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Assessing Collaborative, Project-based Learning Models in Introductory Science Courses

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Abstract: Collaborative, project-based learning models have been shown to benefit student learning and engagement in the STEM disciplines. This case study evaluates the use of highly collaborative project- and problem-based learning models in introductory courses in the geosciences and biology. In the geosciences, we developed project-based modules with a strong local focus. Student teams worked on three project-based laboratories dealing with the local geology/geomorphology, water quality of a local stream, and local flooding issues. These replaced traditionally taught laboratories on topographic maps and rivers and streams. Student teams presented project results in lieu of taking a traditional laboratory practical. In biology, we designed a collaborative learning model that incorporated three problem-based learning modules into a first-semester introductory biology course. Students were assigned topics in evolution, cell biology and genetics to research independently during the course of the semester, with each module culminating in a brief presentation on the topic. Modules were designed to mirror concepts being covered in the lecture. Preliminary results suggest that student performance and attitudes towards course material benefitted from this learning model. The authors consider outcomes, benefits, and challenges to students and instructors.

Keywords: collaborative learning, problem-based learning, project-based learning, introductory science, commuter campus, academic performance, DFW rates.

Introduction

Measurable student outcomes have become increasingly important in program evaluation, accreditation and funding in higher education. Institutions serving historically underserved communities, non-traditional populations, and commuter campuses face special challenges providing students with accessible, meaningful, and achievable education. Vital to the communities they serve, these institutions have historically realized lower persistence and graduation rates than many of their traditional, residential counterparts. The American Association of State Colleges and Universities (AASCU) supports initiatives that seek to strengthen quality, access, and foster inclusion for underserved populations (AASCU, 2018a). The goal of Re-Imagining the First Year (RFY) is to improve the quality of learning and the first year student experience at member institutions (AASCU, 2018b) through addressing student needs and removing obstacles to academic success. One set of initiatives involves increasing faculty pedagogical expertise and widely incorporating modern, evidence-based techniques into the freshman-level curriculum (AASCU, 2016).

An interdisciplinary group of faculty and administrators, originating mainly from the university's College of Arts and Sciences was of the first to address this RFY initiative. Organized by the dean of the college, the director of the campus's Center for Innovation and Scholarship in Teaching and Learning (CISTL) and faculty members from biology, English, geosciences, psychology, and sociology met regularly with the Dean. The group was dubbed, the Pedagogy Interest Group, and came to be known simply as "the PIG." The goal of the PIG was to provide an outlet for interested faculty to explore, discuss, and evaluate the use of modern, evidence-based pedagogy. Styled like a seminar, participants explored literature focused on modern philosophies and designs in pedagogy. Each week, one participant led a discussion on a technique, topic, or research study. As the PIG progressed, participants began to develop ways in which broad ideas could be adapted to benefit general education and freshman-gateway courses in their disciplines. Here, we present results from interventions developed for the geosciences and biology.

Background

Collaborative Learning

Collaborative learning encompasses a wide spectrum of techniques that have, at their core, the common element of students working together in groups to enhance learning (Dillenbourg, 1999). Collaborative learning has been recommended as a bedrock pedagogical practice for the undergraduate curriculum, especially in the first year (Boyer Commission, 1998). In line with the goals for the RFY initiative, collaborative learning has been demonstrated to increase first-to-second year retention (Loes et al., 2017).

There has been wide adoption of collaborative learning modalities in STEM classes. It has been successfully used in mathematics, building on the work of Treisman (1992) who observed increased success rates amongst underrepresented minority (URM) students in freshman college mathematics. Building upon this initial work, Berry notes that collaborative learning is a powerful tool to increase URM student success in the liberal arts curriculum (Berry, 1991). In biology, collaborative learning approaches have generated increased student performance in non-majors general biology (Tessier, 2007), freshman majors biology (Hacisalihoglu et al., 2018) and microbiology (reviewed in Rutherford, 2015).

Problem-based and Project-based Learning

Problem- and Project-Based learning (PBL) refer to an active learning style that shifts the educational focus from finding the "right" answers, to asking questions and exploring an avenue of study that will further knowledge around complex issues. The educational strategy draws on constructivist theories of pedagogy (von Glaserfeld 1989; Savery and Duffy 1995).

In practice, PBL allows learners to develop understandings by engaging with a complex problem that may not have one single correct or ideal answer. These problems are most effective when they have relevance beyond an assigned task for the course grade. They should foster learner ownership over the problem and any potential solutions. The problem should seek to highlight rather than minimize complexity as it is reflected in authentic problems within the discipline or field. Ideally, PBL is reflexive, fostering thinking about both the solution to the problem and the process of learning to arrive at that solution.

Developed for use in medical education, the term problem-based learning is used to describe time spent in and out of the classroom around the attempt to solve a complex, often indeterminate problem with the potential for multiple answers (Schmidt 1983). It is related to, and sometimes used interchangeably with project-based learning. Project-Based learning employs the same strategies and focus. In project-based learning, student-directed inquiry is supported by collaboration and communication. Learning derives from formulating research questions, time management, gathering and analyzing data, interpreting results, drawing conclusions, negotiating value differences among group members, and preparing and communicating findings (Schneider et al., 2002; SERC, n.d.).

Both problem- and project- based learning reorganizes the roles and hierarchy of a traditional classroom. PBL is necessarily self-directed learning where the traditional classroom teacher takes on the role of facilitator rather than knowledge provider (Hmelo-Silver 2004). Critics have noted that the self-directed nature of PBL requires special attention to the construction of appropriate problems and learning resources (Duch, 1996; Woei 2009; Prince, et al. 2003), and that the design and scale are important factors affecting student achievement (Ruiz-Gallardo, et al., 2011).

PBL has been incorporated into a range of disciplines in post-secondary Arts and Sciences curricula (Helle, Tynjälä, and Olkinuora 2006). Examples include chemistry (Woods 1996), biology and physics (Allen, Duch, and Groh), sociology (Ross and Hurlburt 2004), and the geosciences (Moss, et al., 2018; Smith et al., 2018; Rye, et al., 2013; Kirk, 2007).[1]

Problems of local significance are well-suited for PBL in the natural sciences and are widely used in curricula that employ these learning strategies (Moss, et al., 2018; Smith, et al., 2018; Rye, et al., 2013; Ebenezer, 2011; Schneider, et al., 2002). Addressing local issues may help to foster engagement while providing an accessible resource for conducting scientific work.

Context

Indiana University (IU) Northwest is a small (<6000 students) regional commuter campus of the IU system, serving a seven-county region in northwest Indiana and bordering Illinois. As of fall 2018, the

[1] Perhaps the most sustained and integrated application of PBL in an undergraduate curriculum comes from the University of Delaware. A consortium of six faculty members from across a range of physical science departments (chemistry, physics, biology) have developed materials, problems, and evaluations for using PBL in undergraduate science courses (see http://www.udel.edu/inst/).

student population is overwhelmingly undergraduate (>90%), majority women (66%), and has large African-American (17%) and Hispanic (21%) populations reflective of the communities it serves. IU Northwest has a large population of non-traditional students (26%), first generation college students, and students who qualify for federal financial aid. Approximately half attend college full time, and about 70% of undergraduates seek degrees (Indiana University Office of Institutional Effectiveness and Research).

The introductory geoscience laboratory is a one-credit companion to the GEOL-G 101 Introduction to Earth Science lecture course. Students enroll and receive credit separately for the lecture and laboratory sections, and they are not required to enroll in the laboratory to enroll in the lecture course. Successfully completing both satisfies the 4-credit *science course that includes a laboratory* distribution requirement in the College of Arts and Sciences, and the majority of students enroll in the laboratory to satisfy this requirement. The laboratory is a requirement for geology majors, pre-service teachers working toward accreditation in Earth and Space Science, and serves as an elective for Physical and Life Science education majors.

Traditionally, the introductory geoscience labs have been taught with the aid of selected laboratories from the American Geological Institute/National Association of Geoscience Teachers (AGI/NAGT) publication. The laboratory space contains materials and equipment necessary to conduct the full laboratories, including mineral and rocks samples, testing equipment, and topographic maps that are standard in most college labs. In recent years, some activities from the Science Education Resource Center at Carleton College (SERC) have been adopted to supplement the AGI/NAGT laboratories, either on a trial basis or fully integrated into the laboratory by most instructors. Sections hold up to 24 students each and are usually taught by a combination of adjunct instructors, undergraduate TAs, and at least one regular tenure-track full-time faculty member. During the regular academic year, laboratories run in 15-week sessions, with 12 regular laboratory meetings and 3 meetings designated for laboratory practical-style evaluation. Laboratories meet once per week for two hours. Summer laboratories run in accelerated and abbreviated 6-week sessions, where students meet twice per week but the number of meetings is reduced by three. GEOL-G 102 laboratories that run during the regular academic year (fall and spring semesters) are the focus of this study.

