Transformation of an Introductory Biology Course Sequence to Improve Student Success in a Bottleneck Course

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Abstract

In 2017, the Biology Department at Virginia Wesleyan University modified its two-course introductory sequence in response to high DFW rates in the first semester. The revised curriculum created a new third course and moved content that many students struggled with to that course, so that students faced more difficult material after a year of adjustment to the expectations of college-level biology courses. It also added active/structured learning elements to provide additional support in the first two courses. DFW rates in the revised first course showed a significant decrease from 51.2% to 30.4% during the four years post-implementation, with similar DFW rates in other courses pre- vs. post-revision. DFW rates in the new third course were still high (41.9%), but students seemed somewhat better prepared for the material in their second year. Pell status and Race/Ethnicity (but not gender or first generation status) significantly impacted the DFW percentage, but nearly all groups showed a proportional improvement post-change. Fall to spring retention rates did not differ pre- vs. post-revision, suggesting other factors may be more important. Scores on the Major Field Assessment Test did not differ significantly between students that took the original two-course introductory sequence, the new three-course sequence, and those that transferred in. These results suggest that targeted interventions aimed at bottleneck courses can improve student course success without negatively affecting long-term learning outcomes. Departments should sequence and scaffold program content in a logical approach that supports the transition of students from high school to more challenging, college level expectations.

Keywords: DFW rate, active learning, structured learning, curriculum revision, gateway courses

Introduction

In recent years, many college educators have placed increased attention on retaining students in STEM disciplines (Achat-Mendez et al. 2019, Callens et al. 2019, Gonsalves-Jackson et al. 2019) because of the societal need for students educated in these fields (Wieman & Perkins 2005). To achieve this objective, many efforts have focused on the role of introductory or gateway courses in the persistence of students in STEM disciplines (i.e., Ueckert et al. 2011, Scott et al. 2017, EAB 2018, Cohen & Kelly 2019, Hatfield et al. 2022). Successful completion of an introductory course can provide a foundation for success in future courses (Reidl et al. 2021), whereas difficulty with introductory courses can serve as a bottleneck for persistence within STEM (Cohen & Kelly 2019), and failure in these courses can cause some students to switch majors or even drop out of college altogether (EAB 2018, Weston et al. 2019). Underprepared students can be particularly impacted in these bottleneck courses, and are at greater risk of failure (EAB 2018, Anfuso et al. 2022). In some cases, this can present an equity issue, as minoritized populations that do not succeed in gateway courses are at greater risk of not completing a STEM program (Hatfield et al. 2022).

Because of these challenges inherent in gateway courses, educators have focused on evidence-based approaches to improve student success, including active learning (Freeman et al. 2014, Roberts et al. 2018), structured learning (Haak et al. 2011, Eddy & Hogan 2014), supplemental instruction (Achat-Mendez et al. 2019, Anfuso et al. 2022), low stakes assessments (Vyas & Reid 2023), cohort learning groups (Gonsalves-Jackson et al. 2019, Sojka & Sheldon 2022), and summer bridge programs (Bradford et al. 2021, Ghazzawi et al. 2022). Often, educators actually implement several of these approaches, and some researchers have compared the effectiveness of these different types of efforts (Haak et al. 2011, Eddy & Hogan 2014, Vyas & Reid 2023, Ezeh et al. 2023).

Active learning, flipped classes, and structured learning, while related, have each been shown to positively impact student success (i.e., Freeman et al. 2007, Haak et al. 2011, Riedl et al. 2021, Ezeh et al. 2023). These approaches can vary in the degree to which faculty members implement various structured learning activities, ranging from occasional group work on worksheets, to low stakes assessments or regular individual responses (i.e., clickers), to regular group problem solving, to fully flipped classes where students watch video lectures outside of class and use class time exclusively for interactive learning and problem sets (Freeman et al. 2014, Ezeh et al. 2023). In an investigation of these differing types of interventions, Eddy & Hogan (2014) observed that each of these approaches had a positive impact, but moderately structured classrooms (defined as in-class engagement with worksheets or problems 15-40% of the class time, with optional preparatory and review activities - Eddy & Hogan 2014) had the greatest benefits for all students and helped to close the achievement gap for Black and first-generation students. A recent meta-analysis found improved learning when pre-class videos are directly paired with both pre-class and in-class interactive tasks (Ezeh et al. 2023). Weiss et al. (2020) observed that individual response clickers did not help learning as much as group activities combined with clickers. In addition, Deslauriers et al. (2019) reported that while students in an active learning setting learned more, many individuals perceived that they learned less. This discrepancy was attributed by Deslauriers et al. (2019) to the increased cognitive demands required by active learning. Despite these well established educational benefits, many faculty remain hesitant to deviate from lecturing exclusively (Deslauriers et al. 2019, Callens et al. 2019).

Another factor that can impact student success in introductory courses is a potential disconnect between high school and college level expectations, particularly pertaining to scientific terminology (Kelly-Laubscher & Luckett 2016, Zukswert et al. 2019). Students may misunderstand scientific "jargon", causing their perceived understanding of introductory material to be higher than their actual understanding (Zukswert et al. 2019). An investigation of the semantics used in biology textbooks indicated a mismatch in expectations, such that college level courses required a greater semantic range and density than high school classes (Kelly-Laubscher & Luckett 2016). Put another way, university instructors typically expect the use of specific and precise terminology, and that students would be well versed in subtle distinctions between a variety of terms, whereas many high school courses and textbooks do not emphasize these distinctions (Kelly-Laubscher & Luckett 2016). Thus, it is possible that a more structured and scaffolded learning environment (defined as a supportive environment that reduces the level of support needed over time - Davis 2015), where students' learning is initially supported through various means (i.e., opportunities for practice work, supplemental instruction, group activities in class, etc.) can provide the feedback needed to ensure that students master the various aspects of biological literacy (Uno & Bybee 1994, Zukswert et al. 2019) and the process of scientific inquiry (Killpack et al. 2020). In addition, the material presented within individual courses and the curriculum overall must be placed in a logical sequence that establishes a solid foundation of essential terms and concepts, to ensure that the sequential acquisition of knowledge leads to greater student success (Veltri et al. 2011, Bloemer et al. 2017, Killpack et al. 2020).

