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Redesigning Physical Geography 101: bringing students into the discussion

Jeremy Tasch and Weiwei C. Tasch

ABSTRACT
This article analyses student-learning outcomes from the redesign of Introduction to Physical Geography 101. Among the purposes of the redesigned course were to enhance student learning by providing rich interactive online content, provide more meaningful instructor–student and peer–peer exchanges, and to promote attitudes that facilitate student opportunities to construct new knowledge. Through empirically testing two of the redesigned course's key components on students' learning, we determine the positive effects on students' exam scores. We offer, despite the additional work required from instructors and teaching assistants for such a redesigned course, that with further refinement these pedagogical changes may offer potential longer term impact on students' learning behaviors.

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Student-centered learning; course redesign; physical geography; econometric analysis

Introduction

While large class size in US universities is not a new occurrence, there are more students entering higher education than in the past and class size is tending to increase (US News, 2015). Large lecture courses are often used to fulfill university general education requirements and in many instances serve as gateway courses as students decide which major fields of study to pursue. In addition to larger numbers of students, class composition is increasingly – albeit unevenly – diverse in terms of students' socioeconomic and cultural backgrounds, experiences, and ages (Biggs, 1999; Teitelbaum, 2011). Students consequently also vary in terms of their preparation, interest, and motivation. This can further create challenges for and among students, while adding greater and more complex demands on instructors.

Large classes, commonly situated in amphitheater-like rooms with rows of chairs securely bolted to the floor, have traditionally relied on lecture-centered pedagogy with minimal opportunity for active student engagement, and where learning assessment has more often been reliant on memorization than critical thinking. In a lecture format, instructors may find themselves compelled to approach students as if they were homogenous in terms of
course preparation, learning style, motivation, and subject interest. Students may consequently become passive learners, discouraged from asking questions or making contributions (Mulryan-Kyne, 2010). In other words, the traditional large class arrangement can adversely affect students’ intellectual development, learning, and academic success. Instructors in turn may find large class settings more awkward for stimulating student responses, leading to superficial discussions if they actually occur.

Successful completion of introductory courses is particularly vital for first- and second-year students. However, students’ drop-failure-withdraw (DFW) rates in these large-enrollment courses averagely range from 15% at research I universities, to 22–45% at comprehensive universities (Twigg, 2004). Class size can adversely affect the quantity and quality of interactions and exchanges between students and instructors, fostering students’ inattention or absence from class (Biggs, 1999).

William E. “Brit” Kirwan, while chancellor of the University System of Maryland, clearly expressed his perspective on large-lecture format courses: “The passive, large lecture method of instruction is dead. It’s just that some institutions don’t know it yet” (Anderson, 2013). As more students are considering colleges and the number of college-aged students is increasing (US News, 2015) – while concurrently many public and private academic institutions’ are seeking ways to stretch their budgets – Chancellor Kirwan’s pronouncement may be overstated. However, it may be possible to combine the learning advantages associated with small classes and one-to-one student and instructor interactions, with the cost-effectiveness that accompanies large class size.

**Context**

This paper discusses the outcome of a Spring 2013 pilot of the redesign of Geography 101, Introduction to Physical Geography, offered at Towson University, an institution of the University of Maryland System. The redesign aimed to enhance learning quality by delivering meaningful and directed instructor–learner exchanges and providing rich interactive online content (see Sher, 2009; Smart, Witt, & Scott, 2012; West, Paul, Webb, & Potter, 2013). Rather than facilitating the passive memorization of large quantities of information – a feature of many introductory geography 101 courses as well as other physical and life sciences classes – the course redesign attempted to facilitate active inquiry and opportunities for independent learning as students acquire disciplinary knowledge and skills (Gibbs, 1988). Active inquiry-based learning is question driven, instructor facilitated and student centered (Day, 2012). It generally varies in implementation, but for the redesigned 101 it includes small group problem-solving and focused discussion, and independent – but guided – interpretation and analysis through online weekly assignments. Thus, a primary objective of the redesign was to create a student-centered, participatory, motivational course model to give immediacy and relevance to introductory physical geography, and which if successful could lead to a redesign of the university’s other introductory geography classes (see also Smart & Csapo, 2007). Further, the course – and instructor – endeavored to promote a supportive learning environment, where students perceive a direct connection between effort and result and recognize the instructor as a supportive rather than obstructionist influence in the learning process (see Supplementary material for students’ views on the redesigned 101 course).

The focus of this research is to test whether engaging students in this form of active inquiry-based learning can effectively achieve one of the redesign’s major goals, the learning
and retaining of course material. Inquiry encourages knowledge construction by students rather than traditional knowledge conveyance by the instructor. Lecture as part of an exposition instructional model is not necessarily abandoned: after all, students nonetheless will find themselves sitting in lectures, conferences, staff meetings, and other types of "sage on the stage" trainings in and outside of academia. But these traditional approaches are supplemented in the redesigned 101 with daily opportunities for both instructors and students to collaboratively build and reflect on their learning. As a core general education course content acquisition is not forfeited, but rather, students are drawn into the process of their own learning. To be effective, constructivist rather than exposition-centered course designs require significant intellectual and time investment from the instructor and course assistants to turn students into active participants rather than passive listeners (see also Bishop & Verleger, 2013). To this end, the redesigned 101 revised office hours and weekly online assignments into active small group discussions and problem-solving activities that more directly connect to the discipline and to the world – and as much as possible to students’ lives.