Introduction to Biological Sciences I (BIOL-L 101) is one of the largest courses taught at our campus, with annual enrollment averaging approximately 138 students over the semesters included in this study. Two of the authors (PGA and MG) teach this course, offering two sections each fall, averaging nearly 97 total students, and a single section each spring that enrolls an average of 41 students. Most students are Biology majors (59.30%), with most non-majors taking the course either to satisfy their major requirements (Psychology, Chemistry majors) or to prepare for the Medical College Admissions Test (MCAT), Dental Admissions Test (DAT) or other health professions admissions exams.

Students who take the course enroll in three separate sections each semester: a 3 credit hour lecture that meets for 75 minutes twice a week, a 1 credit hour laboratory section that meets for 180 minutes once a week, and a discussion section that meets for 50 minutes once a week. In fall, two lecture sections, five laboratory sections and four discussion sections are offered. In spring, there is only one lecture section, two laboratory sections and two discussion sections. Students' grades are earned through quizzes taken in discussion sections, exams taken during lecture, and activities and assessments performed/taken during the laboratory. In addition, students complete homework exercises online every week that relate to the material covered in the lecture.

Reformed Curriculum

Geosciences

The GEOL-G 102 curriculum was reformed to include three new laboratories focused on water chemistry and water quality, stream processes, and topography and geomorphology of the local area, including a river and floodplain adjacent to the campus. These replaced traditional laboratories on topographic maps (formerly two lab periods), and a laboratory on rivers, streams, and floods (one lab period). The transformed laboratories incorporated similar concepts to those in the traditional laboratory, but differed in the following ways:

1. A new water chemistry/water quality laboratory was designed and implemented. This laboratory contained concepts not previously addressed in the GEOL-G 102 laboratory, and include a strong environmental geology component.
2. The new focus was entirely on local geology. Methods and concept application were geared toward identifying local geologic features, addressing local environmental issues, and drawing relationships related to local geology, natural processes, and human activity. Specifically, "local" was used as a way to engage students – to increase their awareness of local scientific work and to promote a sense that *they* could do this type of work, in *their* community, as a career (if they majored in geology or environmental science). For example, a local disaster became part of the laboratory on Stream Processes and Floods. In 2008, the campus was closed for more than two weeks in response to severe flooding. Flooding was also severe in the surrounding community, where many homes and businesses were damaged or destroyed. The current student population has good collective memory of the event, some having to be rescued from schools in boats, and others having flooded homes. This event was used as an opportunity to heighten interest, drive group interaction, and underscore the importance of scientific study. Lab instructors were encouraged to draw attention to local scientific work and jobs, and language was embedded in new laboratories outlining work of local agencies and scientists, and suggesting career paths to interested students.
3. The new laboratories are highly collaborative. Traditional laboratories encouraged group interaction by seating students in small groups (of four). However, the traditional design contained no *requirement* that students share information, use information provided by others in the group, or contribute to their group. Encouraging interaction was beneficial for many students, but also facilitated an "odd man out" mindset where slower students sometimes found themselves reporting information entirely provided by others. Additionally, students could opt to complete the work entirely on their own with no or minimal group engagement. Finally, there was an opportunity for some students to actively disengage from laboratory activities if they believed their lab group would provide them with enough information to complete the laboratory assignment.

   In the reformed laboratories, students were grouped into 3-4 person teams that remained in place for the entire three week project. Students took on specific responsibilities within the group, and were responsible for working together to complete tasks. Each laboratory was treated as a single assignment; assignments were combined to form parts of the larger project. For individual laboratories, grades were assigned to individuals based largely on participation and task completion.
4. Embedded in the new laboratories were opportunities for teams to develop and test hypotheses, collect and interpret data, and evaluate larger datasets. Teams had opportunities to earn additional points by field-locating landmarks and features from topographic maps

(documented by a group "selfie" with the feature in question), and by providing additional analyses of small, outside of lab investigations.

The project-based nature of the new laboratories allowed deeper examination of topics, but did not allow coverage of as many topics. Some omitted topics were addressed in later laboratories. For example, producing a contour map based on spot elevations was eliminated from the new topography exercise, but contouring the water table from water well elevations was accomplished in a later groundwater laboratory. Still, some concepts covered in the traditional laboratories were omitted from the reformed curriculum.

A group presentation, emphasizing the process of communicating scientific results, replaced a traditional laboratory practical. Student teams were supplied with presentation instructions and an evaluation rubric. Students were also required to evaluate their own performance, the performance of others in their group, and the work of other groups. An individual student's final grade for the unit was based on these factors and the instructor's evaluation of the final presentation using the same rubric supplied to the students.

Reformed laboratories were developed in the summer of 2016 and implemented in individual laboratory sections beginning in fall, 2016. The new curriculum was tested piecemeal and as a pilot study in two laboratory sections in the summer of 2016. The full unit of project-based of laboratories and new evaluation was implemented in one section of the GEOL-G 102 laboratory in the fall 2016. Instructor evaluation of student engagement and performance, and feedback from students, informed further modifications to the laboratories. Revisions focused on addressing ambiguities in the activity instructions and modifying the number and length of activities (to better fit the time available). Later revisions focused also on flexibility in managing methods of sample collection during inclement weather, high river levels, frozen river surface, and road construction near river access points. The reformed curriculum was implemented in three laboratory sections in spring 2017 and in four laboratory sections in fall 2017. Spring 2017 targeted three laboratory sections, one taught by a full-time faculty member and developer of the reformed curriculum, and two sections run by undergraduate TAs. The week prior to implementation of each lab, instructors met to discuss purpose, content, address questions, and to offer (and gather) feedback. Instructional strategies related to engagement and content was also on the agenda. On the day of each lab, undergraduate TA instructors were assisted by the other two. In fall 2017, three of the four laboratory instructors (consisting of one undergraduate TA, one adjunct faculty member, and one full-time tenure track instructor) were new to the study. During that semester, implementation of the project-based, collaborative laboratories was slightly different. Scheduling issues necessitated individual meetings between the laboratory developer and instructors rather than group meetings. The level of assistance in each new instructors' laboratories also dropped. Finally, some instructors made small changes to the revised laboratories to better suit their teaching style and syllabus schedule.

Biology

In spring of 2016, the College of Arts and Sciences identified BIOL-L 101 as a target for a pedagogical intervention due to its high enrollment and the high percentage of students earning lower than a C- in the course (the DFW rate). Since 2013, the DFW rate in this course has ranged from 34.09% to 72.97%, with a mean value of 45.19% and a median value of 42.31%. Three of the authors (HEO, PGA, MG) developed interventions based on a collaborative learning model with the goal of reducing the DFW rate and increasing student success in the course.

The structure of the course is divided into three units – evolution, cell theory and molecular genetics. For the intervention, a set of questions was developed for each of the three units (see Table 1). In addition, students who worked together on question sets also worked together on a variety of presentations that pertained to a particular area of each unit. For the evolution unit, student groups researched an example of human evolution and gave a formal presentation of their findings to the class. For cell biology, students were assigned a disease, studied how the pathology of that disease relates to defects in cellular function, and then performed a skit that communicated to their peers the information they learned about that disease and its relation to specific cellular functions covered in the lecture. Finally, in the molecular genetics unit, students investigated an inherited human disease and put together a short video about the inheritance and pathology of that disease.

The intervention was carried out over four consecutive semesters from fall 2016 to spring 2018. DFW rates were calculated and compared to historical rates from fall 2013 to spring 2016. To minimize variance, fall semesters were compared to fall semesters, and spring semesters to spring semesters. Students who received a grade of incomplete, or who were flagged as receiving an F due to non-attendance, were omitted from our analysis. Further, for all semesters of the intervention, a common final exam was given to compare improvements in student retention of material.

Table 1. Summary of BIOL-L 101 Intervention for Cell Biology Unit.			
Synopsis:	Student groups were assigned a lysosomal storage disorder (Danon disease, Niemann-Pick disease, Hurler disease, Fabry disease) or a mitochondrial insufficiency disorder (Barth syndrome, pyruvate dehydrogenase deficiency, dominant optic atrophy, Leigh syndrome) to study. Students were then tasked to work in groups to prepare a 5 minute skit that would communicate important aspects about the disease to their classmates.		
Learning Outcomes:	Students should demonstrate the ability to identify organelles inside eukaryotic, and in particular animal, cells.	Students should understand how organelles and the endomembrane system allow eukaryotic cells to undertake necessary metabolic tasks, including the importance of compartmentalization and membrane transport.	Students should explain the function of organelles in the context of cellular and organismal physiology.
Collaborative Learning Questions	The role of the lysosome is to chemically digest macromolecules in the cell. What are the basic types of macromolecules in the cell? What types tend to be digested by the lysosome? What materials in the lysosome allow it to perform this function?	Imagine if there were a garbage collectors' strike in your town. What would the consequences be to your community? How would your life be affected? What if the lysosomes in your cells "went on strike"? What would be the consequences to your cells? To your body?	Are there cells that depend more on their lysosomes than other cells? If so, which cells and why?