This study focuses on the 2017 curricular redesign of the biology major at Virginia Wesleyan University (VWU), a small liberal arts institution located in the mid-Atlantic region of the United States. VWU has a diverse population that includes 41% of undergraduate enrollment from historically underrepresented populations (Non Asian/Non White Domestic U.S. students per IPEDS definitions). Nearly all students (99%) receive some type of financial aid and 35% of individuals are eligible for Pell grants. The curriculum modification sought to address high failure rates in a gateway course (the first course of the sequence), by intentionally sequencing and scaffolding student learning to improve student success and retention. Course materials for which students had consistently failed to show mastery of terminology in previous years were moved to later in the instructional sequence (from the first to the third semester). The curriculum was also modified to more effectively bridge the gap between high school and college level expectations, provide a solid foundation for success in higher level courses, and shift more difficult material later in the curriculum. In addition, we added a modest amount of structured active learning elements in the first two courses in the sequence, in an effort to promote student success and provide additional support while students worked to master biological literacy (Uno & Bybee 1994).

Course Requirement for BIO major	Fall 2011-Spring 2017 (pre-change)	Fall 2017-Present (post-change)
Principles of Biology I: Ecology and Evolution	BIO 131 with Lab	BIO 130 Non-lab course plus course enhancements
Principles of Biology II: Cell Biology and Genetics	BIO 132 with Lab	BIO 132 with Lab
Principles of Biology III: The Diversity of Life	n/a	BIO 200 New Course with lab material from BIO 131
Genetics	BIO 311 Genetics	BIO 288 Genetics (same course, moved to 200-level)
Upper-level Ecology course	2 courses	1 course
Upper-level Cell/Molecular course	1 additional course beyond Genetics	1 course
Upper-level Evolutionary/Integrative Biology course	2 courses	1 course
Elective Courses	2 courses	2 courses
Research or Internship	Available as an elective option	4 credits required
Total hours for BA degree	40 credits of BIO 8 credits CHEM	40 credits of BIO 8 credits CHEM
Total hours for BS degree	40 credits of BIO 16 credits CHEM 8 credits Math/Physics/GIS	40 credits of BIO 16 credits CHEM 8 credits Math/Physics/GIS

Table 1. Curricular changes implemented to the Biology major in Fall 2017

Background

During the 2016-2017 academic year, the Department of Biology reviewed assessment data and its curriculum, as a part of ongoing departmental assessment efforts. In doing so, it became readily apparent that the introductory course, Principles of Biology I: Ecology and Evolution (BIO 131 with lab) was an outlier, with a very high DFW rate: over 50% of students received a grade of D, F, or withdrew from the course. DFW rates have been used by many educators as a measure of student success (i.e., Norton et al. 2018, Long et al. 2020, Vyas & Reid 2023) and to guide curricular reform efforts (Ueckert et al. 2011, Roberts et al. 2018). The failure rate (DFW) in this course was especially tied to poor performance in the laboratory sessions, which focused on concepts including the diversity of life, taxonomy and classification, and the interrelationships of form (morphology) and function (physiology). Some of this difficulty was attributed to students' unfamiliarity with the terminology included in the first lab, such as the major phyla or the precise terms used to describe unique structures within these groups. At that time, the department was offering two lecture sections and six lab sections each fall and students were required to enroll in one lecture and lab class. The typical STEM faculty load at VWU is 7-8 course sections per year, so BIO 131 required the equivalent of one third of the departmental teaching load each fall to support student demand, and yet half of the students in the class were effectively failing. The department concluded that this approach was unsustainable, and that it was necessary to make some type of curricular revision to more efficiently staff departmental courses and promote greater student success.

The biology faculty met several times to consider various potential modifications to the major, and conducted curricular mapping (Veltri et al. 2011, Rawle et al. 2017, Branchaw et al. 2020) in an effort to more logically sequence the courses and learning outcomes. We also considered feedback from high school teachers in the National Association of Biology Teachers (NABT) workshops held on campus, who indicated that the diversity of life and taxonomic classifications (BIO 131 lab) were not emphasized in the high school biology curriculum, at least not in Virginia. The department ultimately decided to change from a two-course to a three-course introductory sequence (Table 1), which transformed the first class in the sequence into a non-lab "enhanced" course (requiring students to complete additional outside work beyond the lecture/discussion sections, but dropping the integrated, co-required lab sections) and added a third course (BIO 200: lecture and laboratory) that expanded the depth and range of content formerly covered in the lab from the first course in the old sequence. In this way, the students would address the more difficult material after they had a year of experience in college biology courses, had made their choice of major, and had greater opportunity to improve their scientific literacy (Uno & Bybee 1994, Bloemer et al. 2017). The revised first course in the sequence (BIO 130, non-lab) added some additional structured activities and some active learning elements into this course, such as low stakes quizzes, group activities, and online interactive activities (i.e., HHMI Biointeractive 2015). The second course in the introductory sequence (BIO 132) was also modified to include more active learning and structured elements as well. The genetics class was shifted from the 300-level to the 200-level (Table 1), to clearly indicate its position as the fourth course within the foundational sequence, but without substantial change to course content or pedagogy. Thus, following the curricular change, the additional support (scaffolding) was primarily focused on the first two courses, and tapered off after that, with upper-level courses remaining unchanged.

Additional adjustments were made to the major sequence, in order to maintain the total credits at the same level (Table 1) and require research or an internship as a capstone experience. The decision to reduce the number of required upper-level courses in some of the content areas (Table 1) was based upon the data from the Major Field Assessment Test (MFAT) (ETS 2024), in which subscores in organismal biology and population biology & ecology were consistently higher than those from the cell biology and molecular biology & genetics subsections. Thus, under the revised curriculum, the number of required upper-level courses in ecology was reduced by one and the second evolutionary/integrative biology course was shifted to be BIO 200, the new third course (Table 1). All non-biology course requirements (chemistry, math, etc.) for the major remained the same. Credit hour requirements for the biology program are similar to that of other STEM majors at VWU. For the Bachelor of Arts (BA) in biology, just over a third of the total credits required for the degree come from the major; for the Bachelor of Science (BS), half of the total credits required for the degree come from the major.

