors TILE discussion Project session One 50-min lecture by guest lecturers
Class Time	150 min per week	100 min per week
Classrooms	Lecture hall	Lecture hall TILE classroom
Learning Materials	Textbook PowerPoint (PPT) slides by instructors	Online materials (text information, images, and videos) Lecture videos created by instructors PPT slides by instructors PPT slides by guest lecturers
Assessment	2 midterm tests (multiple-choice questions) 1 final (multiple-choice questions) 1 service learning project	7 prelecture online quizzes (multiple-choice questions) 7 module-cap online tests (multiple-choice questions) Clicker questions in the classroom (multiple-choice questions) 2 individual writing assignments and peer assessments 1 group writing assignments 1 final (multiple-choice questions) 1 service learning project

interpret data relevant to environmental science; (3) understand the relationship between day-to-day life and environmental science, particularly in the context of sustainability; and (4) recognize the multifaceted nature of environmental science. The project team also outlined specific timelines for the tasks.

At the design stage, the team made primary course design decisions after review of evidence-based practices reported in the literature. The selected revisions included plans to (1) increase online learning components for students to prepare prior to each class meeting, (2) provide authentic and hands-on learning experience in class, (3) provide frequent formative assessment opportunities and feedback to students, and (4) incorporate richer, multipronged assessment intended to measure students' achievement of the newly defined course goals.

At the design stage, the team decided to incorporate active learning in class and in the online learning components and to use quiz tools in the course site to provide frequent formative assessment opportunities and feedback. A student response system was also considered to provide formative assessment opportunities and increase students' engagement in class while allowing instructors to gauge students' understanding before the class activities. The team also decided to adopt a new technology, Calibrated Peer Review (CPR), to implement peer assessment for the writing projects. CPR is a Web-based application that was developed by the University of California at Los Angeles and enables frequent writing assignments with limited instructional resources (Walvoord et al., 2008). Incorporating major writing projects into the course would add enormous workload to the instructional staff, which was impossible with the current instructional staff capacity. Review of the literature on peer assessment indicated valuable learning benefits in both writing and critical-thinking skills from both receiving and providing feedback to peers' writing (e.g., Patchan and Schunn, 2015). Several studies reported that peer assessment using CPR was effective in improving student learning without adding substantial workload to instructors (e.g., Hartberg, 2008; Clase, 2010; Enders et al., 2010; Likkel, 2012).

In order to provide an authentic and hands-on learning experience in class, the team decided to adopt active learning classrooms. The University of Iowa offers multiple active learning classrooms (called TILE, for Transform, Interact, Learn, Engage) on campus. TILE classrooms are technology infused, which effectively facilitates group work. Each TILE classroom consists of round tables that seat nine students each, projectors and wall-mounted monitors that facilitate the sharing of information, and whiteboards for working out longer problems and for graphic communication. Each table contains three laptops, all connected to the projectors and wall-mounted monitors. Instructors were able to monitor the content displayed on student laptops and to push out the content of a selected laptop to all projectors and monitors to share with the class. Students could easily access all online resources through the laptops and share their work with the rest of the groups. The instructors decided to develop specific instructional activities that were designed for TILE classroom sessions. Guest lectures by local experts were also planned to provide examples and insights that could engage students in local environmental science issues.

Next, in the development stage, the instructors developed course materials (Table I). In place of a textbook, the instructors developed online content related to seven broad topics important to environmental science and society: science and controversy, dynamic earth systems, ecosystem ecology, water systems, food systems, carbon cycle, and climate change. These learning materials were developed from various open-source resources; the instructors also created lecture videos for certain modules.

Two sets of quizzes, a preclass quiz and a module-cap test, were developed for each module. Preclass quizzes focused on the learning materials posted on the course Web site. The purpose of preclass quizzes was to have students prepare before they came to the first class of each module. Each module-cap test was designed for students to check their understanding of the whole topic at the end of the module, including the posted learning materials and in-class activities. Only a part of each module-cap test was created in the development stage, and many items were dynamically created as each module was completed during the semester. The materials for two writing projects and peer assessment were developed as well. CPR requires writing prompts, a rubric, and three sample writings that guide students through the assessment process for their peers' writings.

Instructional activities for the TILE classrooms focused on the hands-on activities in which students applied knowledge to the presented problems and created a type of solution (see the Supplemental TILE Plan; supplemental materials can be found online at http://dx.doi.org/10.5408/15-084s1). Students' interactions and collaborative learning were emphasized in the design of the materials. All learning materials were organized with a consistent look in the course management system (Fig. 2) and included a list of specific learning objectives aligned to Bloom's taxonomy of learning (Bloom et al., 1956) for each module (Fig. 3). Bloom's taxonomy of learning suggests six cognitive outcomes that indicate different cognitive levels: knowledge, comprehension, application, analysis, synthesis, and evaluation (Anderson et al., 2001).

The Office of Teaching, Learning & Technology purchased a license of CPR, installed it in the university network, and tested its capabilities for facilitating peer assessment. The main roles of the instructional designer during the transforming process were to facilitate the transforming process by arranging meetings and checking the working progress and to provide pedagogical and technological support to the instructors by recommending evidence-based pedagogical methods, providing feedback on developed instructional materials, coordinating technology and classrooms, and preparing technology documents for students. The Office of Teaching, Learning & Technology also provided technology training to the instructors.