For this study, we examined students' performance on three lecture assessments: midterm exam grade (performance on the first two lecture exams), final exam grade, laboratory grade and final course grade (numerical and letter grades were both examined). Results were compared between the six semesters before the intervention (fall 2013-fall 2015 and spring 2014-spring 2016) and the four semesters during which the intervention was used (fall 2016-2017 and spring 2017-2018).

Results

Geosciences

DFW rates in GEOL-G 102 laboratory sections adopting the reformed laboratory curriculum are compared to historical DFW rates (Figure. 1). DFW rates are calculated in two ways. Those shown in blue exclude students who enrolled in the class, but never attended. DFW rates including never-attended students are shown in orange. While rates that include students who never attended the class are a poorer measure of the reformed curricula's effectiveness, they do facilitate closer comparison to baseline data and are included for that reason. Baseline data consists of the three semesters (excluding summer) prior to implementation.

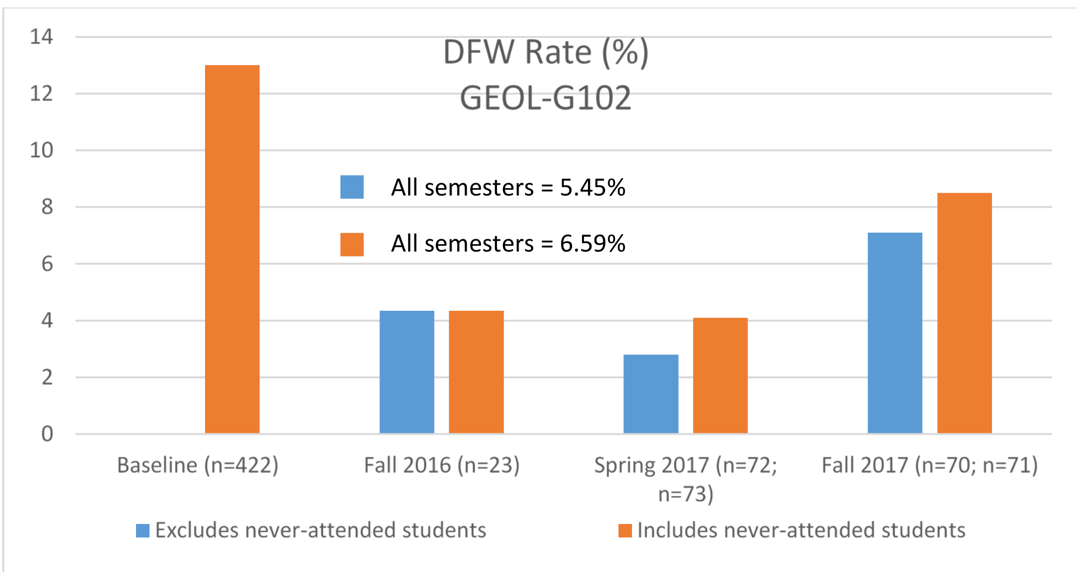

Figure 1. DFW Rates (%) for Reformed GEOL-G102 Laboratory Sections. Baseline DFW is derived from the three semesters preceding implementation of the reformed curriculum. DFW rates for all semesters are 5.45% (excluding students who never attended the lab), and 6.59% when never-attended students are included in the dataset.

There is a marked decrease in the DFW rate of reformed laboratory sections compared with historical baseline rates. Overall, DFW rates in reformed laboratory sections are 5.45% (6.59% including never-attended students) – half the historical DFW rate of 13%. The decrease occurs the first semester the reformed laboratories are adopted. In fall 2016, DFW rates are approximately one third that of the baseline (4.35% compared with 13%). The largest decrease in the DFW rate occurred in spring 2017, where students who collectively attended reformed laboratory sections experienced a rate of 2.8% (4.1% including never-attended students). In fall 2017 the DFW rates increase compared with prior semesters, but are still below historical values.

GPA was higher in reformed GEOL-G 102 laboratory sections than historically (Figure 2). Overall, GPA in reformed laboratory averaged 3.04 (out of a possible 4.0). This is compared with an average 2.76 GPA for the three semesters prior (baseline). The highest average GPAs occur in the fall 2016, and spring 2017 (3.14 and 3.15 respectively). Average GPA drops to 2.89 in fall 2017, to a value just above the historical baseline value.

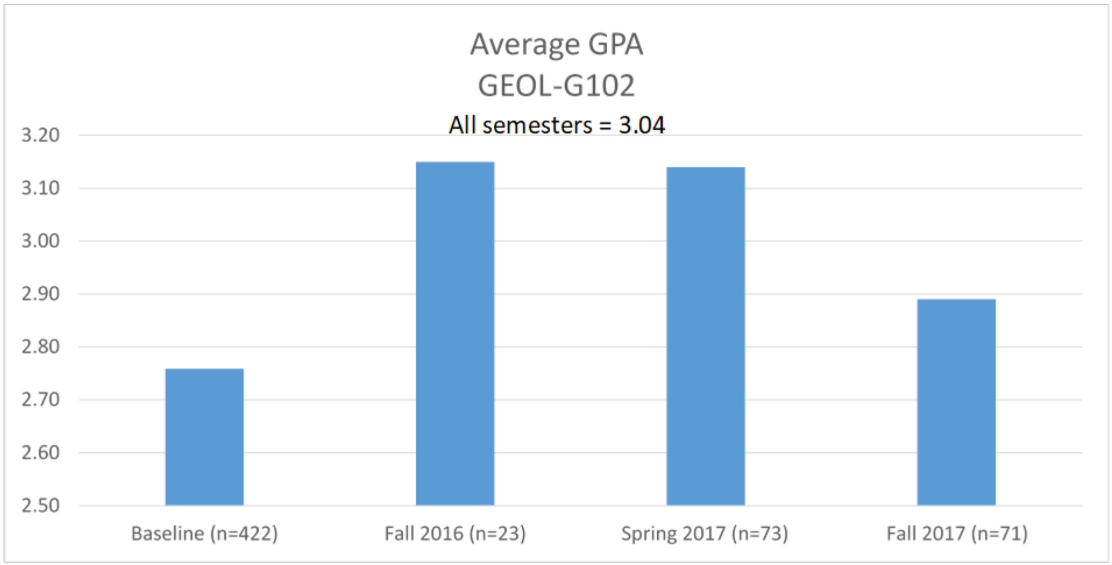

Figure 2. Average Class GPA (4.0 max possible GPA) for reformed GEOL-G102 Laboratory Sections by Semester. Baseline GPA is derived from the three semesters preceding implementation of the reformed curriculum. Average GPA for reformed sections across all semesters is 3.04.

Research suggests a direct relationship between attendance and academic success for most students (Lukkarinen, et al., 2016; Moore, et al., 2003). We wished to ascertain the number of laboratory periods students missed and at which time(s) during the semester students missed labs. Attendance in the reformed laboratories is reported as the average number of laboratories missed per student for each of three educational units (Figure 3). The first unit consisted of four laboratories that covered rocks and minerals and a rock and mineral identification exam. Unit 2 was the Local River Project reformed laboratories followed by the group presentation. Unit 3 consisted of five laboratories that, for most laboratory sections, covered glaciers, plate tectonics, fossils and geologic time, groundwater, and earthquakes. On average, students missed between 0.21 and 0.51 laboratories per unit, and the number of absences increased from Unit 1 to Unit 3.

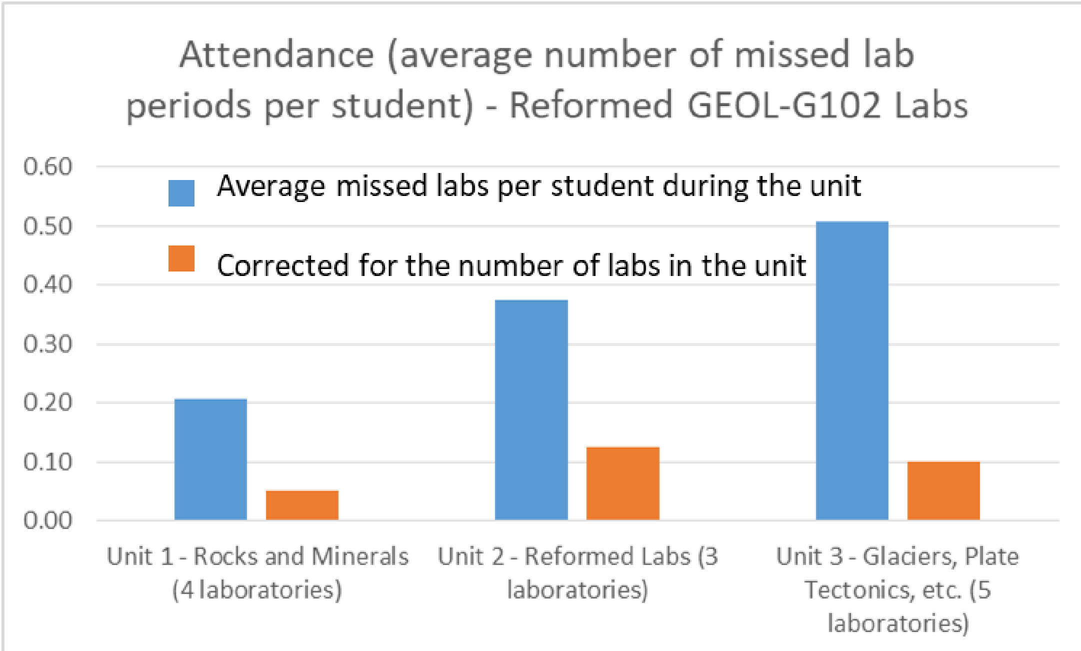

Figure 3. Attendance in Reformed GEOL-G102 Laboratories. Data are reported as missed laboratory periods per students throughout the unit (blue), and corrected for the number of laboratories in the unit (orange). Attendance data includes late-registered students and withdrawn students up to the time of their effective withdrawal. Students who never attended a laboratory are excluded from the dataset.