The research goal of this study is to examine the impact of these curricular changes on student success, persistence, and learning throughout the biology program, comparing the four years prior to the curricular change (2013-2014 through 2016-2017) with the four years immediately following the curricular changes (2017-2018 through 2020-2021). We predicted that the revised curriculum that was structured to sequence more effectively, engage students with active learning, and scaffold student learning throughout the curriculum would result in a lower DFW rate for the first gateway course and would improve retention overall and in the major. It was hoped that this would improve student learning overall, or at least that there would not be a negative impact on long-term student learning throughout the major program, as measured by MFAT total scores and section subscores (ETS 2024) for graduating seniors. Finally, we examined disaggregated DFW data, in an attempt to discern which subgroups (i.e., Pell Eligible students, First Generation students, Racial/Ethnic groups, etc.) benefited most from the curricular changes.

Race/Ethnicity	Mean DFW rate Fall 2013-Spring 2017 (pre-change)	Sample Size Pre-change	Mean DFW rate Fall 2017-Spring 2021 (post-change)	Sample Size Post-change
Black	67.9%	106	48.0%	102
White	44.4%	207	19.7%	233
Hispanic	40.0%	35	40.5%	37
Multiracial	51.5%	33	35.3%	34
Unknown/Other	51.2%	41	34.4%	32
Total	51.2%	422	30.4%	438

Table 2. DWF rates for Principles of Biology 1 (BIO 131 and 130) pre- vs. post-change disaggregated by Race/Ethnicity, with sample sizes for each group. Significant differences were observed among groups ($P < 0.001$, $\chi^2 = 29.351$).

Methods

To investigate the effects of the curricular modifications, we specifically examined changes in 1) DFW rate in the modified first course, 2) DFW rates in other biology courses over the same time frame, 3) fall to spring retention rates for students enrolled in the first biology course, 4) DFW data from the first course disaggregated by race/ethnicity, Pell status, gender assigned at birth, and first generation status, and 5) MFAT scores (total and subscores) of graduating seniors from these cohorts (pre- and post-change) compared with transfer students from these time frames, who took the introductory course sequence at a different institution.

We worked with the VWU Department of Institutional Research to obtain biology course enrollments and numbers of students earning a D, F, or withdrawing during each course-year and used these data to calculate course DFW rates from fall 2013 through spring 2021. These values were grouped as the four years prior to the curricular change (2013-2014 through 2016-2017) and the four years after the change (2017-2018 through 2020-2021), calculating the DFW rate for each course-year during each time period. We explicitly compared the DFW rates between these time periods (pre- vs. post-change) for the Principles of Biology I course (422 students pre-change and 438 post-change), which underwent modification, and the Principles of Biology II course (250 students pre-change and 256 students post-change). These time periods were compared statistically using a t-test, with $\alpha = 0.05$ set as the level of significance, using the four years before vs. the four years after the curricular change (sample size of 8 course-years for each comparison).

For all 200-level or higher BIO courses, which had lower total enrollment, we lumped each course together pre- vs. post change (19 total courses, some were only offered every other year), and excluded courses with a total enrollment <12 students pre- or post-change. DFW rates in these courses were compared pre- vs. post-change ($N = 19$ courses during each period) using a paired t-test, with $\alpha = 0.05$ set as the level of significance. For comparison, we also examined the DFW rates for the new BIO 200 course, which was first offered in fall 2018, during the three years it was offered during our study period, but this course was not included in the statistical analysis, as it was only offered post-change. All DFW data were aggregated within each course-year (100-level courses) or course (higher level courses), so that it is impossible to determine the identity of any individual students.

To examine any potential impacts on retention rate, we compared the fall to spring retention rates (continued enrollment at the university from fall to spring) of the students that took the Principles of Biology I course during the four years prior to the curricular change, vs. the retention rates for the four cohorts post-change. Original cohorts ranged in size from 75-126 biology students each fall prior to the change and 91-126 students after the curricular change. Retention rates were examined statistically using a t-test ($\alpha = 0.05$), comparing the four years before vs. the four years after the curricular change.

To explore effects on different subsets of students, we further analyzed the BIO 131/130 DFW rates using data disaggregated by race/ethnicity, gender assigned at birth, Pell status, and first generation status. We used the university's data that were submitted to IPEDS for race/ethnicity categories (National Center for Education Statistics 2023), so students were assigned to only one of these categories (Asian, Black, Foreign, Hispanic, Multiracial, Native American, Unknown, or White). The category "Unknown/Other" aggregates students who identify as Asian, Native American, Foreign, and students of unknown race/ethnicity, in order to obtain a sample size >30 for each racial/ethnic category both before and after the curricular change (Table 2). Statistical analysis on disaggregated data was conducted using Chi Square analysis ($\alpha = 0.05$), lumping all students in each category pre-change and post-change. We used the mean DFW in each time period and the number of students in each group to determine the expected values for these comparisons. For Pell status,

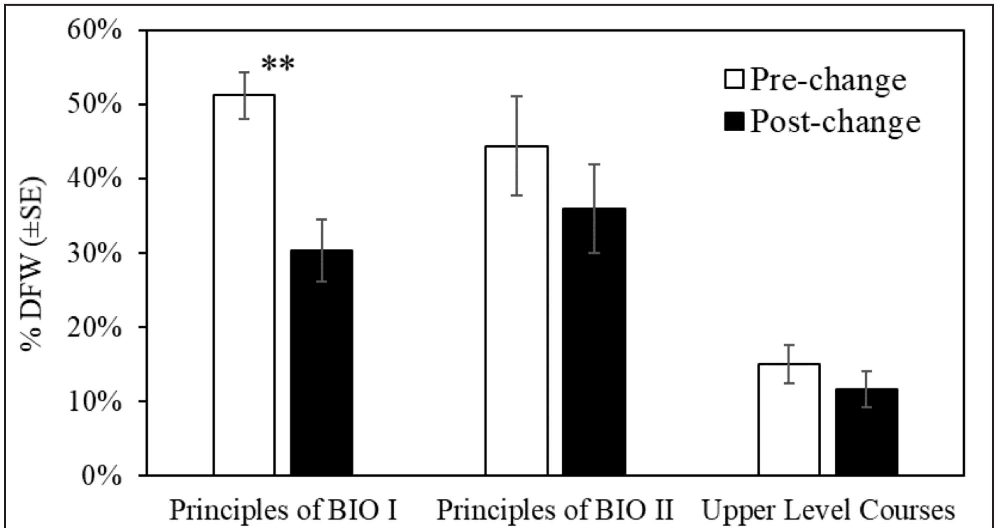

Figure 1. Percent DFW for Biology courses before (white) and after (black) the curricular change. There was a significant ($P = 0.008$) reduction in % DFW for Principles of Biology I, but no significant difference for the other comparisons.