During the transforming process, the team focused on the consistent flow of all course components and learning materials tied to the main course goals that the instructors defined at the planning stage. The team also discussed evaluative criteria and determined the research design and tools to measure the effectiveness of innovations. The assessment researcher completed an institutional review board application and received approval before the beginning of the transformed course.

Toward the end of the process, the team discussed the strategies for communicating with students effectively regarding course values, different course settings, and assessment and how to provide students with effective technology training. As a result, the instructor developed an introductory video providing a course overview and made it available on the course site (watch the Supplemental Introduction to Environmental Science video). The instructors also planned the first class to communicate with students regarding the course overview and specific components. The team provided the teaching assistants with intensive training on how to support students in the transformed course so that they could effectively coach students with various tasks.

Transformed Course

The transformed course structure and class time were dramatically changed. The course design and assessment components are summarized in Table I. The original two 75-min lectures per week were replaced with a series of 2-week modules organized around one of the seven broad topics. Each module consisted of four 50-min sections: an instructor lecture, a project session, a TILE session, and a guest lecture. This structure reduced traditional instructor–student contact time by one-third. Students were required to study online learning materials, including lecture videos created by the instructors outside of class meetings, and to complete an online quiz to check their understanding prior to the first lecture of each module, as well as upon completion of the module. These supplemental activities were the substantial efforts for students, comprising the balance of the contact time.

The instructors' lecture, attended by all students enrolled in the class, focused on deeper concepts and had students engage in exploration and meaningful discussion of the content they had mastered before coming to class. Even though this class was held in the traditional lecture hall, the instructors managed the seating area to facilitate group discussions. In the second 50-min session of each module, a subgroup of students (one-third of the students per group) met alternatively in the TILE session or project session to engage in the group discussion and hands-on activities in collaborative learning environments. In TILE sessions, students applied knowledge learned from online materials and lecture, produced group reports and products, and submitted them to the instructors at the end of the class for evaluation. During lecture and TILE sessions, instructors posted frequent clicker questions to assess student understanding of core concepts, to initiate discussion, and to tailor their teaching. Instructors also identified the concepts that students missed most from the preclass quizzes and incorporated those concepts into the clicker questions. This helped students clarify difficult concepts.

At the start of each module's second week, a local expert delivered a guest lecture focusing on research, an initiative, or a public policy issue germane to the module topic. The goal of the guest lecture was to expand student learning outside of the classroom and understand applications of the course material in the local community or region. The project session engaged students in writing through discussion of popular versus scientific writing styles, the peer review process, techniques for writing a review, and editing and revising under teaching assistants' and instructors' supervision. The module-cap test at the end of each module covered all contents from online learning materials, instructor lecture, guest lecture, and TILE sessions, as well as some materials from previous modules as the semester progressed.

In addition to frequent online quizzes, students had two writing and peer assessment assignments during the semester that were administered using the CPR application. The first writing assignment was to find an article from a popular online media source (e.g., CNN or Science Daily) and write a short essay that summarized reporting on a scientific study related to environmental science. After students submitted the essay, they calibrated as reviewers using three standards written by the instructors and evaluated three peers' writings based on a rubric that the instructors provided. After the peer review process, students reviewed the essay they had submitted at the beginning of the assignment using the same rubric. The second assignment was to write a short essay reviewing the scientific