To eliminate the effect of differences in the number of meetings in each unit, the average was divided by the number of laboratory meetings in that unit. The result (shown in orange), is the per lab absences within each unit. Results suggest that student attendance is best during Unit 1, followed by approximately double the absenteeism in the two units that follow.

b. Biology

Students in the fall semester can choose one of two lecture sections, one in the morning and one in the evening. Because students receive the same assessments in both lecture sections and can be enrolled in any discussion or laboratory section regardless of their enrolled lecture section, we calculated all data using total enrollment, ignoring the particular lecture section in which students were enrolled. Student performance saw modest increases in all four assessments examined – average midterm exam score, average final exam score, average laboratory score and average final course score (Figure 4).

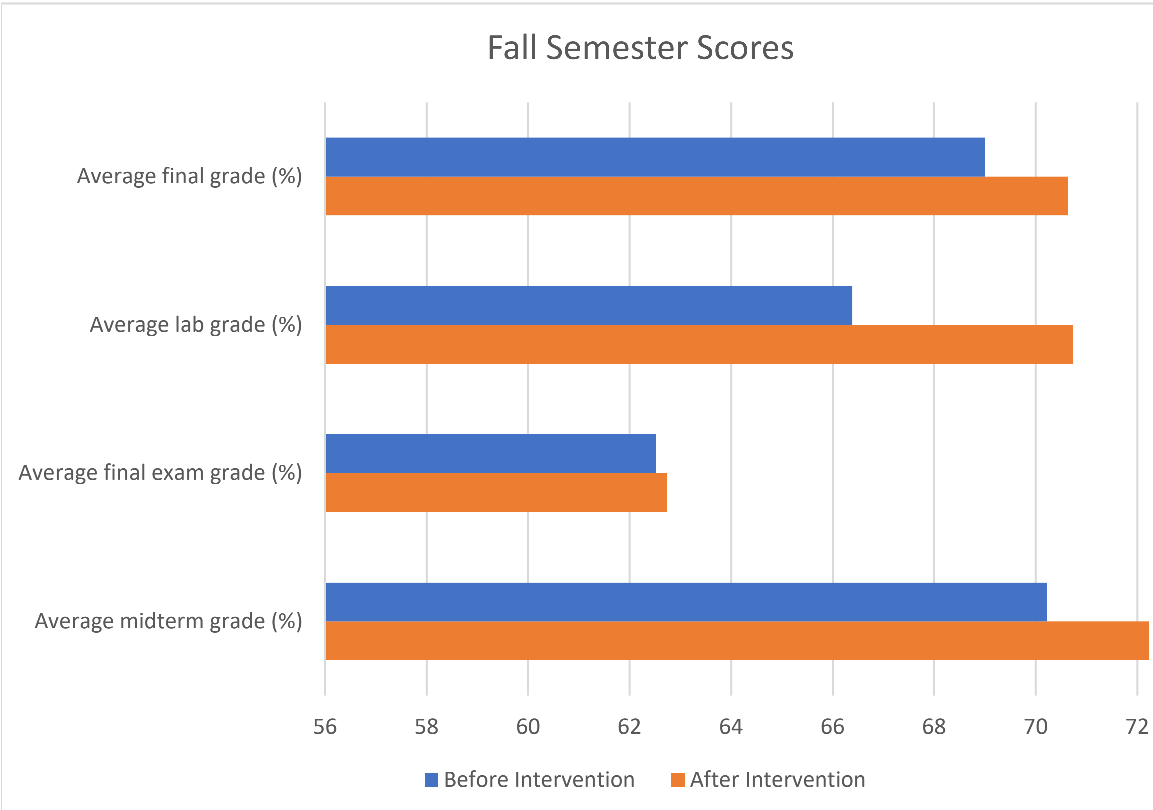

Figure 4. Average student scores for selected assessments in fall semesters. Increases were seen in all measured categories after the intervention, with the largest percent change in average midterm grade and average lab grade.

Despite these improvements, there was little change in DFW rates (Figure 5). For all fall sections examined, DFW rate averaged 43.12%. The average of the three semesters prior to the intervention was 43.04%, and after the intervention was 43.23%, suggesting that there was no noticeable change in DFW. When letter grade distributions were compared between pre-intervention and intervention semesters, we saw little change in the distribution of B, C or D grades (Figure 6). The number of F's did decrease in the intervention semesters, but was accompanied by an increase in the number of students who withdrew from the course (Figure 6). The number of A's increased by the second intervention semester, but did not rise above rates seen in 2013, three years before the intervention (Figure 6). GPA was calculated for each section to quantify grade distribution (Figure 7), and showed a noticeable increase from 2015 (the semester before the intervention) through 2017 (the second fall semester of the intervention). Collectively, these data suggest that the collaborative model employed in fall semesters of BIOL-L 101 may have reduced the percentage of failing students, but did not produce quantifiable improvements in student success or a reduction in DFW rate.

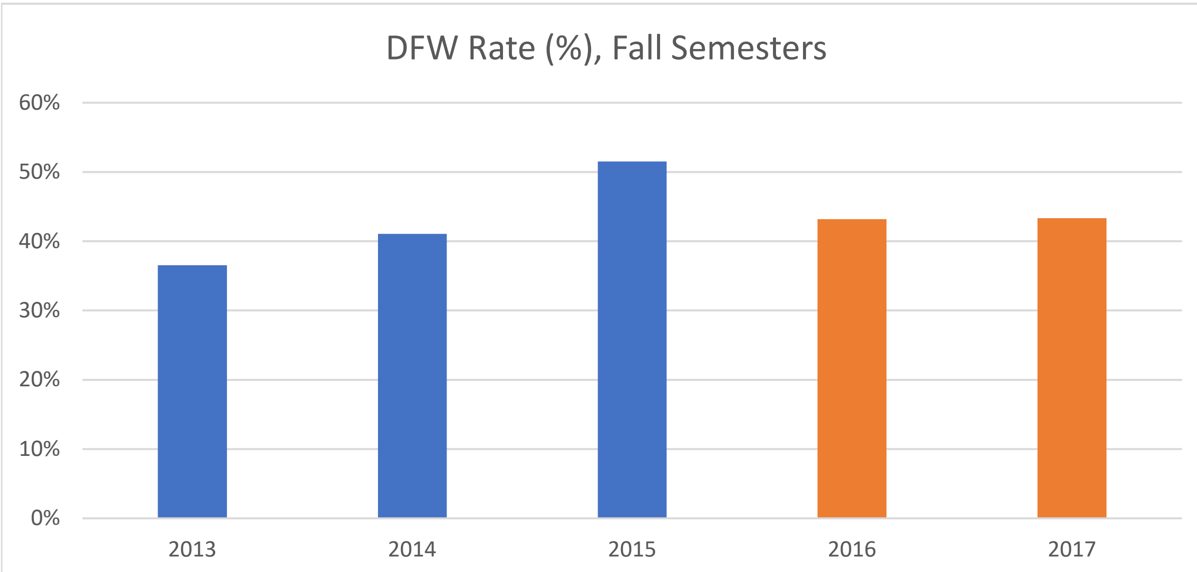

Figure 5. DFW rates for fall semesters. Average rates after the intervention (orange bars) dropped below high levels seen in fall 2015 but were in line with 2014 and higher than 2013.