gender assigned at birth, and first generation status, each category or group had a sample size of at least 124 students during each time period, with df = 3 for most of the χ^2 analyses (df = 9 for the χ^2 analysis of Racial/Ethnic groups). For the larger Chi Square Contingency table (Racial/Ethnic groups), we conducted a post hoc analysis by calculating the standardized Pearson residuals for each of the Chi Square cells to determine which cases deviated significantly from the expected values (Sharpe 2015). Residuals with an absolute value greater than 1.96 would deviate significantly from the expected value at the $\alpha = 0.05$ level (Sharpe 2015).

Major Field Assessment Test (MFAT) data (ETS 2024) were analyzed separately for total MFAT scores and those from each subsection (Cell Biology, Molecular Biology & Genetics, Organismal Biology, Population Biology & Ecology), using ANOVA, ($\alpha = 0.05$). MFAT results were included for graduating seniors that originally completed the BIO 131 during the four years pre-curricular change (N = 57 students), those that originally took BIO 130 during the four years post-change (N = 57 students), and students transferring in the equivalent course credit from another institution or a sufficient score on the Advanced Placement test (N = 22 students in total), who took the MFAT between Spring 2015 and Spring 2023 (the same time frame as the BIO 131/130 students). This ensured that the vast majority of students in the pre- vs. post-change cohorts were followed all the way to graduation. Although ETS did conduct a minor recalibration of the percentile ranks for the MFAT exam in summer 2017, nearly all of our students took the new version of the exam. To examine whether there was any potential difference, we compared the scores of BIO 131 students (the one group that could have been affected) that took the old (N = 27 BIO 131 students) vs. new (N = 30 BIO 131 students) versions of the exam, using a t-test ($\alpha = 0.05$). The old and new versions did not differ statistically ($P = 0.484$, $F_{1,55} = 0.417$), thus for all subsequent analyses, we combined these students (N = 57 BIO 131 students). As with the DFW data, all MFAT data are averaged within a group (BIO 131, 130, and Transfers), so that the identities of individual students are protected.

Results

The DFW rates in the revised first course showed a significant decrease ($P = 0.008$, $F_{1,6} = 15.127$) from 51.2% to 30.4% during the four years post- implementation (Figure 1). Although the mean DFW rates in BIO 132 shifted from 44% pre-change to 36% post-change (Figure 1), this difference was not statistically significant ($P = 0.484$, $F_{1,6} = 0.556$). Likewise, no significant difference was observed for the other continuing 200+ level courses ($P = 0.169$, t = 1.435, df = 18) pre- vs. post-revision (Figure 1). DFW rates in the new third course (BIO 200) were still somewhat high (41.9%), but students appeared somewhat better prepared for the material during their second year. This is particularly notable because the depth of coverage for the BIO 200 course was expanded in comparison to the content covered in the original BIO 131 lab, and yet the failure rate was on average ~42% vs. ~51% for BIO 131. For all other 200-level and higher courses, the DFW rate was typically low across the board (Figure 1), with only two courses out of 19 that had a DFW rate that was consistently over 20% (BIO 221: Anatomy and Physiology 1, and BIO 371: Histology). Likewise, Genetics had a low DFW rate, whether it was at the 200 or 300 level.

Contrary to our prediction, fall to spring retention rates (retention at the university from fall to spring for students in the first BIO course) did not differ significantly pre- vs. post-revision ($P = 0.962$, $F_{1,6} = 0.0025$). Fall to spring retention rates ranged from 81.6-88.9% pre-change and 76.9-90.6% post change, and the means among years were almost identical (84.4% pre-change and 84.2% post-change). It is important to note that the lowest fall to spring retention was observed in fall 2020, the first year of the COVID-19 pandemic. Instruction during the pandemic forced many instructors to rethink their use of technology, and many adopted more of a flipped approach, or a structured approach that relied more heavily on technology (Schaus et al. 2021). Aside from the confounding factor of the pandemic, the standardized test scores and mean GPA of incoming classes varied from year to year, suggesting that these other factors may be more important for retention, at least in this case. We chose not to examine graduation rates of the cohorts, as a measure of retention, focusing instead on fall to spring retention as the most direct measure, which did not differ following the curricular change. It is important to note that BIO 130 is also used as an introductory class for other majors (Earth & Environmental Sciences, Environmental Studies), so the decrease from the students taking the BIO 130 course (438 post-change during this time frame) through graduating

Comparison	Mean DFW rate Fall 2013-Spring 2017 (pre-change)	Mean DFW rate Fall 2017-Spring 2021 (post-change)
Pell Status ($P < 0.05$)		
Pell Eligible	57.5%	39.5%
Not Pell Eligible	46.8%	24.7%
Gender Assigned at Birth (NS)		
Male	51.0%	30.1%
Female	51.6%	30.9%
First Generation Status (NS)		
First Generation	54.0%	38.4%
Not First Generation	50.0%	27.2%

Table 3 - DWF rates for Principles of Biology 1 (BIO 131 and 130) pre- vs. post-change disaggregated by Pell Status, Gender assigned at birth, and First Generation Status. Samples sizes are ≥ 124 for each group.