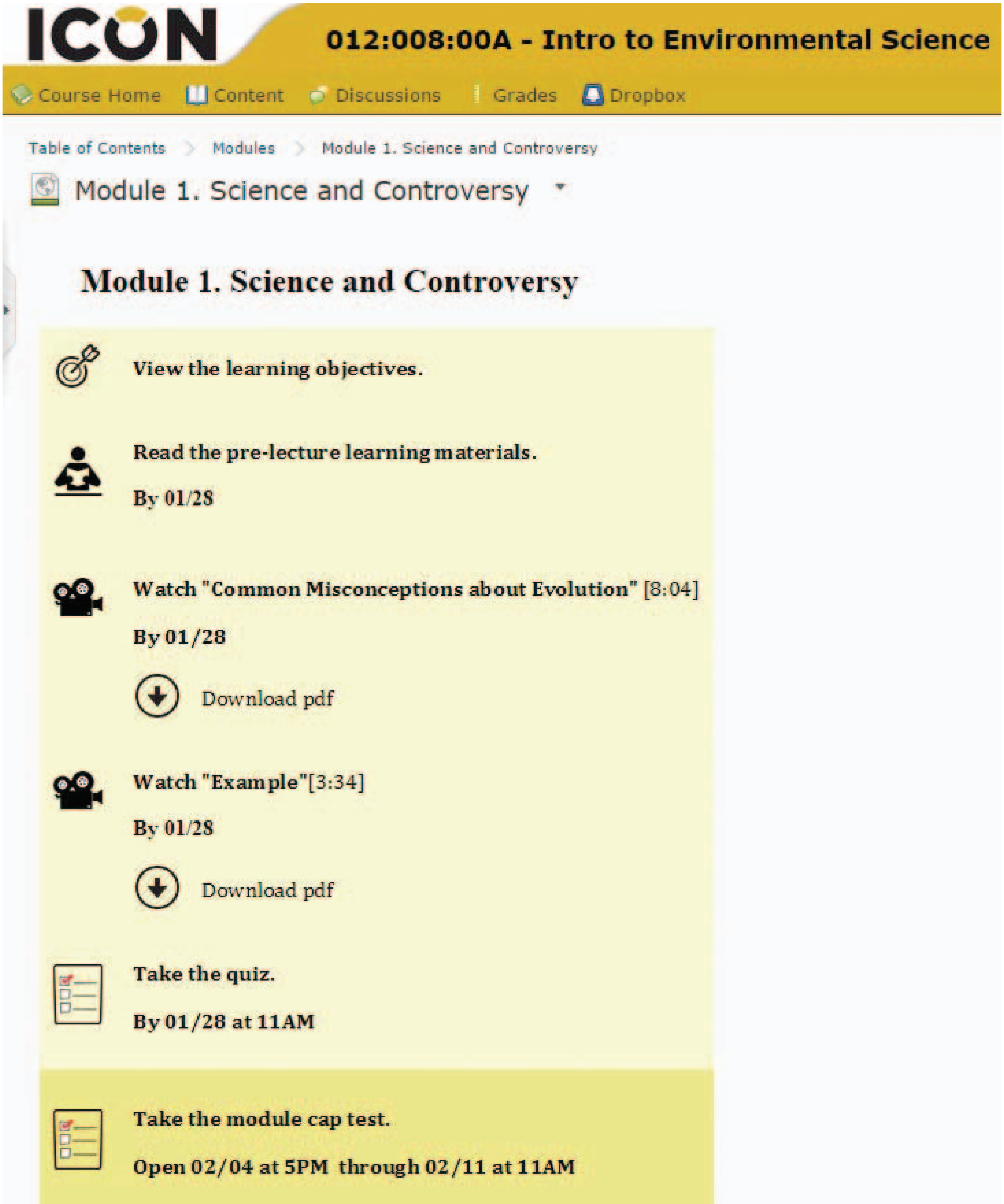

FIGURE 2: Module presentation in the course management site.

Module 1: Controversy in Science

Core Content: Evolution

Learning objectives organized by levels of thinking (Revised Bloom's Taxonomy)

Pre-lecture **Lecture** **Discussion Boards** **Guest lecture** **TILE** **Module Cap**

Increasing cognitive level

Creating	☐ Construct a flow chart to scientifically test the claim "Dr. Ward keeps an invisible dragon in his garage." ☐ Design a study to test the theory of gravity
Evaluating	☐ Compare and contrast the structure, content, writing style of a scientific article and its corresponding news article ☐ Evaluate whether or not humans are currently evolving ☐ Evaluate the effect of controversy on 1) the science community and 2) society as a whole. Do you think controversy is good or bad for each community, and under what conditions? ☐ Why are there so few scientists in political office? ☐ Are humans more highly evolved than other organisms? Explain your reasoning.
Analyzing	☐ Compare the definitions of the words theory, uncertainty and error in science vs. their meanings in broader society ☐ Discuss the effect of political, cultural and economic interests on scientific research ☐ Outline Carl Sagan's baloney detection kit as a supplement to the scientific method ☐ Compare and contrast the structure and information within a scientific journal article with its corresponding news article
Applying	☐ Implement the scientific method to test a hypothesis you can derive from an observation in your classroom (ie., observation: multiple students are wearing "Iowa" shirts, question: are students wearing "Iowa" shirts necessarily from Iowa?, possible hypothesis: only students from Iowa wear "Iowa" shirts) ☐ Apply the four tenets of natural selection to the human population today
Understanding	☐ Explain the process of natural selection and cite examples ☐ Explain the four components of natural selection ☐ Explain the peer review system and its purpose in scientific journals ☐ Explain how uncertainty and error are expressed in scientific articles ☐ Explain specifically how populations of organisms "adapt" to environmental change—is it conscious or unconscious? ☐ Explain how a scientific theory differs from scientific law
Remembering	☐ Define science and distinguish between the findings of science and science as a process ☐ Identify and describe the steps in the scientific method ☐ Characterize the influences of culture and worldview on the public's opinion of science ☐ Describe how the environment influences evolution ☐ Define scientific model ☐ Define theory, uncertainty, and error in science ☐ Describe the "controversy" about the theory of evolution

FIGURE 3: Document of learning objectives posted in the course management site. The document of learning objectives was presented in different colors keyed to indicate to learning contexts. The colors can be viewed only in the online version of the figure.

article corresponding to the popular media article read in the first assignment and critiquing the how the scientific article was presented in the popular media article in light of the results and interpretations presented in the scientific paper. The same sequence—calibration, peer review, and self-assessment—was completed.

All learning activities were presented in authentic contexts (Jonassen, 1999) so that students could see the connection between what they have learned in the course and what is happening in the real world and, in particular, in local contexts. Much effort was put into making meaningful relationships between students' day-to-day life and environmental science. The second week in each module, which was taught by an expert in the topic field, was closely related to current events or issues in the local area that might have had a direct impact on students' daily lives.

The transformed course used technology to provide a rich active learning environment to students; at the same time, it reduced instructors' workload in facilitating activities. Clickers and technology in the TILE classroom greatly contributed to effective teaching and collaborative learning. In addition, the course management system was an effective platform for communicating with students, accessing learning materials, managing resources, and managing frequent formative assessments and feedback. The course management system provided various statistics that the instructors used to customize their teaching to fit students' needs. For example, the item statistics of each preclass quiz enabled instructors understand what concepts students were having difficulty with before starting the module.