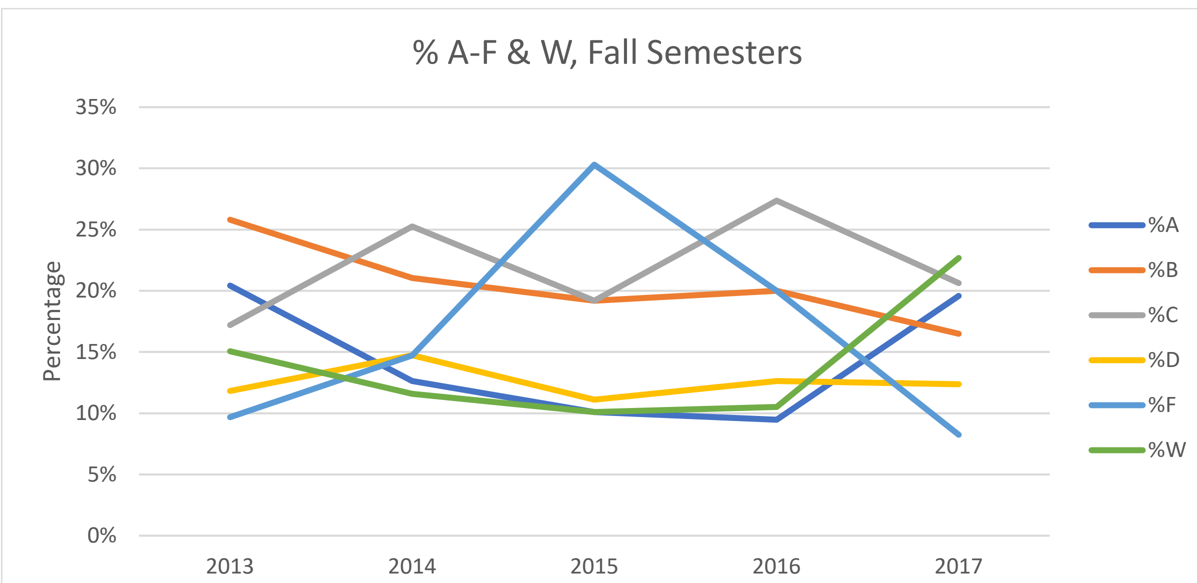

Figure 6. Letter grade percentages in fall semesters. The percentage of students receiving Bs, Cs and Ds did not vary appreciably before or after the intervention. The number of Fs did go down in the intervention semesters (2016 & 2017), with a concomitant increase in students withdrawing from the course. The percentage of students receiving As returned to 2013 rates.

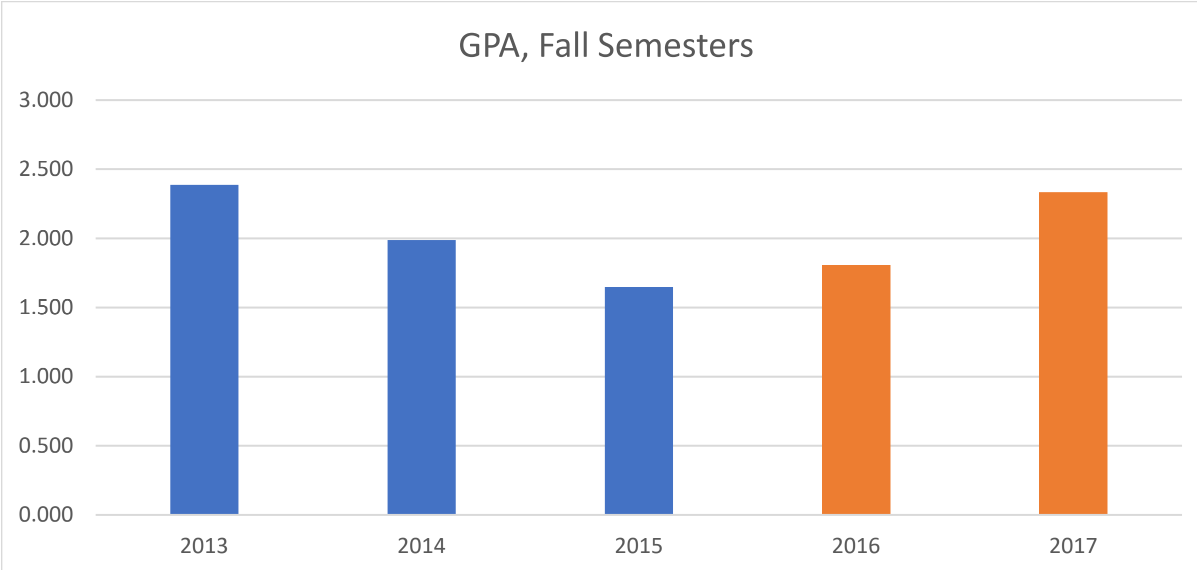

Figure 7. GPA for BIOL-L 101 fall semesters. GPA had been declining prior to the intervention (2013-2015) but increased back to levels seen in 2013 by the second fall semester of the intervention.

In spring semesters, there was a more noticeable change in student outcomes. Midterm exam grade, lab grade, and final course grade all increased after the intervention. However, the final exam grade showed a 4.94% decline after the intervention versus before (Figure 8). The average DFW rate for spring semesters before the intervention (2014-2016) averaged 51.31% (Figure 9).

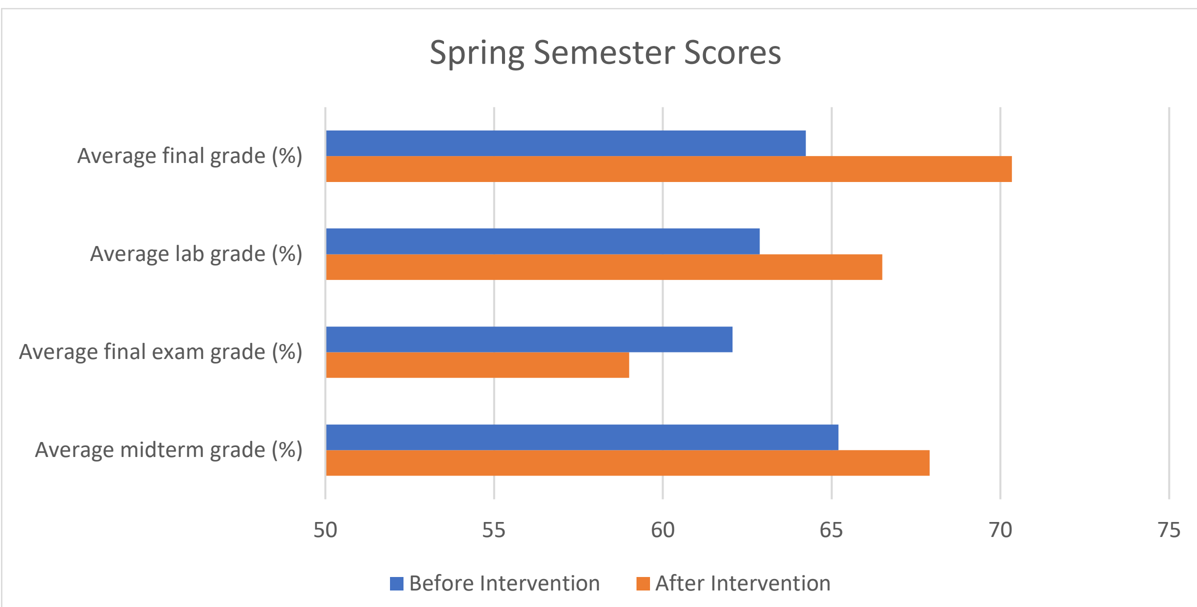

Figure 8. Average student scores for selected assessments in spring semesters. Average for all students for final course grade, laboratory grade, final exam grade and midterm grade. In semesters after the intervention (orange bars), scores went up on all examined assessments except for final exam grade, which declined.

In the two semesters after the intervention began (2017 and 2018), the DFW rate declined to 41.19%, a 24.59% decrease. Grade distributions did show some change during the intervention, with many more Cs than usual in the first intervention semester (Figure 10) and a decline in students withdrawing from the course. These changes, however, did not persist into the following spring semester, when the withdrawal rate climbed again. However, with this increase in withdrawals came an elimination of students receiving an F (0% for spring 2018, Figure 10). GPA for the course increased during all semesters of the intervention, hitting a peak of 2.531 in spring 2018, the highest seen during the study (Figure 11). These results suggest that the intervention may have been more successful for students taking the course in the spring semester than for students in the fall semester.