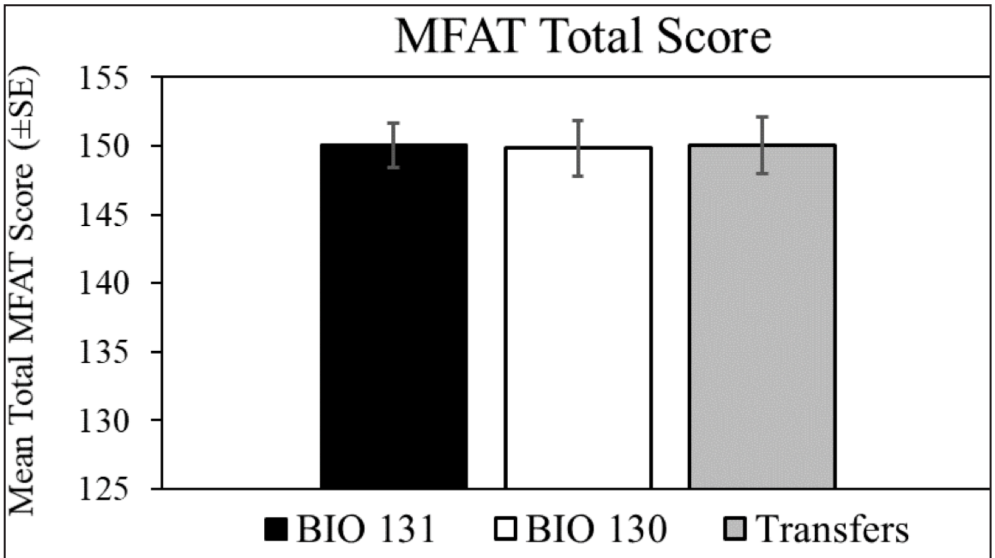

Figure 2 – Mean overall MFAT scores for students taking BIO 131 pre-curricular change (black bar) vs. students taking BIO 130 post-curricular change (white bar) and students transferring in credit for BIO 131/130 (gray bar). No significant difference was observed.

seniors in Biology (57 total from the post-change cohorts) does not function as an effective measure of retention within the BIO major or STEM in general. Any improvement in student success or retention rates could also yield other benefits, such as enhanced graduation rates, improved eligibility for financial aid, etc., but we failed to detect a significant improvement in retention in our case.

For disaggregated data, in the revised first course, Race/Ethnicity significantly impacted the DFW percentage ($P < 0.001$, χ^2 (9, $N = 349$) = 29.351). The DFW rates for Black students were significantly higher than the mean values both prior to ($R = 2.409$) and after ($R = 3.239$) the curricular change. Following the curricular change, the DFW of White students was significantly lower than the mean value ($R = -2.943$). Nearly all groups showed a proportional improvement in DFW rates post-curricular change of about 20% (Table 2). The one exception to this trend was Hispanic students, which were observed to have a consistent DFW proportion prior to and following the curricular change (Table 2); however, in both cases the residuals ($R = -0.925$ prior to the change and $R = 1.123$ following the change) indicated that the observed DFW rates did not deviate significantly from the expected values. All other racial/ethnic groups' DFW rates also did not deviate significantly from the expected values. DFW rates varied significantly based on Pell status ($P = 0.021$, χ^2 (3, N = 349) = 9.737), with Pell-eligible students showing higher DFW rates than non-Pell students; however, both groups showed similar proportional improvements in student success post-change (Table 3). DFW rates did not vary significantly based on the gender assigned at birth ($P = 0.999$, χ^2 (3, N = 349) = 0.027) or first-generation status ($P = 0.262$, χ^2 (3, N = 349) = 3.997) (Table 3). However, all of these populations showed an improvement in DFW post-change (Table 3).

Total scores on the Major Field Assessment Test (MFAT) did not differ significantly between students that took the original introductory course (BIO 131), the new course (BIO 130), and those that transferred in credit ($P = 0.871$, $F_{2,133} = 0.138$) (Figure 2). Likewise, comparisons of MFAT subscores did not vary significantly for Cell Biology ($P = 0.697$, $F_{2,133} = 0.362$), Molecular Biology & Genetics ($P = 0.846$, $F_{2,133} = 0.167$), Organismal Biology ($P = 0.999$, $F_{2,133} < 0.001$), and Population Biology & Ecology ($P = 0.145$, $F_{2,133} = 1.959$) (Figure 3). Thus, student learning for those that completed the Biology program was equivalent, whether they took the two course introductory sequence, the new sequence, or transferred in credit for at least some of the foundational courses.

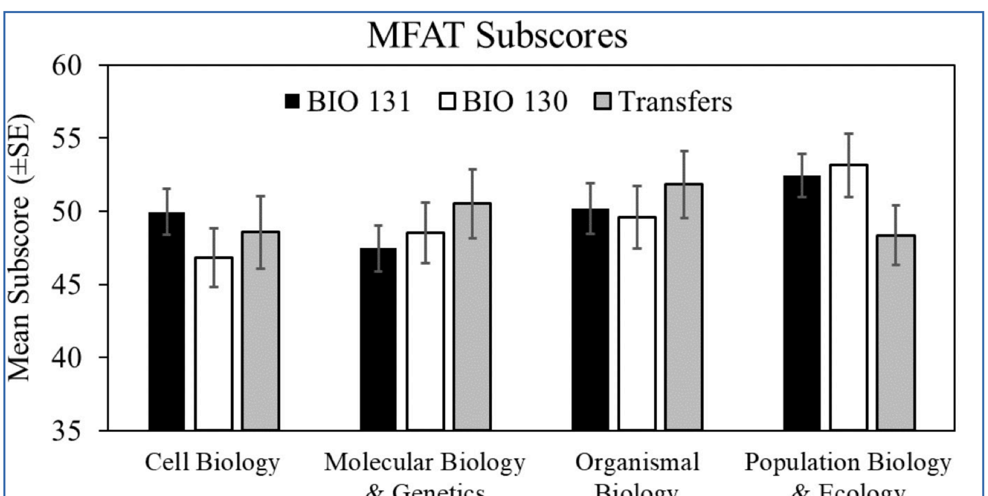

Figure 3. Mean MFAT subsection scores for students taking BIO 131 pre-curricular change (black bars) vs. students taking BIO 130 post-curricular change (white bars) and students transferring in credit for BIO 131/130 (gray bars). No significant differences were observed between the groups for any of the subsection scores.