Faculty who encounter pressure to increase the class size of their introductory courses need to reconcile how to engage larger numbers of students in and outside the classroom as students themselves may feel increasingly distanced from their own learning. Instructors and university administrators must determine the balance between course redesign and pedagogical revision on one hand – which can require substantial instructor commitment of time and energy, and the uncertainty of actual student test score improvements on the other hand. Indeed, advocates for new approaches to active learning are enthusiastic and earnest, but while they tend to emphasize students’ empowerment as students assume more responsibility for their own learning, they may de-emphasize the investment of significant instructor effort that may result in only minor student test score improvements (Colliver, 2000). The significant effort and resources that went into this redesigned geography 101 course compared to the overall – yet modest – improvements in student test scores may appear to some as disheartening. Research indicates, however, that improvements in student learning by changing pedagogical approaches are uncertain. Improved test scores, however, are only one indicator of the potential benefits of course redesign. In this respect, it is fitting to bring students into the discussion. For this redesigned geography 101 course – notwithstanding only minor improvements in students’ average exam results – the majority of students not only enthusiastically supported but actually enjoyed the course’s approach to learning. Improvements, both in students’ academic achievement and attitudes towards learning, should be carefully considered and not be dismissed lightly (Dubin and Taveggia, 1968; Prince, 2004).

In the following section we introduce the conceptual framework for the design of the pilot course, the incentive mechanism for encouraging instructor–student and peer tutor–student interactions outside of the classroom, and briefly discuss the self-managing online learning system. Section two, “The Data,” briefly describes the process we used to generate the data for this study. In section three, “Econometric Models and Estimation Methods,” we introduce the main econometric model employed to test the effect of participation in office hour discussions and online assignments on student test performance, with a range of estimation methods. We present the outcomes in section four, “The Results,” of the econometric analyses. Section five concludes the study, and offers directions for further consideration.
Conceptual framework

Introduction to Physical Geography 101 is primarily taught in a traditional lecture setting, two and a half hours per week, accommodating 600–800 students per semester in 18–24 sections, generally taught by 5–7 tenured and tenure-track professors, and 2–4 contingent instructors. The traditional lecture-and-testing format offers students few opportunities to learn collaboratively from one another or interactively from diverse assignments that could address a range of learning styles. Student participation and engagement with course materials, each other, and with the instructor has tended to be both passive and inconsistent. The department’s use of multiple editions of traditional physical geography textbooks by Arbogast (2007), Christopherson (2015), de Blij (2013), Petersen, Sack, and Gabler (2011) and Strahler (2013), contribute to this conventional exposition-style of pedagogy as these texts tend to approach physical geography as modular (i.e. textbook chapters are designed to stand on their own rather than creating an interconnected narrative) and learning as a matter of factual information acquisition.

The redesigned 101 employed a supplemental course model (see the National Center for Academic Transformation, www.thencat.org/PlanRes/R2R_ModCrsRed.htm). The basic structure of a traditional introductory physical geography course was retained. However, it was supplemented with a stronger emphasis on interactive in-class presentations together with pre-recorded audio–video lectures available online. An incentive mechanism was added to encourage students to participate more actively in the course through small group recitations held during office hours – where one-on-one and small group learning experiences would be facilitated by the course instructor, the graduate teaching assistant (TA) and the seven undergraduate learning assistants (ULAs) who helped ensure that office hours were held five days a week, and twice daily on Tuesdays and Thursdays (cf. Howard-Jones, Demetriou, Bogacz, Yoo, & Leonards, 2011 on the motivational use of incentives for learning). In this manner, the large classroom format was supplemented with a range of focused one-to-one and small group interactions that facilitate higher level cognitive skills and that can help to ensure that the needs of students with low motivation and specific learning challenges are better recognized and addressed (Harfitt, 2013; Mulryan-Kyne, 2010; Vajoczki, Watt, Vine, & Liao, 2011). At the same time students with strong science preparation, who may not be able effectively to exercise their involvement in the course in the setting of a large lecture auditorium, are encouraged to engage in more sustained conceptual and applied discussions. This form of course participation, largely conducted outside of the classroom, is detailed further in the subsection, “Innovating the Traditional Lecture Setting.”

The course also incorporated an online electronic system for weekly quizzes and assignments. This web-based package of learning materials, provided by the publisher through their online platform, provides diverse resources to fit a range of learning styles, is easily editable by the instructor, and accommodates further instructor-created assignments and postings. Students could work on the assignments at their own pace Sundays through Fridays, and could attempt each assignment as many as three times, with guiding hints (and minor diminishment of credit for each unsuccessful effort) in order to achieve a minimum C level mastery of the material. Students had frequently scheduled opportunities to meet with the instructor, the course’s TA, and the ULAs in person as well as online (through
SKYPE, Webex, and email) to review concepts based on individual need synchronously and asynchronously.

For instructors teaching large course sections, online homework is particularly appealing. Online assignments remove the delay in collecting, grading, and offering students feedback. Students receive evaluations in a more immediate manner than had they turned in hard copy assignments to be assessed by even the most conscientious instructors. Because online assignments draw on multimedia – including video, audio, animation and hands-on data manipulation (in addition to reading and writing) – instructors can construct online tasks that target multiple skills, encouraging higher order analysis by building up from lower level cognitive skills.

Drawing from other research, this type of blended learning – where students have access to a combination of classroom instruction, outside of class interaction, and e-learning – seems to enhance students’ understanding of course material compared to traditional classroom pedagogy (Harlen, 2013; Rappolt-Schlichtmann et al., 2013; Thorne, 2003; Yamamoto, Nakayama, & Shimizu, 2014). Engaging students in inquiry-based learning in a blended learning environment, wherein the strengths of face-to-face and online learning approaches are combined for a dynamic learning experience that involves a high level of interactivity among peers and instructors, can provide students greater support and more motivational learning experiences (Cranton, 2006; Hakverdi-Can & Sönmez, 2012). The more often students are able to engage actively in extended discussions and dynamic learning-centered activities, the more likely they are to learn and retain course material (Brackenbury, 2012).