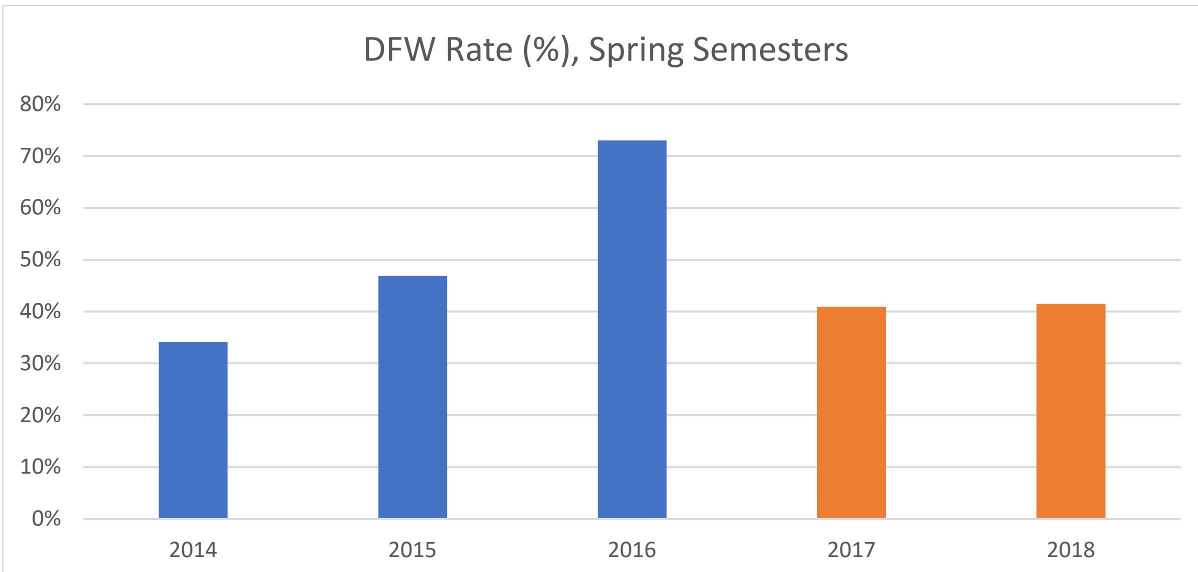

Figure 9. DFW rates for spring semesters. DFW rates in 2017 and 2018, when the intervention was implemented (orange bars), were similar to 2014 and 2015, but much lower than in 2016.

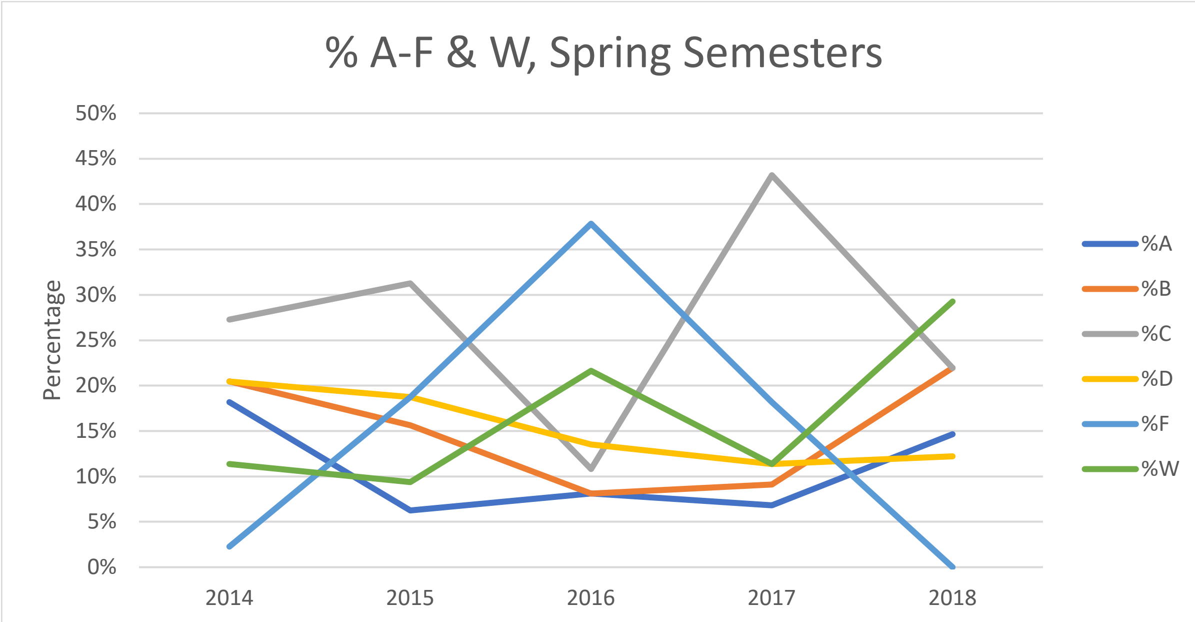

Figure 10. Letter grade percentages in fall semesters. While the percentage of students earning As, Bs, and Ds remained relatively unchanged, many more students earned Cs in the first year of the intervention, with a sharp decline in withdrawn students in that semester. However, by the second semester of the intervention, C grades returned to close to historical values. As was seen in fall semesters, the number of Fs declined during the intervention, accompanied by an increase in withdrawals.

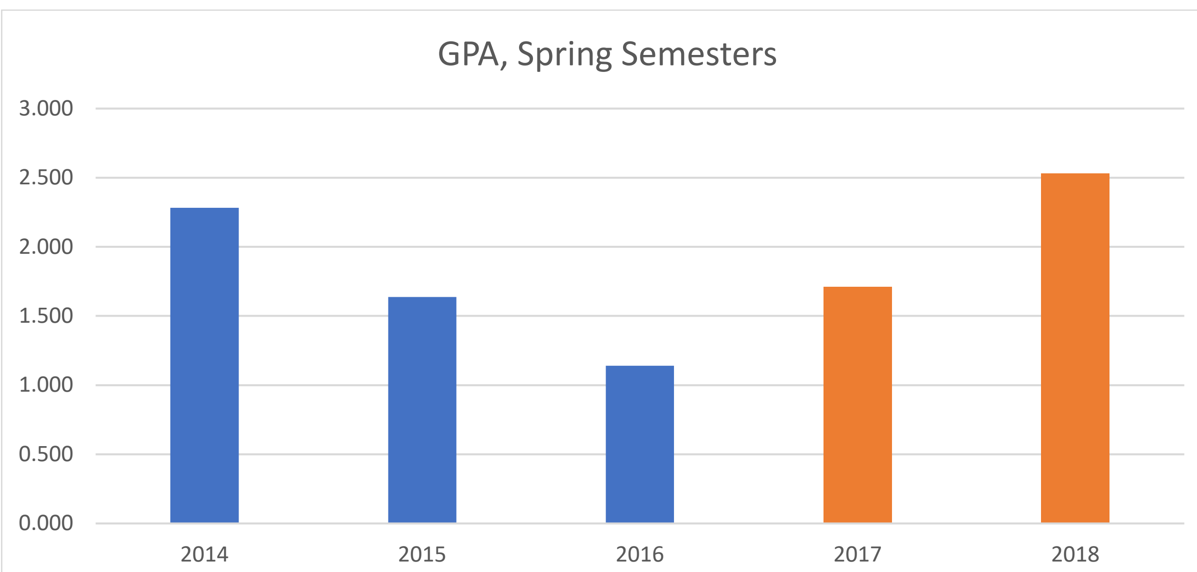

Figure 11. GPA for BIOL-L 101 spring semesters. Declining GPAs from 2013-2018 increased in 2017 and 2018, reaching its highest level in 2018 (2.531).

Discussion

Geosciences

Students enrolled in the revised GEOL-G 102 laboratories performed better and failed/dropped out less than students during the three previous semesters, suggesting a positive effect on student engagement. There is a well-established relationship between student engagement and academic success (Kuh et al., 2008), and recent work suggests that engagement in the academic setting may be even more important to students on commuter campuses (Whitten, et al., 2017).

The dramatic drop in DFW rates in fall 2016 and spring 2017 (4.35% and 4.1% compared with 13% historically) is followed by a comparative increase in fall 2017 (8.3%). While still below historical baseline values, DFW rates rise approximately 4% from previous semesters. The cause of the rise is unclear but may be attributable to the differences in implementation of the reformed GEOL-G 102 laboratories (described above) in different semesters. Differences underscore the importance of consistency in instructor preparation, instructor buy-in, and laboratory versatility. That is, the revised laboratories should be easily adaptable to instructors' own teaching style without diminishing the effect. For the geosciences, the study tested the effect of just three revised laboratories developed by one faculty member. This was a first step, and positive results have encouraged the involvement of additional faculty to further modify the curriculum. Moving forward, we will pursue more robust input from all laboratory instructors. Turnover of adjunct and TA instructors still presents a challenge, however.

We also sought feedback on perceived student engagement, performance, and learning from instructors – specifically those who taught both the revised curriculum and the prior traditional labs. All instructors noted that the revised laboratories enhanced student engagement compared with the traditional laboratories they replaced. Instructors commented specifically on the relationship between students' heightened interest level and focus on the "local river," "local geology," and "local environment." Some instructors reported that students paid more attention, suggesting this was because students understood they would have to present findings to the class. Instructors also commented that the revised curriculum was more interesting to teach and liked that there was less reliance on the laboratory manual.

Instructors perceived that student performance and grades were better, but also expressed concerns over evaluating collaborative work. On the positive side, instructors related better performance to perceptions that students prepared better for the evaluation, that group pressure encouraged harder work (in some instances), and that presentation instructions and grading rubrics were helpful to students. However, instructors were also concerned by instances of unequal division of labor and poor team dynamics in some groups. Instructors commented that individual accountability should be evaluated more directly and noted that the previous lab format was easier to grade. These comments suggest the need for developing a more robust peer assessment, personal assessment/reflection, and group management model, areas of concern identified in previous research (Brooks and Ammons, 2003; Almond, 2009).