Discussion

The curricular changes in the biology program at VWU that occurred in 2017 had a profound and substantial impact on student success in a bottleneck course (first semester, introductory biology). Our interventions decreased DFW rates in the first course from 51.2% to 30.4%. Although there was no significant benefit in subsequent courses in the sequence, there was also no adverse impact of the change on long-term learning outcomes (as measured using MFAT scores). When students faced the more difficult material (taxonomic nomenclature and conceptualizing trends in lineage evolution), which shifted from the first lab to the third course, they appeared to be more prepared for the content, and performed somewhat better overall (average DFW of 41.9%, vs. 51.2% in the first course). Placing a difficult course later in the instructional sequence can result in better student persistence despite the inherent difficulty of a course with high DFW (Bloemer et al. 2017).

Faculty teaching these courses reported that many aspects of the curricular change worked well in their courses. For the BIO 130 class, adding the outside of class activities (i.e., night insect sampling) and required field trips (visiting a natural history museum, constructing an ethogram of zoo animal behaviors, sampling on the research vessel) worked well to supplement the in-class time and maintain some of the hands-on activities formerly contained in the BIO 131 lab. These added activities worked to engage students without necessitating the staffing required to teach six lab sections. In addition, faculty in both of the 100-level courses reported that the outside of class quizzes were effective, especially instructor-developed quizzes placed on Blackboard (our learning management system). These low-stakes assessments gave students structured ways to practice the material and reinforce their learning. Likewise, these course instructors indicated that in-class group activities also typically worked well, and some sought to increase the frequency of these active group activities (from low to medium levels) in subsequent years.

In some cases, instructors needed to make additional changes in the next courses in the sequence to further scaffold the material. As an example, because the first course no longer had an integrated lab, instructors of the Principles of Biology II course (BIO 132) could not assume that students knew how to properly use a microscope, and the timing and sequence of BIO 132 lab topics needed to be adjusted to more effectively sequence and scaffold the lab material. As they refined courses, instructors felt that their courses ran better when the lecture and lab materials were more fully synchronized. After the four years post-curricular change (i.e., beyond the scope of these results), one of the BIO 200 instructors fully flipped his portion of the "lecture" and added quizzes with feedback and extensive in-class group work. He also noted that the grade distribution became even more bimodal since that point, with most students strongly engaging with the material in the active learning format, whereas some students did not put in the independent effort to watch the outside of class videos, take the Blackboard quizzes, and complete the low-stakes supporting assignments, and fared poorly. Other researchers have found that active learning and targeted interventions can increase course performance, decrease DFW rates, and reduce performance gaps (Haak et al. 2011, Roberts et al. 2018). Freeman et al. (2007) found that regular participation in a variety of types of active learning (clickers, practice tests, group activities) each led to higher student achievement in gateway biology classes. Likewise, Norton et al. (2018) observed significant decreases in DFW rates in Calculus I classes following the implementation of active learning practices, and then observed an increase in DFW rates eight years later, following a return to a more traditional course approach. In our study, these types of interventions were targeted toward the first 2-3 courses in the sequence. Subsequent courses remained more or less unchanged, with fewer supporting elements; however, the DFW rates in those upper level courses were consistently low (Figure 1).

In the future, it is likely that the instructors of the foundational courses (the three Principles of Biology courses plus Genetics) will implement additional modifications to further these efforts. A couple of years post-curricular change, some of the instructors started adding Teaching Assistants (TAs) to the class, but at that time the TAs' involvement was much more limited (taking attendance, grading quizzes, occasionally helping to facilitate during group work), so this does not represent a confounding change in our approach. Beyond the scope of the data we report here, we are currently in the process of expanding the TA role to more fully realize the Peer Supplemental Instructor (PSI) model (Arendale 1994, Rath et al. 2007), with peers present in class, conducting weekly instructional sessions, providing in-class support during group work, and offering exam prep opportunities. This model is designed to support all students in challenging courses and is not intended as remedial tutoring for underperforming students (Arendale 1994). Rather, it normalizes having all students seek support in challenging courses and helps build good study skills and a foundational knowledge base (Rath et al. 2007). This approach can provide benefits to all students that utilize this opportunity, especially underprepared and historically underserved students (Anfuso et al. 2022).

Others have found that integrating inquiry and course-based undergraduate research experiences (CUREs) into introductory biology courses helped students increase their confidence in research and experimental design skills (Killpack et al. 2020, LaForge & Martin 2022). This approach emphasizes the process of scientific inquiry and models independent investigation in a more structured course-based context. Interestingly, both of those studies found that students' scores were the same in both traditional and enhanced inquiry labs (CUREs), but the students felt they engaged in "real science" and increased their confidence in the CUREs sections (Killpack et al. 2020, LaForge & Martin 2022).

One of the most important aspects of several of these findings is the equity impact on underprepared and historically underserved groups. In our case, we observed that nearly all groups showed an improvement of ~20% rather than a complete closing of the achievement gap. Our DFW data disaggregated by racial/ethnic groups (Table 2) and Pell Status (Table 3) suggest that we must implement further interventions targeted at improving the success of Black and Pell-eligible students, to ensure that these groups are not left behind. Active learning, supplemental instruction, and other interventions have been shown to be particularly effective in improving achievement of underrepresented minority students (Rath et al. 2007, Eddy & Hogan 2014, Roberts et al. 2018, Anfuso et al. 2022) and underprepared students in general (Anfuso et al. 2022), potentially enabling them to close the achievement gap (Eddy & Hogan 2014, Roberts et al. 2018). Anfuso et al. (2022) observed that Black students showed the largest proportional increase in student success from Peer Supplemental Instruction, even when they attended as few as 3-5 PSI sessions. Eddy and Hogan (2014) found that even modest levels of intervention and course structure had disproportionately large benefits for Black students. Likewise, Haak et al. (2011) found that highly structured courses with regular group activities and opportunities for students to practice their learning had disproportionate benefits for underrepresented minority students. Engaging marginalized groups in course activities has been demonstrated to increase student performance (Roberts et al. 2018, Anfuso et al. 2022). Attrition of members of marginalized groups has been tied to a lack of engagement or a sense of belonging (Bradford et al. 2017, Ghazzawi et al. 2022, Hansen et al. 2023), suggesting that peer supplemental instruction (Anfuso et al. 2022), summer bridge programs (Ghazzawi et al. 2022) and cohort-based interventions (Gonsalves-Jackson et al. 2019, Sojka & Sheldon 2022, Hansen et al. 2023) each could be particularly effective in helping to close the achievement gap.