Writing assignments and peer assessments were possible in this large enrollment class with the CPR system. Once the instructors created an assignment by entering writing prompts, rubrics, three sample writings, and answer keys and setting the grading criteria in the CPR system in advance, the CPR system then managed the students' activities. After students submitted their writings, the CPR system shuffled all writings and randomly assigned three students' writings to each student to review and evaluate. In reviews, students not only gave a numeric value but also provided detailed written feedback for each rubric item. After the reviews, students evaluated their own writing using the same rubric. Anonymity was guaranteed in the whole process. After the assignment, students accessed the results, including their performance on calibrations, reviews, and self-assessment, and evaluation results and detail feedback from all three reviewers.

DATA COLLECTION

Multiple data were collected to assess students' attitudes, engagement, satisfaction, and performance in the transformed course compared to the previous course that was traditionally taught. In addition, main course components were investigated related to students' perceptions of helpfulness to their learning. Student surveys were administered four times during the semester: at the beginning and at end of the semester and two times in the middle of the semester. Participants' demographic information, prior learning (e.g., ACT scores and cumulative grade point average, or GPA), and course grades were collected at the end of the semester. In addition, one focus group interview was administered during the semester. A focus group interview and free-response comments in the self-reported surveys were used to assess students' perceptions of helpfulness of course components and overall perceptions of the transformed course in depth. After the entire interview was transcribed, the contents of the transcription and students' comments in the surveys were examined with respect to the main course components.

Baseline Data From the Traditional Course

The same instructors taught the course in the traditional lecture-centered course format a year before the transformed course was offered. In order to assess the effectiveness of the transformed course on students' attitudes, engagement, satisfaction, and performance, the baseline data from the same course were collected. The baseline data were from 191 students who participated in the study. The assessment researcher collected those students' prior learning data, including cumulative GPA, demographic information, and performance scores, from the registrar's office and administered a survey at the end of the semester. The survey was used to assess students' engagement level, satisfaction, interest, and preparedness; the same questions were used in the fourth survey in the transformed course.

Survey Instruments

Interest and Preparedness

Five questions were asked to assess students' interest and preparedness for the class (see Supplemental Survey Questions). Each question had a 5-point response scale rating from 1 (never) to 5 (very often).

Engagement

The engagement measure contained three separate subscales: behavioral engagement, emotional engagement, and cognitive engagement. This measure consisted of 14 items with a 7-point response scale rating from 1 (strongly disagree) to 7 (strongly agree). Behavioral and emotional engagement questions consisted of 10 questions and were adopted from the questionnaire in Skinner et al.'s study (2009). Cognitive engagement questions consisted of 4 questions and were from Senko and Miles's study (2008).

Satisfaction

Four questions were created to assess students' overall satisfaction with the course. This measure included four Likert-scale items with a response scale ranging from 1 (completely disagree) to 7 (completely agree).

Course Objectives

Four overall course objectives were presented to assess students' perceptions of helpfulness of the course to achieve them: (1) be able to critically evaluate popular media articles related to environmental science; (2) be able to locate and interpret data relevant to environmental science; (3) understand the relationship between day-to-day life and environmental science, particularly in the context of sustainability; and (4) recognize the multifaceted nature of environmental science.

Course Components

Nine course components were presented to assess students' perceptions of helpfulness of each component to achieve the course objectives (see Supplemental Survey Questions).

Participants

Data from 191 students (77% of the total enrollment) were collected in the traditional course for the baseline. Of the 191 students, male students were 53.4% of the participants, and freshmen were the largest group (38.7%). The next year, 132 students participated in the research study of the transformed course, representing 85% of the total class enrollment. Of the 132 students, male students were 43.2% of the participants, and freshmen were the largest group, comprising 37.9% of the participants. White students were the largest group (75%) and the race/ethnicity information of nine students (6.8%) remained unknown (Table II). There were no significant differences in the demographic background of the students in terms of gender and academic years between the students in the traditional course and those in the transformed course.

TABLE II: Participants in traditional and transformed courses.

	Traditional	Transformed
Total Participants	191 (77% of the total enrolled students)	132 (85% of the total enrolled students)
Gender	Male: 53.4%	Male: 43.2%
	Female: 46.6%	Female: 56.8%
Academic Year	Freshmen: 38.7%	Freshmen: 37.9%
	Sophomores: 26.5%	Sophomores: 22%
	Juniors: 21.5%	Juniors: 23.5%
	Seniors: 12.6%	Seniors: 16.7%
	Other: 0.5%	
Ethnicity		White: 75%
		African American: 2.3%
		Asians: 3.8%
		Hispanic or Latino: 6.1%
		International: 2.3%
		Multiracial: 3.8%
		Unknown: 6.8%

Results

Student Self-Reported Survey

Student interest, preparedness, engagement, and satisfaction in both traditional and transformed courses were assessed by a student self-reported survey at the end of the semester. However, students' perceptions of helpfulness of the course to achieve the course goals and how helpful each course component was for achieving the course objectives were assessed only in the transformed course. In particular, students' perceptions of helpfulness of the course components were assessed two times in the middle of the semester.

Five questions were asked to assess student interest in the course and preparedness. The results from an independent *t*-test indicated that students in the transformed course prepared for the lecture and were interested in the course significantly more than students in the traditional course (Table III). In particular, the effect size of completing all readings before the lecture was significantly large ($d = 1.4$). However, there was no significant difference regarding note taking during the lecture between two groups.

In both courses, 14 questions were asked to assess student engagement at the end of the semester. The students in the transformed course reported a significantly higher engagement level than did the students in the traditional course. Among the three types of student engagement (behavioral, emotional, and cognitive engagement), behavioral and emotional engagement were significantly higher, with the p value at a 0.001 level, and cognitive engagement, with the p value at a 0.01 level, than the engagement levels in the traditional course (Table III).