Thus, the interconnected goals of this redesign initiative were to restructure a larger-than-average-lecture course (120 students and more) to better create the atmosphere of a smaller, interactive class, and to use technology to augment students’ learning (Rooney, 2012). Further, if this model were to be applied across all sections of geography 101, among the broader goals would be a lowering of the DFW rate (grades of D and F, and class withdrawals), while maintaining – and perhaps reducing – the costs of instruction for the university (e.g. fewer instructors teaching the same if not more students would lower the cost of instruction and reduce demands on classroom space).

**Challenging traditional pedagogy and challenged pedagogical innovation**

As a general education course that fulfills a university scientific literacy requirement and that also serves as a gateway course to a major in geography, physical geography is not only about knowledge acquisition but includes development of intellectual skills and attentiveness to the learning process. Although students meet weekly in a classroom, education obviously is not constrained by the classroom's walls. As part of a robust physical geography course, students are expected to understand and use particular vocabulary to describe major ideas, apply logical reasoning to analyze information, and develop the confidence and background to discuss scientific issues of current importance to society (Bednarz, Chalkley, Fletcher, et al., 2008; David, 2005; Wainwright, 2012). Students can learn to do this and to demonstrate their competence through active one-on-one and small group engagement with their peers and the instructor, as well as through active independent work. In other words, active participation is a significant component of this redesigned physical geography course and thus, in addition to assessment based on in-class exams, participation in outside of class
active discussions and problem solving with peers and the instructor is both encouraged and tangibly recognized (cf. Wrenn & Wrenn, 2009).

Classroom instruction in a large lecture hall can be challenging: students may be reticent to participate in large class discussions and instructors may find facilitating an inclusive discussion with many students unmanageable. Smaller group settings, however, may put some students at ease and can offer instructors a more manageable venue. Researchers following Vygotsky (1962) find that student learning is strongly facilitated through the interactions students have with their peers and with their instructors. Accordingly, instructors can create a learning environment that augments learners’ opportunities to interact with each other through collaboration, feedback, and discussion (Vygotsky, 1962). Discussion is a powerful method for active learning. A well-facilitated discussion allows the space and the time to explore new ideas and to review challenging concepts in a collaborative environment. Part of the challenge, however, is to attract students to join small group discussions beyond scheduled class meeting times. Many students believe that lecture attendance and independent review should be adequate to “learn the material.”

Rather than requiring students to participate in discussion groups scheduled outside of the course’s regular lectures, an incentive mechanism was implemented as a way to encourage involvement in weekly office hours. Although called “office hours,” these were organized as academic recitations to help students clarify and review course material that was perhaps not fully understood or that was inadequately discussed in the limited time of the more formal lecture. Joining office hours was consequently considered a form of course participation (see also Meyers, 2003; Skyrme, 2010). Not only is the inclusion of participation – as a function of office hours engagement – a “carrot” to the “stick” of learning (the “stick” often equated with exam points), participation in small group and one-to-one office hours can provide encouragement and confidence to students, who then may be better prepared to participate in the larger lecture-hall discussions (Pfund et al., 2013; see also Li & Pitts, 2009. See Supplementary material for students’ anonymous comments on this form of course participation).

Innovating the traditional lecture setting

With a large number of undergraduate students meeting in a traditional amphitheater-style lecture hall, in-class instruction prior to the course redesign only occasionally included small group hands-on experiments and smaller group discussions. Class meetings, while sometimes including some form of pair-share activity as well as full class discussions, more frequently relied on short animations and directed lectures.

Lecturing remains among the most widespread teaching strategies in higher education; it offers a direct method to communicate information (Bligh, 2000; Burgan, 2006). Cognitive neuroscience and applied psychological research, however, suggests that more direct student-centered learning approaches – including small group discussions – are more effective for stimulating critical thinking, inspiring subject interest, and improving oral communication skills (Dallimore, Hertenstein, & Platt, 2008; Hamann, Pollock, & Wilson, 2012; Huerta, 2007). But as class size increases, instructors are more challenged to facilitate inclusive discussions and students have less motivation to participate (Nicol & Boyle, 2003). Consequently, the redesigned course transformed office hours into an incentivized setting for students to participate in collaborative small group discussions (Casteel & Bridges, 2007; Pollock, Hamann, & Wilson, 2011).
An office hour visit – which is counted as a minimum of 30 minutes of interactions but often lasting for an hour and a half – allows an actively attending student an opportunity to earn two “participation points,” the equivalent of one correctly answered exam question. All students were invited to participate in these relaxed discussion groups, but only students asking questions and joining the discussion received actual participation credit. Because students can spend an entire lecture class simply listening and taking notes, these small group meetings were intended to encourage risk-free active questioning, discussing, and collaboratively puzzling through problem sets and applying course concepts to real-world examples. To this end, students were requested to bring their own prepared questions to office hours, which they might draw from the weekly homework assignments, the textbook, or from the examples introduced in the classroom. Indeed, throughout the semester the instructor, graduate teaching assistant, and the ULAs encouraged students to ask and answer their own questions in the small group settings as well as in the classroom, and to choose questions from the weekly homework assignments that they felt were particularly intriguing or, conversely, confusing. Questioning plays a critical role in cultivating critical thinking skills and active learning; it models for students not only how to observe the physical environment, but to think about what they observe.

Students determined their own frequency of outside-the-lecture course participation, and they were consequently – and tangibly – recognized for their efforts. To provide students with additional flexibility for outside of lecture participation ULAs – undergraduate learning assistants – were incorporated into the course.