In our study, the instructors of the foundational sequence's courses have extensive experience working with underprepared students from a variety of backgrounds. Implementing changes to the major requirements, more deliberate sequencing, a scaffolded approach, increased course structure and an active learning approach in the foundational courses yielded improvements in student success. Our current expansion of supplemental instruction could potentially yield further gains and the closing of any equity gaps (Haak et al. 2011, Anfuso et al. 2022) by engaging students from marginalized groups (Ghazzawi et al. 2022, Hansen et al. 2023), and strengthening students' biological literacy and foundational knowledge base (Uno & Bybee 1994, Zukswert et al. 2019). It is the obligation of higher education in general to respond to the type of student that we have and meet them where they are, promoting educational equity for all of our students.

Using DFW rates to guide departmental interventions was effective in our case. The goal of these curricular improvements should not be solely to remove the difficult material of a course with high DFW, but rather to structure the overall curriculum with appropriate timing of that difficult material (Bloemer et al. 2017), and to identify cases where targeted intervention may be appropriate (EAB 2018). Departments should also target the use of strategies proven to impact student success (i.e., supplemental instruction, increased course structure, active learning) toward the courses where their use will have the greatest impact on student success, such as introductory courses with higher enrollments (Arendale 1994, Rath et al. 2007, Anfuso et al. 2022). This is not to say that these teaching strategies should not be used elsewhere; clearly their proven success can improve outcomes in many courses. Rather, if the goal is to realize the greatest impact of an intervention, it makes sense to start where the students are performing poorly, where the population of students is larger, and where the benefits of solid foundational knowledge can also be of benefit in subsequent courses (Riedl et al. 2021). Overall, our results indicate that even modest types of targeted interventions can have large positive outcomes for student success and educational equity.

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References:

Achat-Mendez, C., Anfuso, C., Johnson, C., Shepler, B., Hurst-Kennedy, J., Pinzon, K., Simmons, R., Dekhane, S., Savage, J., Sudduth, E., D'Costa, A., Leader, T., Pursell, D., Runck, C., & Awong-Taylor, J. (2019). Learning, leaders, and STEM skills: Adaptation of the supplemental instruction model to improve STEM success and build transferable skills in undergraduate courses and beyond. *Journal of STEM Education, 20*:14-23.

Anfuso, C., Awong-Taylor, J., Savage, J.C., Johnson, C., Leader, T., Pinzon, K., Shepler, B., & Achat-Mendez, C. (2022). Investigating the impact of peer supplemental instruction on underprepared and historically underserved students in introductory STEM courses. *International Journal of STEM Education*, 9:55.

Arendale, D.R. (1994). Understanding the Supplemental Instruction model. In D.C. Martin, & D.R. Arendale (Eds.), Supplemental Instruction: Increasing student achievement and retention. (New Directions in Teaching and Learning, No. 60, pp. 11-21). San Francisco: Jossey-Bass. Retrieved from: https://conservancy.umn.edu/handle/11299/200381.

Bloemer, W., Day, S., & Swann, K. (2017). Gap Analysis: An Innovative Look at Gateway Courses and Student Retention. *Online Learning, 21*(3): 5-14.

Bradford, B.C., Beier, M.E., & Oswald, F.L. (2021). A Meta-analysis of University STEM Summer Bridge Program Effectiveness. *CBE-Life Sciences Education*, 20:ar21.

Branchaw, J.L., Pape-Lindstrom, P.A., Tanner, K.D., Bissonnette, S.A., Cary, T.L., Couch, B.A., Crowe, A.J., Knight, J.K., Semsar, K., Smith, J.I., Smith, M.K., Summers, M.M., Wienhold, C.J., Wright, C.D., & Brownell, S.E. (2020). Resources for Teaching and Assessing the Vision and Change Biology Core Concepts. *CBE-Life Sciences Education,* 19:es1.

Callens, M.V., Kelter, P., Motschenbacher, J., Nyachwaya, J., Ladbury, J.L. & Semanko, A.M. (2019). Developing and Implementing a Campus-Wide Professional Development Program: Successes and Challenges. *Journal of College Science Teaching,* 49 (2):68-75.

Coehn, R. & Kelly, A. (2019). Community College Chemistry Coursetaking and STEM Academic Persistence. *Journal of Chemical Education,* 96: 3-11.

Davis, E.A. (2015). Scaffolding Learning. p. 845-847 In Gunstone, R. (ed.) *Encyclopedia of Science Education*. Springer, Dordrecht. Retrieved from: https://link.springer.com/content/pdf/10.1007/978-94-007-2150-0_206.

Deslauriers, L., McCarty, L.S., Miller, K., Callaghan, K., & Kestin, G. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proceedings of the National Academy of Sciences (USA*), 116(39):19251-19257.

Eddy, S.L. & Hogan, K.A. (2014). Getting Under the Hood: How and for Whom Does Increasing Course Structure Work? *CBE-Life Sciences Education*, 13:453-468.

Education Advisory Board (EAB). (2018). The Course Completion Playbook: Analyses and Tools to Improve Student Outcomes in Critical Gateway Courses. Retrieved from: https://eab.com/research/academic-affairs/toolkit/course-completion-playbook/.

Educational Testing Service (ETS). (2024). About - ETS Major Field Tests. Retrieved from: https://www.ets.org/mft/about.html.

Ezeh, C., Adesope, O., Kehinde, O., & Jaiyeola, E. (2023). Effects of flipped instruction on college students' learning in STEM subject domains: A meta-analysis. *Journal of STEM Education*, 23(4):12-27.

Freeman, S., O'Connor, E. Parks, J.W., Cunningham, M., Hurley, D., Haak, D., Dirks, C., & Wenderoth, M.P. (2007). Prescribed active learning increases performance in introductory biology. *CBE-Life Sciences Education*, 6:132-139.

Freeman, S., Eddy, S., McDonough, M., Smith, M., Okoroafor, N., Jordt, H., & Wenderoth, M.P. (2014). Active Learning increases Student Performance in Science Engineering and Mathematics. *Proceedings of the National Academy of Sciences (USA)*, 111:8410-8415. Retrieved from: https://doi.org/10.1073/pnas.131903011.