Four questions were asked to assess students' satisfaction at the end of the semester in both courses. The students in the transformed course indicated that they were more likely to take another course in environmental science than the students in the traditional course and were more interested in environmental science than they were before they took this course. The students in the transformed course reported higher overall satisfaction with the course than did the students in the traditional course (Table III).

In the transformed course, we assessed how helpful the course activities were to the students for achieving the course goals. The instructors in the transformed course clearly defined four overall course goals and redesigned the course to facilitate students' achievement of these goals: (1) be able to critically evaluate popular media articles related to environmental science; (2) be able to locate and interpret data relevant to environmental science; (3) understand the relationship between day-to-day life and environmental science, particularly in the context of sustainability; and (4) recognize the multifaceted nature of environmental science. Students' perceptions of the effectiveness of the course to achieve those goals were positive. The means of students' responses on each goal ranged from 5.91 to 6.01 on a 7-point scale. More than 90% of students responded positively that the course was helpful to achieve the course goals.

Two separate surveys (Surveys 2 and 3) asked students about how helpful each course component was for achieving the course objectives. Nine course components were presented to assess students' perceptions of helpfulness: online reading materials, online videos, lectures by the instructors, guest lectures, TILE activities, clicker questions, group projects, CPR writing assignments, and online quizzes. The CPR assignment was not included in Survey 3, because there was no CPR assignment in that period. The means of students' responses on all components were higher than the midpoint. That is, students perceived all components to be relatively helpful. There were no significant differences between two times except in terms of clicker questions and group projects. Students responded that the clicker questions and group projects were less helpful in Survey 3 than they did in Survey 2. Among the nine components, students reported that online readings and video materials were the most helpful elements, whereas guest lectures, group projects, and CPR assignments were reported as less helpful. Surprisingly, students reported the online quizzes were helpful in their learning, along with online videos and readings (Fig. 4).

TABLE III: Results of *t*-test and descriptive statistics for students' interest in the course, preparedness, engagement, and satisfaction.

	Traditional			Transformed			95% CI for Mean Difference (Upper, Lower)	*t*	df
	Mean	SD	*n*	Mean	SD	*n*			
Interests and Preparedness									
How often did you complete all of the reading assignments before the lecture?	2.06	0.92	141	4.53	0.84	110	2.70, 2.25	21.84***	249
How often did you bring your clicker with you to class?	4.40	1.12	141	4.87	0.41	110	0.70, 0.24	4.01***	249
How often did you feel interested in the content of the lecture?	2.50	0.81	141	3.60	1.03	110	1.30, 0.88	9.5***	249
How often did you talk about what you learned in the course with friends and family?	2.27	0.96	141	2.79	1.28	110	0.80, 0.24	3.69***	249
How often did you take notes during the lecture?	3.54	1.44	141	3.28	1.28	109	0.09, 0.60	−1.45	248
Engagement (combined all 3 constructs ([14 questions])	4.58	1.20	140	5.26	0.99	109	0.96, 0.40	4.75***	247
Behavioral engagement	4.69	1.32	140	5.12	0.94	109	1.04, 0.45	4.99***	247
Emotional engagement	4.35	1.43	140	5.22	1.23	109	1.10, 0.42	4.44***	247
Cognitive engagement	4.74	1.44	140	5.26	1.28	109	0.82, 0.13	2.74**	246
Satisfaction									
Would take another course in environmental science	4.26	2.06	140	4.83	1.91	109	1.06, 0.06	2.20*	247
More interested in environmental science than I was before I took this class	4.71	1.88	140	5.24	1.63	109	0.97, 0.08	2.32*	247
Would recommend this course to my friends	4.85	1.80	140	5.60	1.55	109	1.17, 0.32	3.45***	247
Overall satisfaction with this course	4.87	1.58	136	5.39	1.42	110	0.90, 0.15	2.77**	244

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Focus-Group Interview and Free-Response Comments in the Surveys

In the transformed course, a focus-group interview was conducted to assess students' perceptions of each course component in depth. Three students participated in the focus-group interview. In the surveys, open-text fields were provided to collect students' comments about the course as well. Students' comments were organized by each course component, and their perceptions of each component were summarized. Students' quotes were directly extracted from the transcription of the focus-group interview and the comments in the surveys.

Online Learning Materials and Quizzes

Overall, students perceived the online learning materials and quizzes as helpful. Students reported that the online materials were thorough and interesting, and they liked the flexibility of being able to read and watch videos on their schedule and in any location. Students felt that online quizzes were relatively difficult and detail oriented, but overall, students perceived them as helpful in their learning.

> *"[I] liked everything available online to do at your own pace and when you have free time." (student 802003 from Survey 4)*

> *"Small quizzes kept me going. To be honest I feel like I am already prepared for my final exam." (student 802011 from Survey 4)*

> *"I really liked the biweekly quizzes/capstone tests. Breaking the class into modules was great and I really feel like I learned a lot." (student 802047 from Survey 4)*

TILE Discussion

Students perceived that the TILE discussion sessions were fun, were interactive, and allowed them to exchange ideas, and they believed that tasks and activities were closely connected to the real world.