The time intensive nature of the project-based approach required tradeoffs. Instructors expressed concerns over the loss of time spent on particular skill development, especially for geology majors. Specific concerns were that less time was spent on concepts related to topographic maps in order to accommodate the new water quality laboratory and that students needed more practice with "the basics" before applying skills to the local area. However, instructors also commented that most students did not understand the old labs very well and learned much more from the new geology laboratories. All instructors verbalized the perception that a tradeoff exists between the two educational styles and discussed where the appropriate balance lies. Finally, instructors gave specific suggestions for improvement to be incorporated into future laboratories.

GEOL-G 102 laboratory absenteeism increased as the semesters progressed, reaching a peak near the middle of the semester. This is the case even though late registrants are included in the dataset. This trend is likely no surprise to faculty teaching on commuter campuses enrolling significant numbers of students with jobs, spouses, children, and other significant outside stressors. Research on college persistence rates find that part-time, minority, and non-traditional students have lower persistence rates than their full-time, white, traditional counterparts (Kuh, et al., 2008; National Center for Education Statistics, 2012). The former are populations for which the standard university curriculum presents a multitude of challenges. While we do not have historic attendance data, the lower DFW rate does suggest that the laboratories are helping students persist through the semester compared with earlier semesters.

Biology

While numerical increases in student assessments, or meaningful decreases in DFW rate, were not seen in our intervention, we did see an increase in course GPA. This increase likely reflects the increased percentage of withdrawals and decreased percentage of students receiving F's documented in semesters after the intervention. Although no aspect of the intervention was designed to increase a student's likelihood to opt to withdraw from the course rather than remain enrolled and receive a failing grade, this may have been an unexpected outcome of the intervention. This could be explained by the increased communication between students fostered by the collaborative exercises and projects incorporated into the course.

Low GPA has been shown to be an effective predictor of freshman student retention (Hurford et al., 2017). As a withdrawal does not hurt a student's GPA as much as an F, we are interested in determining whether this decrease in F's translated to increased student retention. Preliminary data provided by the Dean of the College of Arts and Science at IU Northwest suggests this may be the case. Students who received an F in BIOL-L 101 in spring 2014, 2015 or 2016 returned to IU Northwest the following fall at a rate of 46.15%. Students enrolled in those same sections who opted to withdraw returned the following fall at a rate of 66.67%. Overall, looking at year-to-year retention for all sections between spring 2014-spring 2017, the retention rate for students receiving an F was 39.29%, compared with 57.14% for students who withdrew from L101. Such an increase in spring-to-fall and year-to-year retention is entirely in line with the goals of RFY.

We were intrigued by the greater success of the intervention in the spring semester. The student population that takes BIOL-L 101 in the spring consists primarily of students who fall into one of three categories: (1) students who failed to earn a C- or better in the fall, (2) students who took a non-majors biology course in the fall instead of L101 because of their score on the placement exam for the course, and (3) students who are taking the course late in their undergraduate career, either to complete their graduation requirements or to prepare for advanced studies. Given these differences, it is entirely possible that the interventions we attempted worked better with one or more of these groups of students, leading to the slight increase in student performance and the decline in the DFW rate we observed.

In addition, it is important to note that the spring 2016 semester, immediately before the intervention was started, had a much higher than usual DFW rate and lower than usual values for midterm exam and final course grade. When this semester is removed from the data analysis, the increases in laboratory grade and final course grade persist, but are much smaller (5.30% increase for laboratory grade, 1.93% increase for final course grade). Importantly, the DFW rate no longer decreases, but goes up by 6.50%. The instructor who taught this course in spring 2016 was a first year instructor, and the lower than usual scores and higher than usual DFW rate may be directly attributable to inexperience. It is therefore unclear from our observations whether these interventions truly accounted for the increased student success seen in spring semesters, or if it was simply a "leveling off" when the course was taught again by two instructors, one of whom has many years of experience teaching the material. (Of note, the "experienced" instructor had a similarly high DFW rate in their first semester teaching the course.) However, the GPA and grade distribution data are independent of this one semester effect and again suggest it may be worth examining fall-to-spring retention rates between non-intervention and pre-intervention semesters.

Beyond numerical student success, the instructors themselves noted that their own enthusiasm for teaching the discussion sections was notably increased, and for this reason alone felt that continuing the intervention was in the best interest of the students taking BIOL-L 101. However, in student evaluations of teaching, few comments were made regarding the interventions in L101, and the majority of the comments indicated that students did not enjoy the group work or felt that the time could have been better spent in review of material. As these comments were a small percentage of the total enrolled students (4 negative comments over four semesters, with a total of 277 graded students), it is difficult to gauge how accurately they reflect overall student sentiment. Additionally, instructors perceived that students seemed to engage more fully in the group projects included as part of the intervention when compared with prior semesters.

In future semesters, we plan to focus more on identifying those at-risk students who are withdrawing from the course. These students will be offered additional mentoring, focused problem sets, and student-focused learning methods to help keep them enrolled in the course and earning a C- or better.

Conclusions

Findings suggest several benefits of project-based, collaborative educational strategies in introductory science courses. In the Geosciences, students persisted at higher rates, and performed better in reformed GEOL-G 102 laboratories than in previous semesters - indicated by lower DFW rates and higher average GPAs. An attendance baseline was established, and the effect of future modifications on attendance can now be tracked. Future work will focus on expanding the number of reformed laboratories offered in conjunction with the course, stronger instructor involvement in laboratory development, and developing better personal, peer, and group assessment models.

In the biological sciences, the intervention pursued did not produce the anticipated changes in student performance in the specific course but may have led to increased student GPA overall and increased first-to-second year retention amongst students enrolled in the course.

That early success in college courses can have a substantial effect on a student's success throughout college is one of the central tenets of the RFY initiative. As more institutions strive to attract, retain, and advance less traditional student populations, greater importance is placed on removing administrative and educational barriers to student success. Meaningful pedagogical practices play a central role in the success of such efforts – helping students develop their sense of place, purpose, and belonging within the higher educational environment. Beyond the student persistence and performance measures already discussed, the authors' engagement in the process of developing, implementing, and assessing the pedagogical intervention described in this manuscript gives rise to several important perceptions and recognitions. The following outlines some of the lessons the authors have learned as we have engaged in our collaborative and project-based learning model.

Enthusiasm of Instructors and Students

Instructors involved in the interventions described in this manuscript noticed that their enthusiasm for teaching the material increased as a result of the changes made. The instructors of BIOL-L 101 were particularly interested in finding a better use for the 50-minute discussion periods associated with lectures and had found it challenging to utilize this time in a way that helped students interact with the material covered in the 150 minutes of lecture time each week. Incorporating collaborative learning exercises renewed the instructors' interest in the discussion periods. The instructors also noted that students were more engaged during laboratories and discussion periods in the intervention than in previous iterations of the course. Some GEOL-G 102 instructors perceived a causal effect between greater student engagement and their own heightened interest in teaching the redesigned laboratories. We believe that increased enthusiasm on the part of the instructors and the students provides its own positive feedback loop where increased student engagement can encourage instructors/course designers to further experiment with evidence-based pedagogies, and is an effective catalyst for improved learning outcomes.

Course Design and Instructor Endorsement

Collaborative and project-based learning models call for approaches to course design and to teaching that are different than more traditional models. For example, one of the challenges we have faced in implementing the biology collaborative learning exercises has been tailoring the activities and questions to best help students understand the material being taught. We have found that questions must require students to think critically. Further, questions must be aspirational in nature, such that no one student would be expected to come up with the entire answer. Instead, the questions ideally should require students to work together to come up with the correct answers. Similarly, there were challenges designing geoscience activities that necessitated substantial teamwork and contribution from all student group members throughout the entire four-week unit. One lesson learned is that producing a course design that achieves the desired student outcomes is a highly iterative process. Having a process in place to collect student and instructor feedback, improve, and redesign questions and activities are a key component of success. Where multiple instructors teach laboratories, flexible project designs that can be adapted to instructors' own teaching style are also important.

Finally, it is important for instructors teaching the reformed curriculum to have the opportunity to develop their understanding of pedagogical techniques in a meaningful way. For the course designers, the seminar-styled PIG was an important outlet for exploring evidence-based research on modern pedagogies. It provided impetus, was an important forum for discussion and exchange of ideas, and provided a signal of support from administrators for this type of scholarship. We suggest that a similarly-styled workshop for adjunct faculty and TAs could provide a robust opportunity for study and exploration of evidence-based pedagogies and the reasons behind employing them.