Ghazzawi, D., Pattison, D.L., Horn, C., Hardy, J., & Brown, B. (2022). Impact of an intensive multi-disciplinary STEM enrichment program on underrepresented minority student success. *Journal of Applied Research in Higher Education*, 14:660-678.

Gonsalves-Jackson, D., Reese, M. & Martorell, G. (2019). Strategies for Student Retention in STEM at a Small Liberal Arts Institution. *Journal of Virginia Science Education,* 12:19-27.

Haak, D., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology. *Science,* 332: 1213-1216.

Hansen, M.J., Palakal, M.J., and White, L. (2023). The Importance of STEM Sense of Belonging and Academic Hope in Enhancing Persistence for Low-Income, Underrepresented STEM Students. *Journal for STEM Education Research,* 2023. Retrieved from: https://doi.org/10.1007/s41979-023-00096-8.

Hatfield, N., Brown, N. & Topaz, C.M. (2022). Do introductory courses disproportionately drive minoritized students out of STEM pathways? *PNAS Nexus,* 1(4):1-10.

HHMI Biointeractive. (2015). Lizard Evolution Virtual Lab. Retrieved from: http://www.hhmi.org/biointeractive/lizard-evolution-virtual-lab.

Kelly-Laubscher, R.F. & Luckett, K. (2016). Differences in Curriculum Structure between High School and University Biology: The Implications for Epistemological Access. *Journal of Biological Education*. 50 Retrieved from: https://doi.org/10.1080/00219266.2016.1138991.

Killpack, T.L., Fulmer, S.M., Roden, J.A., Dolce, J.L., & Skow, C.D. (2020). Increased scaffolding and inquiry in an introductory biology lab enhance experimental design skills and a sense of scientific ability. *Journal of Microbiology and Biology Education,* 21(2):1-10.

LaForge, J. & Martin, E.C. (2022). Impact of authentic course-based undergraduate research experiences (CUREs) on student understanding in introductory biology laboratory courses. *American Biology Teacher,* 84:137-142.

Long, M., Cottrell-Yongye, A., & Huynh, T. (2020). Backward Redesign of a Nonmajors' Biology Course at a Two-Year Technical College. *Journal of College Science Teaching,* 49(6)7-16.

National Center for Education Statistics. (2023). Definitions for New Race and Ethnicity Categories. Retrieved from: https://nces.ed.gov/ipeds/report-your-data/race-ethnicity-definitions.

Norton, P., Bridges, W., & High, K. (2018). Impact of Course Policy Changes on Calculus I DFW Rates. *Journal of STEM Education*, 19(1): 41-47.

Rath, K.A., Peterfreund, A.R., Xenos, S.P., Bayliss, F., & Carnal, N. (2007). Supplemental Instruction in Introductory Biology I: Enhancing the Performance and Retention of Underrepresented Minority Students. *CBE-Life Sciences Education*, 6:203-216.

Rawle, F., Bowen, T., Murck, B., & Hong, R.J. (2017). Curriculum mapping across the disciplines: Differences, approaches, and strategies. Collected Essays on Learning and Teaching, 10. Retrieved from: https://doi.org/10.22329/celt.v10i0.4765.

Riedl, A., Yeung, F., & Burke, T. (2021). Implementation of a Flipped Active-Learning Approach in a Community College General Biology Course Improves Student Performance in Subsequent Biology Courses and Increases Graduation Rate. *CBE-Life Sciences Education*, 20:ar30.

,

J.A, Olcott, A.N., McLean, N.M., Baker, G.S., & Möller, A. (2018). Demonstrating the impact of classroom transformation on the inequality in DFW rates ("D" or "F" grade or withdraw) for first-time freshmen, females, and underrepresented minorities through a decadal study of introductory geology courses. *Journal of Geoscience Education*, 66(4): 304-318.

Schaus, M., Larkin, S., & Wilkinson, D. (2021). All that you can't leave behind: Essential COVID-19 technology and pedagogy. *Metropolitan Universities* 32(3):27-36. Retrieved from https://doi.org/10.18060/25331.

Scott, A.N., McNair, D.E., Lucas, J.C., & Land, K.M. (2017). From Gatekeeper to Gateway: Improving Student Success in an Introductory Biology Course. *Journal of College Science Teaching*, 46(4): 93-99.

Sharpe, D. (2015). Your Chi-Square Test is Statistically Significant: Now What?. *Practical Assessment, Research, and Evaluation*, 20: article 8. Retrieved from: https://scholarworks.umass.edu/pare/vol20/iss1/8.

Sojka, S. & Sheldon, P. (2022). Cohort intervention impacts on undergraduate science students' success. *Journal of STEM Education*, 24:14-22.

Ueckert, C., Adams, A., & Lock, J. (2011). Redesigning a large-enrollment introductory biology course. *CBE-Life Science Education*, 10:164-174.

Uno, G.E. & Bybee, R.W. (1994). Understanding the dimensions of biological literacy *BioScience*, 44:553-557.

Veltri, N.F., Webb, H.W., Matveev, A.G., & Zapatero, E.Z. (2011). Curriculum Mapping as a Tool for Continuous Improvement of IS Curriculum. *Journal of Information Systems Education*, 22:31-42.

Vyas, V.S. & Reid, S.A. (2023). What moves the needle on DFW rates and student success in general chemistry? A quarter-century perspective. *Journal of Chemical Education*, 100:1547-1556.

Weiss, D.J., McGuire, P., Clouse, W., & Sandoval, R. (2020). Clickers Are Not Enough: Results of a Decade-Long Study Investigating Instructional Strategies in Chemistry. *Journal of College Science Teaching*, 49(3): 58-65.

Weston, T.J., Seymour, E., Koch, A.K., & Drake, B.M. (2019). Weed-out classes and their consequences. In Seymour, E., Hunter, AB. (eds) *Talking about Leaving Revisited.* Springer, Cham Switzerland. Retrieved from: https://doi.org/10.1007/978-3-030-25304-2.

Wieman, C. & Perkins, K. (2005). Transforming Physics Education. *Physics Today*, 58:36-41.

Zukswert, J.M., Barker, M.K., & McDonnell, L. (2019). Identifying Troublesome Jargon in Biology: Discrepancies between Student Performance and Perceived Understanding. *CBE-Life Sciences Education.* 18:ar6.

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