Designing Gateway Statistics and Chemistry Courses for Today's Students:

Case Studies of Postsecondary Course Innovations

Digital Promise

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Case Study Overview

This report describes findings from case studies of innovative courses in introductory statistics and general chemistry with data on their effects on student learning or course completion rates. The goal of the research was to identify and learn about individual faculty-level interventions (pedagogical or curricular) and programmatic approaches (department- or program-level interventions, policies or practices) that reliably increase gateway statistics and chemistry course completion rates for students, particularly those for Black, Latinx and Indigenous students, and students from a low-income background. Detailed information about each of the innovative statistics and chemistry courses can be found in the case study reports in Appendixes A and B.

Search Process

The search for innovative courses began with a search for statistics and chemistry education projects that received awards from the National Science Foundation's (NSF) Improving Undergraduate STEM Education (IUSE) program. In addition, for statistics, we obtained nominations of innovative course designs from members of the Statistics Disciplinary Advisory Group (DAG) assembled for the Exemplar Statistics Courseware Research. We then conducted web searches of all courses that were identified to obtain descriptions of the innovation and to determine if there were available data on effectiveness. For both statistics and chemistry, we reached out to the authors of recently published studies included in Digital Promise's meta-synthesis of evidence-based teaching (EBT) practices and the authors of studies included in Phase Two Advisory's literature scan of the evidence base for innovative introductory statistics and general chemistry courses. A summary of the output from our search efforts is below in Table 1.

Table 1
Outcomes of Case Study Search Process

Identification source for innovations	Statistics	Chemistry	Total
NSF IUSE Awards	16	9	25
Disciplinary Advisory Board (DAG) recommendations	4	N/A	4
Published studies	3	7	10
Professional contact	2	15	17
Web searches for HBCU / HSI	N/A	7	7
Total	**25**	**38**	**63**

Statistics and chemistry innovations were eliminated from consideration for a case study for a number of reasons. In most cases, innovations were eliminated because researchers were unable to contact the course contact or instructor despite multiple outreach efforts. Many of the innovations that were NSF awards were eliminated because the innovation was not a course; for example, if it took the form of a single curriculum module, a web-based simulation, or a teaching assistant training program. Course innovations were also eliminated if they were not part of introductory courses designed for first-year students and if there were no data available for determining the effectiveness of the course for increasing course completion rates. Table 2 lists the number of courses eliminated by each exclusion criterion.

Table 2

Outcome of Course Elimination Process

Reason for Exclusion	# Cases Eliminated		
	Statistics	Chemistry	Total
Instructor/course contact not responsive	10	32	42
Innovation was not a course	1	0	1
Course was not introductory	2	1	3
Student outcome data not available	7	2	9
Number of cases excluded	**20**	**35**	**55**

After eliminating ineligible innovations, the final result was five statistics course innovations and three chemistry course innovations appropriate for exemplary course case studies. We interviewed the instructor of each of these courses to learn about the design elements of their statistics or chemistry course. Instructors were asked how their course differed from the way introductory statistics or general chemistry was usually taught and what made the course interesting for students. We also asked about supports for students who have gaps, weakness, or anxiety in terms of their math skills, and techniques the instructor used to encourage deep engagement with course concepts and practice opportunities for students to gain competency. Finally, we asked each instructor about the evidence-based teaching (EBT) practices they employed when teaching introductory statistics or chemistry. The full interview protocol is provided in Appendix C.

We obtained data from each of the case study course innovations with respect to its effectiveness in terms of student success (course completion rates) for different subgroups of students (race/ethnicity, gender). The institution sites for the case study courses are listed in Table 3.

Table 3
Final Case Study Courses

Statistics Courses	Chemistry Courses
Lorain County Community College	University of Arizona
Portland State University	University of South Florida
Skyline College	Western Research University[1]
University of Michigan	
Wesleyan University	

Summary of Interventions

Three types of interventions were considered for the case studies: pedagogical, curricular, and structural. An intervention was pedagogical if it involved one or more changes to a faculty member's instructional practice. An intervention was curricular if it involved changing the content of the course. We defined structural interventions as those that involved programmatic changes implemented at the department or institutional level. Interventions that were pedagogical and curricular could be implemented either at the individual faculty level or at the department level.

All eight of the innovative course case studies involved a pedagogical intervention. All but two of the innovations involved a curricular intervention as well as a pedagogical one (see Table 2). One each of the statistics and chemistry course innovations did not include a revised curriculum. The statistics course implemented a web-based support platform (ECoach) as the intervention, and the chemistry course implemented social-psychological interventions (utility-value and growth mindset) in the form of online homework assignments.