We have been encouraged by the preliminary results of our intervention and are committed to incorporating the collaborative learning model more fully in current classes and in other classes in our curricula. For example, as a direct result of the initial successes seen by using the collaborative learning model in discussion, we have adopted a "flipped classroom" for BIOL-L 101. Students spend lecture periods working on collaborative exercises intended to further their understanding of concepts covered in assigned readings and pre-recorded lectures. The investigators have further committed to implementing collaborative learning exercises in upper-level courses. One investigator (H.E.O.) has already seen substantial increases in student performance in a sophomore-level course by implementing a collaborative-based strategy (data not shown). This course was heavily populated with students involved in the BIOL-L 101 intervention described herein.

We are interested in expanding the role of active learning and collaborative learning in all of our science classrooms. The interventions described in this report were confined to discussion sections. Lecture sections were left largely unaltered, hewing to the traditional model of "sage on the stage" lecturing using PowerPoints, with students sitting passively in the lecture hall. As noted, we are already changing this in the Biology curriculum. We also want to focus our efforts on assisting those students who run the risk of withdrawing from the course, and find ways to keep them enrolled and earning a grade of C- or better. Not only will this help these students remain in good academic standing, it will help increase spring-to-fall and year-to-year retention rates.

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References

AASCU (2016) AASCU American Association of State Colleges and Universities Re-Imagining the First Year of College: Planning Toolkit IU Northwest. Retrieved June 14, 2018, from http://www.iun.edu/academic-affairs/docs/RFY_PLAN_IUN.pdf

AASCU (2018a), AASCU American Association of State Colleges and Universities. Retrieved June 23, 2018, from http://aascu.org/strategic-plan/VisionandMission/

AASCU (2018b), Re-imagining the First Year of College, AASCU American Association of State Colleges and Universities. Retrieved June 23, 2018, from http://www.aascu.org/RFY/

Allen, D.E., Duch, B.J., and Groh, S.E., (1996), The Power of problem-based learning in teaching introductory science courses, *New Directions for Teaching and Learning.* 68, 43-52.

Almond, R.J. (2009). Group assessment: comparing group and individual undergraduate module marks, *Assessment and Evaluation in Higher Education*, 34 (2), 141-148. DOI: 10.1080/02602930801956083

Berry, L. (1991) Collaborative Learning: A program for improving the retention of minority students. Retrieved June 20, 2018 from https://eric.ed.gov/?q=lemuel+berry&id=ED384323.

Brooks, C.M., and Ammons, J.L. (2003) Free riding in group projects and the effects of timing, frequency, and specificity of criteria in peer assessments, *Journal of Education for Business,* 78 (5), 268-272, DOI: 10.1080/08832320309598613

Dillenbourg, P. "What do you mean by collaborative learning?" in *Collaborative Learning:Cognitive and Computational Approaches*, P. Dillenbourg (ed.), Oxford: Elsevier.

Duch, B.J., (1996). Problems: A key factor in PBL. *About Teaching* 50, 7-8

Ebenezer J, Kaya O, and Ebenezer, D (2011) Engaging students in environmental research projects: perceptions of fluency with innovative technologies and levels of scientific inquiry abilities. *Journal of Research in Science Teaching* 48, 94–116. doi: 10.1002/tea.20387

Hacisalihoglu, G., Stephens, D., Johnson, L., and Edington, M. (2018) The use of an active learning approach in a SCALE-UP learning space improves academic performance in undergraduate General Biology. *PLoS ONE, 13* (5)

Helle, L., Tynjälä, P., and Erkki, O. (2006). Project-based learning in post-secondary education – theory,practice and rubber sling shots. *Higher Education*. 51, 287-314.

Hmelo, C. E., & Ferrari, M. (1997). The problem-based learning tutorial: Cultivating higher order thinking skills. *Journal for the Education of the Gifted*. 20(4).

Hmelo-Silver, C.E. 2004. Problem-based learning: What and how do students learn?, *Educational Psychology Review*. 16(3), 401–422.

Hurford, D. P., Ivy, W. A., Winters, B., and Eckstein, H. Examination of the variables that predict freshman retention. *The Midwest Quarterly, 58* (3): 302-317.

Indiana University Office of Institutional Effectiveness and Research, 2016 data. Retreived June 12, 2018, from http://www.iun.edu/institutional-effectiveness/fast-facts/index.htm.

Kirk, K. (2007). Experience-based environmental projects. *Starting Point* Retreived June 21, 2018, from https://serc.carleton.edu/introgeo/enviroprojects/index.html

Kuh, GD., Cruce, T.M., Shoup, R., and Kinzie, J. (2008). Unmasking the effects of student engagement on first-year college grades and persistence. *Journal of Higher Education*, 79, 560-563.

Loes C. N., An B. P., Saichaie K., and Pascarella E. T. (2017) Does collaborative learning influence persistence to the second year of college? *Journal of Higher Education*, *88* (1), 62–84.

Lukkarinena, A., Koivukangasa, P., and Seppäläa, T. (2016). Relationship between class attendance and student performance. *Procedia - Social and Behavioral Sciences* 228, 341 – 347. DOI: 10.1016/j.sbspro.2016.07.051

Moore, R., Jensen, M., Hatch, J., Duranczyk, I., Staats, S., and Koch, L. (2003). Showing up: The importance of class attendance for academic success in introductory science courses. *American Biology Teacher*, 65, 325–329.

Moss, E., Cervato, C., Genschel, U., Ihrig, L., and Ogilvie, C.A. (2018). Authentic research in an introductory geology laboratory and student reflections: Impact on nature of science understanding and science self-efficacy. *Journal of Geoscience Education*, DOI: 10.1080/10899995.2018.1411730

National Center for Education Statistics, (2012). Higher education: Gaps in access and persistence study. Retrieved June 21, 2018, from https://nces.ed.gov/pubs2012/2012046.pdf .

Prince KJ, van Mameren H, Hylkema N, Drukker J, Scherpbier AJ, van der Vleuten CP. (2003). Does problem-based learning lead to deficiencies in basic science knowledge? An empirical case on anatomy. *Medical Education* 37(1), 15–21.

Ross, S.M. and Hurlbert, J.M., (2004), Problem-based learning: An exercise on Vermont's legalization of civil unions, *Teaching Sociology*. 32 (1), 79-93

Ruiz-Gallardo, J.R., Castaño, S., Gómez-Alday, J.J., and Valdés, A. (2011). Assessing student workload in Problem Based Learning: Relationships among teaching method, student workload and achievement. A case study in Natural Sciences. *Teaching and Teacher Education* 27 (3), 619-627. doi.org/10.1016/j.tate.2010.11.001

Rutherford S. (2015). E pluribus unum: the potential of collaborative learning to enhance Microbiology teaching in higher education. *FEMS Microbiology Letters, 362* (23):fnv191.

Rye, J., Landenberger, R. and Warner, T.A. (2013). Incorporating concept mapping in project-based Learning: Lessons from watershed investigations. *Journal of Science Education and Technology* 22 (3), 379-392. https://doi.org/10.1007/s10956-012-9400-1

Savery, J.R., and Duffy, T.M. (1995). Problem based learning: An instructional model and its constructivist framework. *Educational Technology*. 35(5), 31-38.

Schmidt, H.G. (1983) Problem based learning: Rationale and description. *Medical Education*. 17, 11-16.

Schneider, R.M., Krajcik, J., Marx, R.W., and Soloway, E. (2002). Performance of students in project-based science classrooms on a national measure of science achievement. *Journal of Research in Science Teaching* 39 (5) 410-422.

SERC, the Science Education Resource Center at Carleton College (n.d.) Assessing project-based learning. *Starting Point*. Retrieved June 23, 2018, from https://serc.carleton.edu/introgeo/assessment/project.html

Smith, D.L., Hoersch, A.L., and Gordon, P.R. (2018) Problem-based learning in the undergraduate geology classroom. *Journal of Geological Education*, 43 (4), 385-390, DOI: 10.5408/0022-1368-43.4.385

Tessier, J. (2007). Small-group peer teaching in an introductory biology classroom. *Journal of College Science Teaching 36* (4): 64-69.

Boyer Commission on Educating Undergraduates in the Research University. (1998). Reinventing undergraduate education: A Blueprint for America's Research Universities. Retrieved June 20, 2018 from https://eric.ed.gov/?id=ED424840.

Treisman, U. (1992) Studying students studying calculus: A look at the lives of minority mathematics students in college. *The College Mathematics Journal, 23* (5), 362-372.

von Glaserfeld, E. (1989) Cognition, construction of knowledge, and teaching. *Synthese*. 80 (1), 121-140.

Whitten, D., James, A., and Roberts, C. (2017) Factors that contribute to a sense of belonging in business students on a small 4-year public commuter campus in the Midwest. *Journal of College Student Retention: Research, Theory, and Practice*. First Published August 29, 2017 https://doi.org/10.1177/1521025117726520

Woei H. (2009). The 9-step problem design process for problem-based learning: Application of the 3C3R model. *Educational Research Review* 4, 118–141.

Woods, D. R. 1996. Problem-based learning for large classes in chemical engineering. *New Directions for Teaching and Learning*, 68, 91–99.