> *"I thought (TILE) was fun because it was very open ended.... It was interesting to see all of the other students, they came up with different ideas.... I like that ... they're fun and out of ... non-traditional, and very interactive.... I liked the food one where we had to look up where food came from. I thought that was very real world... applicable... so like now when you're at the grocery store purchasing something you kind of like remember ... 'Oh I wonder where this came from.'" (student 1 from the focus group interview)*

> *"Having TILE activities to help give real world examples of the material we learned about in class."(student 802013 from Survey 4)*

CPR Assignments

Students expressed mixed perceptions of the CPR assignments. The positive points were related to anonymity

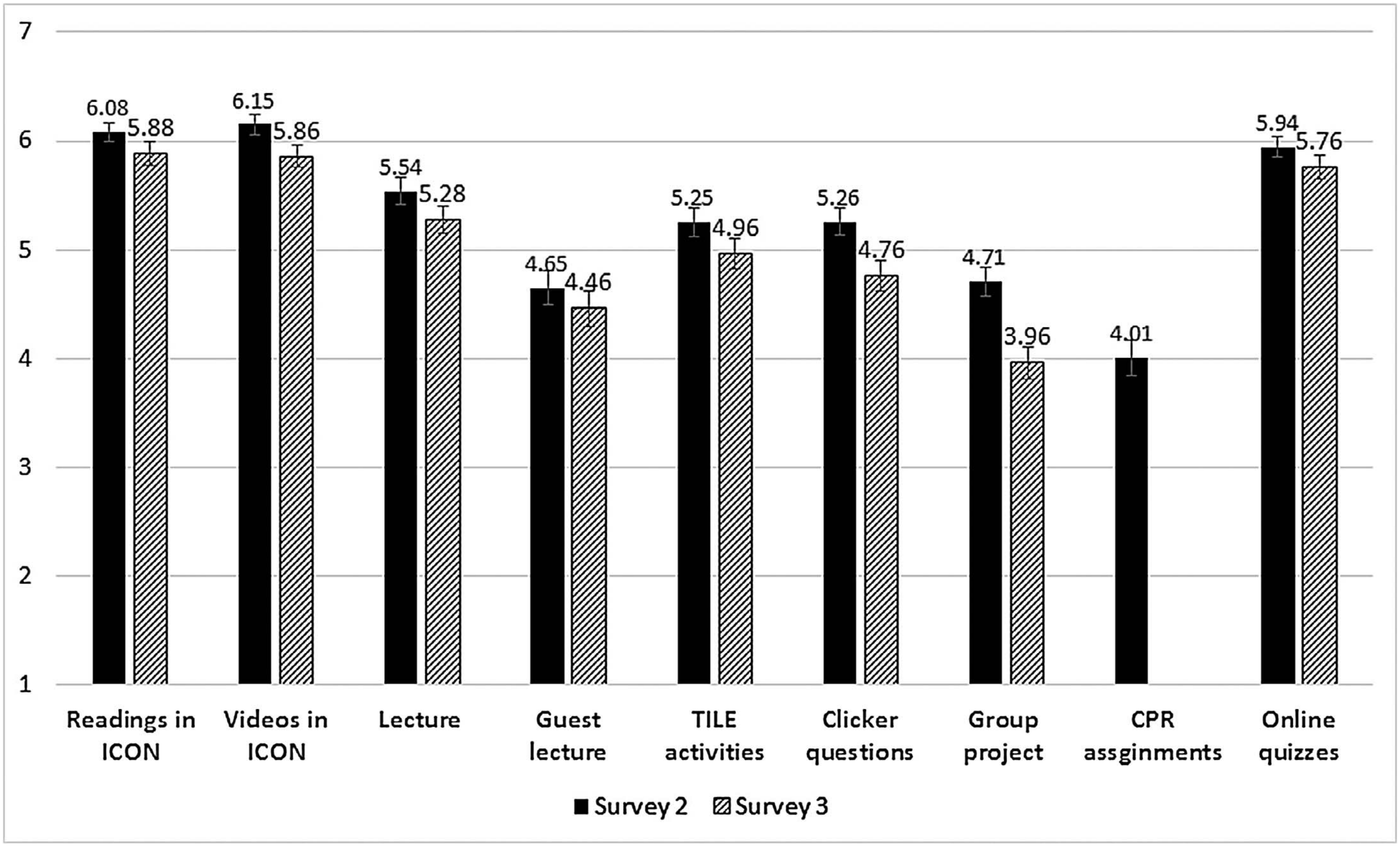

FIGURE 4: Students' perception of helpfulness of the course components for achieving the course goals.

and helpful guidelines in the process. Students did not know whose writings they were evaluating and who evaluated their writings. Students perceived that the rubrics were helpful because they clearly guided students in what to look for in peers' writings. Another positive point was the process of evaluating their own writing after reviewing three peers' writings because they could see their mistakes more easily.

> *"[I] paid more attention more about my writing, which is probably the whole purpose of it because you review your own.... It's very guided, you know. Peer review is usually pretty tough. I like that you don't know whose paper it is, you don't know who's writing it. And having 3 reviews was helpful.... The guidelines were easy to follow.... Like compare your writing to your peers so when ... I think that the last stage of the peer review that you have to review your own writing, and you kind of change your perspective writing after you've seen other people's and kind of you can see your mistakes better." (student 2 from the focus group interview)*

However, some students mentioned that learning the CPR system was confusing and that they did not like to be evaluated by peers. Not surprisingly, students seemed to need time to understand the CPR system. Several students expressed difficulty in the second survey, which they completed after the first CPR assignment. However, a few students mentioned a difficulty in the fourth survey, which they completed after the second CPR assignment.