With respect to the adoption of the interventions, four of the five statistics course innovations and three of the chemistry course innovations were implemented by individual faculty. One statistics course innovation and two chemistry course innovations included structural changes and were implemented at the department level.

[1] The institution and course name for this case study have been anonymized.

Table 4

Intervention Types and Adopters for Statistics and Chemistry Courses

	Study site	**Intervention type** Pedagogical	Curricular	Structural	**Used by** Individual faculty	Department wide
Statistics	Lorain County Community College					
	Portland State University					
	Skyline Community College					
	University of Michigan					
	Wesleyan University					
Chemistry	University of Arizona					
	University of South Florida					
	Western Research University					
		8	6	3	5	3

Course Innovation Elements

To explore the course design elements of the interventions we reviewed information collected from published papers, public web documents, and data from interviews with course instructors. Selected findings from the research are shared below.

Statistics

A common element among four of the five statistics case studies was a shift in the curricular focus away from formal mathematical equations towards emphasizing the application of statistical reasoning, often through a project-based learning approach. This was particularly the case with Wesleyan University's Passion-Driven Statistics course where students learn about and apply statistical concepts to research problems of their own choosing. In Skyline College's project-based statistics course (Data Path), students conduct a literature review related to their project topic before reviewing the datasets and related variables of existing research studies.

The central innovation of the other three statistics courses was partially or entirely digital. Lorain County Community College added courseware to provide opportunities for additional skills practice for underprepared students, and the University of Michigan employed a web-based support called ECoach that promoted students' metacognitive and self-regulation practices. Portland State University's CATALST Introduction to Statistics course incorporated the TinkerPlots™ software into a project-based approach so students could create visualization of their data in order to support their understanding of statistics concepts. All five of the statistics case study courses utilized technology to facilitate computations, using programs such as SAS, SPSS, R, or Python.

Instructor interviews provided insight into the use of evidence-based teaching (EBT) practices in the statistics case studies. Active learning activities—both individual and peer-based—were found to be a central part of the curriculum in all five statistics courses. Peer-based active learning took the form of project-based learning, small group assignments, and peer tutoring support. Four of the five statistics courses embedded aspects of a flipped classroom method. In these courses, students review course content as homework and use class time to work on problem sets through individual and peer learning activities. These courses also provided students with the opportunity to take multiple low-stakes skills assessments that provided them with performance feedback.

Students' sense of belonging in college and in the statistics course was supported in different ways in the five case study courses. In Lorain County Community College, the instructor routinely reached out to students individually to express concern if the student was late on a homework assignment or if they performed poorly on an assessment. Students taking Passion-Driven Statistics at Wesleyan University reported increased confidence on specific data analysis tasks, along with a growing interest in conducting research studies in future statistics courses (see Dierker et al., 2018).

Chemistry

A common element among the three chemistry case study courses was the transition from a traditional lecture-based classroom approach to one that incorporates peer-based active learning. At the University of South Florida, peer-based instruction was combined with a utility-value intervention (see Eccles & Wigfield, 2002) that allowed students to establish how the course content was connected to their future goals, thus allowing student to see the relevancy of chemistry concepts to their own academic and professional goals. Small groupwork activities organized around peer instruction and problem-solving sessions provided students with immediate feedback, which was previously not feasible when the high-enrollment class was taught through traditional lectures.

A chemistry instructor at Western Research University implemented a flipped classroom approach where students watched short videos created by the instructor and answered several online questions about the content they watched before attending the class. This enabled students to evaluate their understanding of the content and ask necessary questions in class to improve their conceptual understanding. The course assessment practices were also changed. Instead of high-stakes mid-term and final exams, the course used multiple quizzes spaced throughout the year and a final project to evaluate students' understanding of the material.

The chemistry department at the University of Arizona redesigned its introductory chemistry course to increase the focus on conceptual understanding and critical thinking. The redesigned course is guided by discussions that contextualize learning on the analysis of relevant issues such as energy sources, environmental issues, life and medicine, and materials by design. In this curriculum, students actively engage with core concepts and ideas through instructional tasks (three to seven tasks per lecture) that ask them to analyze data, model chemical systems, and generate evidence-based arguments and explanations. Students' understanding of chemistry concepts was deepened through the use of multimedia tools such as interactive visualizations of chemical structures. Since most students taking the course are not chemistry majors, the instructors strove to provide them with tools and frameworks of chemistry that they could use in other courses and in the field they eventually pursue.

All three chemistry case study instructors reported using a number of evidence-based teaching practices. At the University of South Florida, the chemistry course implemented social-psychological interventions around growth mindset and utility-value that allowed students to see how the course content was relevant to their lives.