Adding ULAs to the redesigned 101 fundamentally increased the opportunities for personalized assistance available to students while providing ULAs with part-time academic employment at a fraction of the cost of a graduate teaching assistant. Because students usually regard ULAs as their peers, they may be more comfortable admitting their course difficulties to ULAs than to a graduate teaching assistant or to the professor. Drawn from colleagues’ recommendations for students who had taken the course previously and had scored in the upper 20th percentile, and had demonstrated appreciation for the subject and seemed reliable, a pool of outstanding undergraduate students was interviewed and seven ULAs were selected. The combination of ULAs, one graduate teaching assistant, and the instructor provided 18 hours of weekly office hours. To supplement questions brought by participating students, the instructor, graduate teaching assistant, and ULAs exchanged pre-prepared, open-ended but directed discussion questions to ensure office hour sessions were more than informational exchanges and to better engage students in the active learning process. A careful record of attendance – including time, date, and participation level (i.e. which students brought questions to the office hour and who engaged in discussion) – was maintained for every student for each of the three exam periods of the semester. Students were permitted to choose for themselves how many participation points they would earn (i.e. how many office hours in which they would participate). The semester was divided into three exam periods: points earned during each exam period were added to that respective exam’s raw score.

The course’s three tests were all equally weighted for 25% of the total grade and none of the three tests were cumulative. Before the first test, 54 students made 127 office hour visits; between the first and second tests, 55 students participated in 236 office hour visits. As the semester progressed, an increasing number of students participated more often in discussions outside of the scheduled lecture. Following the second test and leading up to
the last exam, 72 students completed 405 office visits. Across the semester, 86 students (approximately 70% of enrolled students) visited office hours 768 times.

The integration of office hours as a fundamental course component was not attempted previously in Geography 101. Indeed, the department’s full-time and contingent faculty who teach Introduction to Physical Geography 101, in answer to an informal survey, reported that during an average semester perhaps fewer than 10 students might attend respective office hours, regardless of class size. The spring 2013 pilot course, with 768 recorded office hour visits by 70% of the class, logged more visitations than any other 101 class.

**Self-managing the learning experience**

Inquiry-based learning is an instructional method that involves significant amounts of self-directed, albeit guided learning by the students, where relevant problems provide the context for the learning that follows. The aim is to empower students to both acquire knowledge and to exercise analytical judgment. Through the disciplinary lens of geography, the weekly assignments employed a diverse range of web-based material and activities that required students to scrutinize logical relationships among data, construct and test arguments, view phenomena from different vantage points, and to derive evidence-based solutions.

The online system was set up to allow students up to six days to complete each assignment. Students could work at their own pace, independently or collaboratively, on their own schedule at the time and location of their choosing, with pre-determined and consistent weekly submission deadlines announced at the start of the semester. In cases where students working through their assignments incorrectly answered a question, they would be offered online guidance in the form of a directed hint, a textbook page number, a web link, or an analogy to assist them to reconsider their answer. Thus, rather than simply providing students with graded work following submission, the course’s online multimedia system facilitates a dynamic learning environment for students who might otherwise have found assignments static and the learning materials disengaging (Johnson & McKenzie, 2013; Tambouris et al., 2012). In this pilot semester, the average percentage of completed online assignments was above 80%, and the average score across the semester was approximately 71%.

**The data**

The spring 2013 pilot of the redesigned Physical Geography 101 course generated the data used in this analysis. Students enrolled in this course are predominantly first- and second-year students, although third- and fourth-year students also frequently enroll. In the pilot course, 126 students enrolled at the beginning of the semester. Four students dropped during the two-week add/drop period at the semester’s start, and 122 students completed the course. In the first class meeting, the instructor distributed hard copies of the course syllabus in addition to posting it online, explained course policies and expectations – including an overview of the textbook (available as hard copy and e-copy), grading structure, the mechanism to earn participation points, and demonstrated the online assignment system. Students were also introduced to the graduate teaching assistant and the seven ULAs.

At the beginning of the semester the instructor, TA and the ULAs discussed among themselves their time availabilities and together they scheduled their office hours to maximize
opportunities for student attendance. For every office hour attended participants’ names were recorded, as was the length of time each attended as well as the type of attendance (e.g. active involvement or passive listener). For students who chose not to participate, a “0” was recorded for them. The three in-class tests administered during the semester divided the course into approximately three equal segments. Each segment generated a set of cross section data consisting of 122 observations, since there are 122 students. Pooling these three sets of cross section data, we generated a panel data-set constructed from the three equal semester segments consisting of 366 observations, three observations for each of the 122 students.

Students’ online homework assignments were assessed through the Pearson Publishing Company’s *Mastering Geography*, and individual performances were reported to each respective student in real time as they completed each weekly assignment. There were 13 homework assignments distributed across the 15-week semester. Each assignment varied in the number of questions as well as topic. Each assignment, however, included a distribution of reading comprehension, graphing, animation and video, and brief research questions. There were four homework assignments in the period before the first test, and five and four for the second and third exam periods, respectively. The total points a student could earn cumulatively from the assignments in each of the three exam periods were 27, 67, and 56. The points a student earned in each period were scaled to a 100% base. For instance, if a student earned 13.5 points (out of 27), 33.5 (out of 67) and 28 points (out of 56) in exam periods one, two, and three, then the scaled assignment performance is transformed to 50, 50, and 50% for first, second, and third segments, respectively. Each of the 122 students has a scaled assignment score for each exam period.

Tests included material covered during each specific period of the semester and each was assessed on a 100-point scale. There are 122 observations (i.e. 122 students) for each test and 366 total observations for the three tests distributed across the semester in panel data (used for the fixed effect estimation, see discussion, below), and 122 observations in the cross section data. As the semester progressed from the first to the final exam, the number of students participating in office hours steadily rose. This positively correlates with an upward trend in test scores. Concurrently, as the semester progressed a greater number of students not only performed better on the three tests but they also performed increasingly well on the weekly online homework assignments. Because these positive correlations can obviously be attributed to a variety of confounding effects (including unobserved factors such as frequency on campus, prior science courses, current GPA and study habits, and so forth), we apply specific estimation methods to account for these variables and to distinguish causation.