> *"The Calibrated Peer Review assignments are difficult to complete correctly. I do not feel editing papers has anything to do with Environmental Science." (student 802067 from Survey 2 after the first CPR assignment).*

The same student mentioned "CPR review from peers" as the most helpful aspect of this course.

> *"CPR review from peers, gave me a better understanding on how to improve my writing." (student 802067 from Survey 4 after the second CPR assignment)*

Guest Lecture

Students expressed mixed opinions about the helpfulness of the guest lectures in their learning. A few students mentioned that the guest lecturers were hard to follow and some were too dry, while some students perceived they were helpful to understand real application in local areas and liked the connection between what they learned and what is happening in the real world.

> *"I found the guest lecturers difficult to pay attention to and learn from. I had a hard time relating it to the class content and what I was supposed to be learning." (student 802046 from Survey 4)*

TABLE IV: Measures of learning outcomes.

	Traditional			Transformed		
	n	Mean	SD	*n*	Mean	SD
Cumulative GPA	184	2.89	0.58	131	2.99	0.62
Final grade	191	2.49	0.91	129	3.33	0.88

"I actually really liked the guest lectures.... We're learning from environmental scientists and it's interesting to learn from like paleontologists and biologist about the same sorts of things. So we hear different perspectives." (student 2 from the focus group interview)

Overall Course

Many students indicated positive perceptions of the course. First, students felt that their instructors were more approachable than the instructors in other large lecture courses. Second, providing different ways of learning, such as online learning, guest lectures, and TILE sessions, were viewed positively by many students. However, the various learning contexts presented challenges to some students. A few students expressed that it was hard to make connections among learned concepts from the different contexts of lecture, TILE discussion, and guest lecture. Furthermore, students felt that they needed self-regulated learning skills, planning, and better organization in order to succeed in this course.

"I definitely appreciate that they're trying to go about a different approach to the class, it's not a traditional Monday, Wednesday, Friday lecture." (student 2 from the focus group interview)

"I loved how the professors were our discussion teachers! It made it feel more personalized which was helpful to me because science is not my strong area. I felt more comfortable going up to these professors and asking questions than any of my other professors." (student 802124 from Survey 4)

"The different components (lecture, TILE, discussion, lab) all coming together and reinforcing concepts learned in different ways." (student 802027 from Survey 4)

"The biggest challenge was trying to incorporate lab, lecture, and TILE/project session. I felt they didn't flow well together, so it was a challenge to connect the material together." (student 802079 from Survey 4)

Learning Outcomes

Students' final exam results and course grades in both courses were collected to examine the effectiveness of transforming the course on students' learning outcomes. The mean score of students' final test in the transformed course was 64.27 (SD = 11.83), and the mean in the traditional course was 58.58 (SD = 10.26). Multiple linear regression analysis was used to test whether the course variable (traditional versus transformed) significantly predicted students' final test performance. The results indicated that two predictors explained 47% of the variance [$R^2 = 21.6$, $F(2, 309) = 42.60$, $p < 0.001$]. The course variable significantly predicted the final scores ($\beta = 21.8$, $p < 0.001$), as did cumulative GPA ($\beta = 38.9$, $p < 0.001$). The results indicated that students in the transformed course achieved higher scores on the final test than did the students in the traditional course after controlling for their cumulative GPA.

Likewise, students in the transformed course received higher grades than the students in the traditional course ($F = 95.44$, $p < 0.0001$). The means of the final course grades were 2.49 for the students in the traditional course and 3.33 for the students in the transformed course (Table IV). In the multiple linear regression analysis, students' cumulative GPA was controlled to assess the effect of the transformed course on students' final grade. The results indicate that the course variable was highly significant ($\beta = 0.78$, $p < 0.0001$): students in the transformed course earned, on average, about three-fourths of a letter grade higher on their final grade in the course after controlling for cumulative GPA (Table V).

DISCUSSION

The instructors defined clear course goals and redesigned the course incorporating evidence-based pedagogy and instructional technology that had been previously supported by multiple research studies. Incorporating online learning elements seemed to have a positive impact not only on students' learning, with mastery of content knowledge, but also by developing self-regulated learning, which is one of the critical skills needed for success in academics (Schunk and Zimmerman, 1994). While students could access the learning materials anytime and anywhere, they needed to manage their own time effectively to learn the materials and complete the required assignments on time. One of the significant differences between the traditional and the transformed courses was students' preparedness for the course. The students in the transformed course reported that they read assigned readings significantly more often than the student in the traditional course. Furthermore, the students in the transformed course reported that online quizzes were one of the most helpful elements of the course. Many students expressed

TABLE V: Parameter estimates for model predicting final grades.

Parameter	Estimate	SE	*t* Value	Pr > |*t*|
Intercept	0.43	0.22	1.95	0.0524
Cumulative GPA	0.71	0.07	9.63	<0.0001
Transformed course (baseline = traditional course)	0.78	0.09	8.87	<0.0001

$F(2, 309) = 95.44$, $p < 0.0001$.

that online quizzes helped them to keep on track during the semester and had them better prepared for the final exam. Frequent preclass and module-cap online quizzes seemed to foster self-regulated learning skills. In the transformed course, students regularly prepared for each class by studying the course materials, taking preclass quizzes, and reviewing what they learned at the end of the module. The module-cap online quiz included the materials from lecture, guest lecture, and TILE discussion, in which students could not perform well without attending and paying close attention to all classes. This preparation and the reviews might contribute to higher engagement in the transformed course compared to the course that was traditionally taught in 2013.