**Econometric models and estimation methods**

While records of students’ office hour participation and online homework assignment scores suggest an encouragingly high degree of course involvement outside of the scheduled lectures, we need to see whether engaging students in this form of active inquiry-based learning can effectively achieve one of the initiative’s major goals, the learning of course material (Sekeres, Coiro, Castek, & Guzniczak, 2014; Harlen, 2013). In this section, we test the effect of office hour visits and online assignments on students’ test performance using the empirical data generated by the pilot course. We test whether there is potential
causality from two of the key redesign components – participation in office visits and online assignments – on students’ test performance, and then to what extent this can be shown. Since each method of estimating the effects that these two redesign elements may have on test scores will have limitations, in the following discussion we construct and refine our model to account for confounding influences, triangulate findings, and cross-check results for consistency. The use of multiple estimations can enhance confidence in overall conclusions and offset the biases or shortcomings of any single method (Beichner & Saul, 2005; Judd and Kenny, 1982). Furthermore, we ask whether there is a threshold after which participation in additional office hour visits will not produce a positive marginal benefit on student test performance.

**The model**

Equation (1) can represent the relationship between test score, office hour participation and online assignments,

\[
\text{Test} = \beta_0 + \beta_1 \text{Visit} + \beta_2 \text{Assignment} + \epsilon
\]

(1)

“Test” is a student’s raw test score, not including any credits earned from office hour participation and online assignments. We choose the raw test score to avoid any compounded inflation in the estimated effect of office hour participation and online assignments on test performance. “Visit” is the frequency a student participates in office hours with the instructor and teaching assistants in advance of an exam, and “Assignment” is the total a student earns from all possible online homework assignments before an exam. The course has three independent tests, and each test focuses on a selection of key topics; thus, Visit and Assignment before the first test is directly relevant only for the first test. Similarly, Visit and Assignment between the first and second test have a direct bearing only for the second test; Visit and Assignment following the second test applies only to the third test. Test is determined by the two explanatory variables, Visit and Assignment, and other unobserved factors are contained in \( \epsilon \).

**Potential for compounding effects**

When we estimate the Model in Equation (1) using simple ordinal least square estimation, or linear least squares, the estimated effect from the independent variables is potentially subject to unobservable variables and other compound influences. Thus, while using OLS estimation appears intuitive, we expect that OLS estimation might offer a misleading estimation between Test and the explanatory variables. The covariance between the independent variable Visit and the error term \( \epsilon \) and the covariance between the independent variable Assignment and the error term \( \epsilon \) are both likely to be positive, and thus we would likely overstate the true effect of office hour participation and online assignments on students’ test performance.

Moreover, students’ performance may systematically improve as the semester progresses, or, conversely, may worsen as the pressure of the final examination period approaches. Consider, for example, that in the first segment of the semester a number of students might not fully recognize the possible benefits they could derive from actively participating in office hour visits. As the semester was concluding, however, it is also quite plausible that students
might perform poorly on the final 101 exam due to their overwhelming end-of-semester schedules, other courses' demands, and associated anxieties. Furthermore, there are a range of other factors that may influence an individual's test scores, including prior education and familiarity with basic environmental science knowledge, other academic, professional, and familial demands, time management skills, and so forth. Therefore, to control for these unobserved compounding effects, we use fixed effect estimation not only to account for differences among students, but also to address the systematic differences among students’ test performance, office visiting behavior and assignment participation relative to each of the three exam periods (Imbens & Wooldridge, 2009; Wooldridge, 2006/2009). Thus, fixed effect estimation accounts for omitted variable bias (i.e. the potential for compounding effects) by measuring change within the total group of 101 students at specific time periods. By measuring in this manner, across the three semester segments, we are able to control for a number of the potential omitted variables unique to this group of students (Dougherty, 2008/2014).

The fixed effect estimation: how to account for student differences and systematic changes between the three test periods (time fixed effect)

To capture these individual compounding effects, we define period one as the time period before test one, period two as the time between tests one and two, and period three as the time period between the second test and final test. We denote a variable’s subscript “i” as an individual student, thus \( i = 1, 2, 3, \ldots 122 \), and \( t \) as a semester time segment, thus \( t = 1, 2, 3 \). (Note the meaning for these subscripts remains for the following five equations.) The fixed effect estimation method disaggregates the error term, \( \varepsilon \) in Equation (1). Consequently, let \( \varepsilon_{it} = u_i + z_{it} \) to separate the inherent differences among individual students in the class, thus students’ individual differences are denoted by \( u_i \), and the error term for student \( i \) in time \( t \) by \( z_{it} \). Assume that both the covariance between office visit participation and the error term and the covariance between assignment and the error term are zero, then we derive

\[
\text{Test}_{it} = \beta_0 + \beta_1 \text{Visit}_{it} + \beta_2 \text{Assignment}_{it} + \beta_3 \text{Period} + \alpha u_i + z_{it}
\]  

In Equation (2), Test_{it} is the test score of an individual student, \( i \), in period \( t \). Visit_{it} and Assignment_{it} are office hour participation and the online assignment result of student \( i \) in time period \( t \). The particular differences among individual students now are captured by \( u_i \). The variable Period is simply the particular test period of the semester, 1, 2, and 3. \( \alpha \) is a group of dummy variables (each representative of an individual student).

Following Equation (2), we consider that there are systematic differences among students’ test performances, office visiting behavior and online homework assignment participation during each of the three exam periods. Thus, in Equation (3), we add a new variable, \( \nu_t \), to better denote students’ changing performance between the three semester time periods, where \( t = 1, 2, 3 \). Accordingly, let \( \varepsilon_{it} = u_i + \nu_t + z_{it} \) to further separate the period effect from inherent differences among individual students, \( u_i \), and the error term for student \( i \) in time \( t \) by \( w_{it} \). The coefficient \( \delta \), which is a group of dummy variables, estimates students’ performance variability between the time periods systematically.

\[
\text{Test}_{it} = \beta_0 + \beta_1 \text{Visit}_{it} + \beta_2 \text{Assignment}_{it} + \alpha u_i + \delta \nu_t + w_{it}
\]
Table 1. Variable description, Equations (1)–(3).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test raw</td>
<td>Raw test score, range 0–100, used for fixed effect estimation</td>
</tr>
<tr>
<td>Test1 raw</td>
<td>Raw test score of test 1, range 0–100</td>
</tr>
<tr>
<td>Test2 raw</td>
<td>Raw test score of test 2, range 0–100</td>
</tr>
<tr>
<td>Test3 raw</td>
<td>Raw test score of test 3, range 0–100</td>
</tr>
<tr>
<td>Visit</td>
<td>Times visited office hours, used for fixed effect estimation</td>
</tr>
<tr>
<td>Visit1</td>
<td>Times visited office hours in first period of the semester</td>
</tr>
<tr>
<td>Visit2</td>
<td>Times visited office hours in second period of the semester</td>
</tr>
<tr>
<td>Visit3</td>
<td>Times visited office hours in third period of the semester</td>
</tr>
<tr>
<td>Scaled assignment</td>
<td>Scaled assignment performance, %, used for fixed effect estimation</td>
</tr>
<tr>
<td>Scaled assignment1</td>
<td>Scaled assignment performance in first period, %</td>
</tr>
<tr>
<td>Scaled assignment2</td>
<td>Scaled assignment performance in second period, %</td>
</tr>
<tr>
<td>Scaled assignment3</td>
<td>Scaled assignment performance in third period, %</td>
</tr>
<tr>
<td>Period1</td>
<td>Period between the beginning of the semester and test 1</td>
</tr>
<tr>
<td>Period2</td>
<td>Period between test 1 and test 2</td>
</tr>
<tr>
<td>Period3</td>
<td>Period between test 1 and test 3</td>
</tr>
</tbody>
</table>

Dependent variable: Test raw (for panel data) and Test1 raw, Test2 raw, Test3 raw (from cross section data).

**Partial effect of assignment on visit and marginal return on office hour visits**

Student participation in an office hour visit may have varied effects on test scores for students who performed differently on online homework assignments. To address this additional potential confounding effect, we would like to know that given a particular score on an assignment – say the mean value of an assignment – how many points, if any, might one additional office hour visit change a student’s test score from the mean. At the same time, we recognize that too many office visits may lead to a diminishing return on students’ raw test scores. Thus, we need to determine the optimal number of office hours, per exam period, in which a student can participate in order to strengthen their raw exam score.

In Equation (4) we add an interaction term of Visit and Assignment, “Visit * Assignment,” in addition to Visit, to estimate the effect participation in an office hour may have on a test score.

$$\text{Test}_i = \beta_0 + \beta_1 \text{Visit}_i + \beta_2 \text{Assignment}_i + \beta_3 \text{Visit}_i \times \text{Assignment}_i + \alpha u_i + \delta v_i + w_{it} \quad (4)$$

In Equation (5), we introduce another new term, \(\text{Visit}^2\). This new variable will help us to uncover whether participation in an office hour will have a negative, positive or constant return on test performance. If participation in office hour visits has a diminishing marginal return, then we will be able to estimate the optimal number of office hour visits, per exam period, that a student can expect will lead to a stronger exam score.

$$\text{Test}_i = \beta_0 + \beta_1 \text{Visit}_i + \beta_2 \text{Assignment}_i + \beta_3 \text{Visit}^2_i + \alpha u_i + \delta v_i + w_{it} \quad (5)$$

Taking into consideration both the partial effect and the marginal return from participation in an office hour, the fixed effect may give us an even better estimation of the effect of participating in an office hour visit, as well as the optimal number of visits. This is shown in Equation (6), below.

$$\text{Test}_i = \beta_0 + \beta_1 \text{Visit}_i + \beta_2 \text{Assignment}_i + \beta_3 \text{Visit}_i \times \text{Assignment}_i + \beta_4 \text{Visit}^2_i + \alpha u_i + \delta v_i + w_{it} \quad (6)$$
Level effect on test

We also want to estimate the nonlinear relationship between test performance and the explanatory variables. Regressions on the log of Test and the variables of Equations (3)–(6) will allow us to test the approximate constant percentage effect of office hour participation and assignment results on test performance. The results of these regressions are summarized in Table 3.

Results

Table 1 describes all the variables considered in Equation (1) and its refinements – Equations (2) and (3). Table 2 presents the summary statistics for these variables. Table 3 summarizes the main findings determined from the regression performed on all six equations discussed above and their level effect tests. Each of the Estimations – 3–6 – passed F tests, which allows us to reject the hypotheses that the coefficient of any variable in the above estimations is zero. In other words, each variable (e.g. office hour visits, weekly assignments, student differences and so forth) effectively explains the dependent variable (i.e. student test performance).

Result from regressions on log of test and the variables of Equations (3)–(6) (level effect on Test) is consistent with the result of regressions on the test raw score and the regressions on Equations (4)–(6). Details of log test are summarized in Table 3.