Adding writing assignments and peer assessments using the CPR system seemed to contribute to not only expanding student learning outside of the classroom but also cultivating critical thinking skills of how to critique popular media articles related to science. As several students expressed, the CPR assignments provided opportunities for students to identify mistakes in their writing and improve their writing skills. A few students, however, reported negative perceptions with the CPR assignments, such as feeling uncomfortable with being evaluated by peers, difficulty to understand the CPR system to complete assignments correctly, and not fully understanding of the purpose of writing assignments in a science course. The nature of students' resistance to peer assessment in higher education has been explored by several research studies (e.g., Kaufman and Schunn, 2011). This resistance has been documented despite the findings that peer assessment has improved student writing and critical thinking skills (e.g., Topping, 1998). However, that resistance can be alleviated when students have positive learning experiences in the process of giving and receiving helpful feedback. Instructors' thoughtful design of writing assignments and rubrics are essential for guiding students effectively, and proper training and communicational strategies are required in advance. Students need to understand the values and purpose of the activities to engage in the tasks meaningfully and gain the positive learning experiences as instructors intend.

Incorporating TILE discussion seemed to have a positive impact on students' engagement. Unlike a typical large lecture hall, the active learning classroom provides an informal, relaxed, and egalitarian classroom environment, and it fosters learning alliances between students and instructors and among students (Baepler and Walker, 2014). Several students mentioned that their instructors were more approachable than other instructors in typical large lecture courses that they had taken. Informal and relaxed classroom environments might contribute to creating positive relationships between students and instructors. In addition, the physical layout of the TILE classroom facilitated collaborative learning effectively, and the technology in the room might increase the productivity and creativeness of group work.

Jonassen (1999) specified that the optimal learning environment cultivates students' active construction, allowing students to explore, discuss, and meaningfully construct concepts and relationships in contexts that involve real-world problems and projects that are relevant to the learners. Many students in the transformed course appreciated the different ways of learning and enjoyed engaging in multiple tasks that were connected to real-world applications. Presenting the course contents in various contexts and having students engage in hands-on projects in collaborative learning environments seemed to increase students' interest and engagement.

Limitations and Future Work

While assessment results showed a significant increase in student engagement and learning outcomes, two recurring negative comments from the students should be recognized. First, connectivity of multiple learning contexts was mentioned as an issue. Although the instructors tried to create good flow among different learning contexts—large class sessions, TILE sessions, guest lectures, and project sessions—some students could not fully understand the core concepts and main objectives of those different contexts and seemed to be confused. Many students are accustomed to a typical large lecture format and might expect the same learning environments throughout the semester. Therefore, multiple learning contexts might sometimes disrupt their flow of learning. Additional communication strategies, including visual elements, could be developed to show how different learning contexts come together to foster the learning process.

Second, the guest lectures should be reconsidered. While many students perceived guest lectures as helpful for understanding how their learning applied to real-world settings, some students viewed them as too dry and hard to understand. The course instructors cannot control the content and delivery of guest lectures. All guest lectures should be reviewed, and those that fit broad student interests and students' level of understanding should be incorporated into the class.

Lastly, among the course components, students responded that the clicker questions and group projects were less helpful in Survey 3 than in Survey 2. The third survey was conducted after completing Modules 4 and 5, whereas the second survey was given after completing the first three modules. The clicker questions and group projects in Modules 4 and 5 should be reexamined and revised, if necessary, to improve student learning.

Essentials for Course Transformation

Redesigning a course, in particular, a large enrollment course, is a daunting task to instructors, who lack time, resources, and a background in educational design. However, collaboration with the Office of Teaching, Learning & Technology made this transformation successful. The team started the process 8 mo before offering the redesigned course, which was the appropriate time to plan, design the course components, and develop course materials. The clear course goals that instructors defined in the planning stage were critical in the design and development stages. The course goals were developed in terms of learning outcomes, which students should have achieved when they completed the course. All design decisions were made and materials were developed to achieve the course goals. Pedagogical and instructional technology support from the instructional designer assisted instructors not only with the decision-making process but also with the coordination of multiple instructional technologies in the process so that instructors could focus on the learning materials and instructional activities that would matter most in student learning. Having sufficient time to redesign the course was essential, in particular, when new pedagogical methods and instructional technology were implemented. Instructors needed to fully understand the advantages of newly adopted instructional technology and to be aware of potential issues that might occur during the semester. To be effective in implementing new course activities with instructional technology, instructors need to address those potential issues to facilitate their students' learning. The key to success in this transformation was the continued support of all team members through all project stages, including implementation and discussion of outcomes.

CONCLUSIONS

Today's complex world demands that employees be creative and flexible problem solvers who can work effectively in groups rather than simply knowing how to use tools and knowledge in a single domain (Grabinger, 1996). In order to be a creative and flexible problem solver and effective collaborator, students must learn to think critically and apply knowledge to multiple contexts in collaborative learning environments.

Redesigning a course to create a rich active learning environment is not a simple task for instructors who teach a large number of students. However, the instructors of the Introduction to Environmental Science course collaborated with the team of the Office of Teaching, Learning & Technology and redesigned the course by adopting evidence-based pedagogy and technology to provide a rich active learning environment. This collaborative work significantly increased student engagement and learning outcomes compared with the same course that was traditionally taught by the same instructors in a previous semester. This study suggests that clearly defined course goals and measurable learning outcomes will initiate the process of redesigning a course to encourage meaningful student engagement, thereby leading to better student success.

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