The results of ordinary least squares, (estimation 1 in Table 3), suggest that participation in office hours has statistically significant positive effects on raw test scores in each of the three exam periods of the semester. The coefficients of office hour participation in the three periods are 0.53 ($t = 1.60, p < 0.10$), 0.38 ($t = 2.53, p < 0.05$) and 0.19 ($t = 1.76, p < 0.01$). Thus, holding online assignment ("Assignment" in the equations) fixed, participating in one more office hour ("Visit" in the equations) tends to increase a student’s test score by 0.53, 0.38, and 0.19 points in the semester’s exam periods one, two, and three, respectively. The online homework assignments show statistically significant positive effects in each exam period of the semester. The coefficients of Assignment are 0.13 ($t = 2.54, p < 0.05$), 0.14 ($t = 3.95, p < 0.05$), and 0.11 ($t = 3.00, p < 0.01$) in periods one, two, and three respectively. Holding everything equal, a 10% increase in assignment performance increases test scores in period one, two, and three by 1.3, 1.4, and 1.1 points, respectively. While the positive effects on student test scores from office hour participation and online assignments are anticipated, office hour participation and online homework assignments together explain only a small
Table 3. Results derived from regression performed on Equations (1)–(6).

<table>
<thead>
<tr>
<th>Equation</th>
<th>Test1 raw</th>
<th>Test2 raw</th>
<th>Test3 raw</th>
<th>Test raw</th>
<th>Test raw</th>
<th>Test raw</th>
<th>Test raw</th>
<th>Log test</th>
</tr>
</thead>
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<tr>
<td>Visit1</td>
<td>0.534</td>
<td>0.135</td>
<td></td>
<td>(2.54)**</td>
<td>(1.69)*</td>
<td>(1.69)*</td>
<td>(1.69)*</td>
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<tr>
<td>Visit2</td>
<td>0.347</td>
<td>0.141</td>
<td></td>
<td>(2.53)**</td>
<td>(2.53)**</td>
<td>(2.53)**</td>
<td>(2.53)**</td>
<td>(2.53)**</td>
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<tr>
<td>Visit3</td>
<td>0.190</td>
<td>0.114</td>
<td></td>
<td>(1.76)*</td>
<td>(1.76)*</td>
<td>(1.76)*</td>
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<tr>
<td>Visit</td>
<td>0.939</td>
<td>0.853</td>
<td>1.028</td>
<td>(3.44)**</td>
<td>(3.73)**</td>
<td>(3.24)**</td>
<td>(3.12)**</td>
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<td>(3.44)**</td>
<td>(3.73)**</td>
<td>(3.24)**</td>
<td>(3.12)**</td>
<td>(3.21)**</td>
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<td>Scaled</td>
<td>0.070</td>
<td>0.075</td>
<td>0.098</td>
<td>(1.65)*</td>
<td>(1.17)**</td>
<td>(2.16)**</td>
<td>(1.96)*</td>
<td>(2.08)**</td>
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<tr>
<td>assignment</td>
<td></td>
<td></td>
<td></td>
<td>(1.65)*</td>
<td>(1.17)**</td>
<td>(2.16)**</td>
<td>(1.96)*</td>
<td>(2.08)**</td>
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<tr>
<td>Period</td>
<td>−0.527</td>
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<td>(3.00)**</td>
<td>(0.72)</td>
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<td>−0.0003</td>
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<tr>
<td>Visit²</td>
<td>−0.083</td>
<td>−0.071</td>
<td>−0.002</td>
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<td>61.665</td>
<td>60.490</td>
<td>58.763</td>
<td>59.035</td>
<td>58.300</td>
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<td></td>
<td>(14.72)**</td>
<td>(21.18)**</td>
<td>(22.12)**</td>
<td>(18.00)**</td>
<td>(20.08)**</td>
<td>(18.02)**</td>
<td>(19.14)**</td>
<td>(17.89)**</td>
</tr>
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<td>R²</td>
<td>0.084</td>
<td>0.194</td>
<td>0.116</td>
<td>0.079</td>
<td>0.606</td>
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<td>366</td>
<td>366</td>
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</tbody>
</table>

Notes: Absolute value of t-statistics are shown in parentheses. Statistical significance is indicated by *** for the 0.01 level, ** for the 0.05 level, and * for 0.10 level. Regressions with Test raw and log test as dependent variable used Robust standard error.
portion of raw test scores in each period ($R^2 = 0.08$ in period one, $R^2 = 0.19$ in period two and $R^2 = 0.12$ in period three).

The result of fixed effect estimations (estimations 2 through 6, in Table 3), however, generates more accurate estimations and enhances the explanatory power of the model. When considering that there are differences among students (in terms of their course preparation, disciplinary interest, motivation, and so forth), participation in office hours displays statistically significant positive effects on test performance at the 1% level in each of the estimations. Completion of online homework assignments also offers statistically significant positive effects at a minimum of the 10% level (note that in Equations (3)–(6), the positive effect is statistically significant at the 5% level). The $R^2$ values for all estimations – estimation 3–6 – are consistently above 0.56. The results of Equation (2) through (5) are presented in Table 3.

Equation (6) suggests that – holding everything else equal – one more office hour visit tends to increase test score performance by 1.86 ($t = 3.12$, $p < 0.01$) points, and a 10% increase in assignment performance tends to improve students’ test scores by 0.94 ($t = 1.96$, $p < 0.01$) points in a single exam period. Given that the mean value of Assignment across the students is 70.6 (this is the average of the three scaled assignment means, Table 1), then from this the effect of each office hour participation on test score yields a 1.15 point increase above the mean test score (which is calculated from 1.86 to $0.01 \times 70.6$, where 1.86 is the coefficient of Visit and 0.01 is the coefficient of Visit*Assignment). Estimation 6 also reveals that participation in office hour visits may reach a diminishing marginal return on test performance (the diminishing marginal return is not statistically significant in Equation (6), $t = 1.57$, $p > 0.10$; however, it is significant in Equation (5), $t = 1.98$, $p < 0.05$). Equation (5) suggests that the optimal number of office hour visits for students during each of the three exam periods is 11. Further, Equation (6) suggests, given that office hour participation might have a partial effect on online assignment performance, and that there are likely varied effects for students who have different assignment performance levels, that for a student who has an average assignment performance (e.g. 70.6%), eight office hour visits during each of the semester’s three test periods is optimal to increase individual test scores. By the same token, students performing less than the average on the weekly assignments may benefit by attending more than eight office hours. Conversely, students who are performing above the average on their weekly assignments may benefit by attending fewer than eight office hours.

**Conclusion**

Theories of learning have long emphasized the benefits for students when instruction facilitates collaborative and engaged construction of their own understanding (Kropotkin, 1885; Piaget, 1926). But undergraduate science instruction largely remains caught in an instructional model of the professor and the textbook as the primary conveyors of knowledge and instruction dependent on lecturing. Student-focused learning theories and practices, however, challenge the theoretical bases of the traditional instructor-centered “teaching by lecture” method. Few investigations, however, employ quantitative analyses to uncover how active learning influences student exam performance in undergraduate science courses (Freeman et al., 2014).

We found strong evidence that office hour participation has significant effect on students’ test performance during each of the semester’s three testing periods. For the entire class (from the least to the highest performing students), in each of the three exam periods one
more office hour visit will increase the test score by 1.86 points (up to an optimal 11 office hour visits, generally speaking, per exam period). A 10% increase in assignment performance increases a test score by less than one point. While this suggests some improvement on test performance by students who improve their results on the weekly homework assignments, clearly the effect is relatively minor. This, however, is not surprising as the online assignments and exams assess related but parallel skills and types of knowledge. To do as well as possible in the course it is obviously important to attend class, participate regularly in office hours, complete weekly assignments, and habitually review the textbook.

The piloted redesign of Introduction to Physical Geography 101 aimed to promote analysis, synthesis, and evaluation of course material through meaningful and directed instructor–learner and peer–peer exchanges and to enhance learning by providing parallel interactive online content. These two primary components of the redesigned 101 show positive effects on students’ test performance throughout the entire semester. It does not necessarily follow from these results, however, that students who successfully complete the redesigned 101 consequently developed deeper, long-lasting and transferable problem-solving skills to their other courses. Tracking the possible long-term pedagogical impacts associated with the redesigned 101 is difficult, and the incentive mechanism for instructor–student interaction and peer-to-peer exchange is only available in this single redesigned course section. But for this particular course, participation in office hours and weekly online homework assignments enhanced students’ overall performance in the course.

Instructors – and increasingly administrators – must assess for themselves how much improvement in student test scores is significant enough to warrant course redesign and pedagogical revision. Advocates for active learning may enthusiastically cite improvements in student course performance, but omit that the extent of the enhancement may be small (Colliver, 2000). This can be problematic when extra effort is required to produce student improvement, as is clearly the case for the redesigned 101. But at the same time, research indicates that achieving improvements in student learning through changing instructional approaches is quite challenging. Thus, improvements in students’ academic achievement should be carefully considered and not be dismissed lightly (Prince, 2004).

Consequently, we suggest that these pedagogical and curricular adjustments are worth consideration as they will not only positively impact average student performance in individual courses but could have longer term influence on students’ learning behaviors and practices. One undergraduate ULA, for example, speaking from her experience working with 101 students, insightfully offered that

A 75-minute lecture is only good for a well-focused, auditory learner and even they may struggle as there is a limit to how much information can be retained in this time. This approach [employed by the redesigned 101] to teaching is innovative in that it engages students in various ways that will ultimately increase retained knowledge …. I also believe this kind of an approach is a good transition for 101 students who are typically right out of high school in that it encourages out of classroom critical thinking skills and develops studying habits traditional public high schools do not give kids. In addition to this, most of the students I have worked with the past two semesters have never had a geography class and are so overwhelmed by the breadth and depth of information that they barely know where to begin asking questions.

In considering the merits of course redesign, it is appropriate to bring students into the discussion. In fact, from the perspective of students, the majority who completed Introduction to Physical Geography 101 indeed suggests that opportunities to participate
in small-facilitated discussion groups are both instrumental in the learning process and enjoyable (see Supplementary material). The literature largely agrees: students tend to appreciate being active participants rather than passive receivers. The traditional techniques used in large lecture courses to involve students during the lecture have limitations. Particularly challenging is engaging more than a few select students into a discussion, where instructors nonetheless remain the communicators of knowledge and students the recipients. Small group discussions, however, when well facilitated and with clear accountability measures, encourage participants to build shared understandings of new concepts while developing a more vigorous appreciation of the nature of the discipline as they engage in dialogue with their peers.

Several of the goals of the redesign were achieved. In addition to acquiring introductory disciplinary knowledge, students who completed the redesigned 101 practiced many of the skills needed in the workplace, ranging from collaborating in small groups to applying information to solve real problems. The redesigned 101 enrolled more students than any other course offered by the geography department, while at the same time it provided more daily opportunities to discuss and interact with peers and the instructor than any other geography course before or since its piloting. Students applied web-based technology interactively to explore and illustrate geographic concepts and techniques, and were more empowered compared to traditional physical geography courses to manage their own learning. This redesign, however, did require the instructor to dedicate more time and energy than needed for traditional 101 courses. Thus, as geography faculty in general strive to win grants, publish research, and remain active citizens in the academic community, informed reflection is required before teaching a course that requires the additional work of such a redesigned 101, particularly absent tangible instructor benefits.

As more students enter higher education and class size continues to increase, instructors will need to determine their particular philosophy of participation for actively engaging a larger number of students and how they will apply this to their teaching. This involves determining how to assess and grade participation, work with apprehensive, reticent, as well as overactive students, consider which approaches mesh with their particular course and teaching style, their institutional workload requirements, and so forth. But if this type of course redesign influences more students to enjoy participation in their courses rather than to simply “get through them,” the more this itself may be a rewarding measure – for students, instructors, and administrators – to indicate how well universities are creating communities of learners rather than only producing graduates.

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Disclosure statement

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