Students at Western Research University were encouraged to develop agency over their learning. The ability to preview the course material prior to attending the classroom lecture and testing their conceptual understanding provided an opportunity for students to learn at their own pace, reflect and revise, and internalize self-efficacy. The instructors of all three chemistry courses made extensive use of peer-based active learning activities where students learned from asking and answering questions with their peers.

A summary of the evidence-based teaching (EBT) practices used across the statistics and chemistry case study courses is shown in Table 5.

Table 5

Use of Evidence-Based Teaching (EBT) Practices Across Case Study Courses

EBT	Selected Applied Practices	Stats (n=5)	Chem (n=3)
Active Learning	Peer-based active learning activities in the form of small groupwork and peer assignments and projects	5	3
	Individual active learning through practice and application of concept after short lectures (≤15 minutes) of new content	5	3
Sense of Belonging	Examples of content and assignments that demonstrate how course content is relevant to students' lives and their future goals	5	3
	Instructor reaches out individually to students to express care about their progress and to offer extensions for assignment deadlines	5	3
Formative Practice	Increased use of low-stakes formative assessment techniques in lieu of high-stakes assessments such as midterms and final exams	5	2
Metacog, Self-reg, & Agency	Activities that value affirmation and growth mindset	4	3
	Automatic nudges/tailored messages about students' learning approach and study plans	3	3

Evidence of Effectiveness

The eight course case studies had varied levels of evidence regarding their impact on improving course completion rates. We used the Department of Education's Every Student Successes Act (ESSA) Tiers of Evidence framework to evaluate the rigor of the course case study evidence. The ESSA tiers are based largely on the Institute of Educational Science's

What Works Clearinghouse (WWC) standards for high-quality studies that assign the highest level of evidence only to randomized controlled trial studies, which are notoriously difficult and expensive to conduct in higher education settings. Other WWC research design elements include using the same outcome measure for the treatment and control/comparison groups and conducting a baseline of student equivalency between the two groups being compared. The study design elements required for each level of the ESSA framework are shown in Table 6.

Table 6
ESSA's Four Tiers of Evidence

	Strong Evidence Tier 1	**Moderate Evidence** Tier 2	**Promising Evidence** Tier 3	**Demonstrates a Rationale** Tier 4
Study Design	RCT study that meets WWC standards without reservations	QED study that meets WWC standards without reservations	Correlational study with statistical controls for selection bias	Logic model based on rigorous research
Study Results	Statistically significant positive outcome	Statistically significant positive outcome	Statistically significant positive outcome	An intervention study is planned or underway
Previous Findings	No strong negative findings from RCT or QED study	No strong negative findings from RCT or QED study	No strong negative findings from RCT or QED study	N/A
Sample Size & Setting	≥350 participants from more than one institution	≥350 participants from more than one institution	N/A	N/A
Match	Similar population and setting to study setting	Similar population or setting to study setting	N/A	N/A

As shown in Table 7, one statistics course case study innovation was backed by Tier 1 (strong) evidence of a positive impact on students. This course tested the impact of the Exam Playbook, a self-regulation support embedded within the ECoach platform in a randomized study involving two cohorts of introductory statistics students. In the course, students in the treatment condition strategized before each exam about which academic resources they would use for studying, why each resource would be useful, and how they would use their resources. In Cohort 1, treatment students performed an average of 3.64 percentage points higher on their final course grades than students in the control condition (Cohen's d = 0.33). The performance advantage was replicated with Cohort 2, where treatment students scored an average of 4.21 percentage points higher in the class than students in the control condition (d = 0.37).

Three of the other seven course case study innovations had an evidence level of Tier 3 (promising) and four had an evidence level of Tier 4 (demonstrates a rationale). The Tier 3 (promising) studies fall short of the Tier 2 (moderate) evidence standard because they were not conducted at more than one educational site or did not have a sample size of 350 students or more. For example, a randomized study of a general chemistry course innovation at the University of South Florida found statistically positive outcomes on students' interim tests and final exam, yet because the study was not conducted at a second institution, the evidence is Tier 3 (promising). A summary of research design elements for the case studies is shown in Table 7.

Table 7
Research Design Elements of Course Case Studies.

ESSA/WWC study design element	Statistics courses (n=5)	Chemistry courses (n=3)
Study was a radomized control trial (RCT)	1	0
Study groups used same outcome measure	5	3
Study conducted baseline measure of student equivalency	2	3
Total study sample was ≥350 students	2	2
Study was conducted at more than one educational site	1	1
Study had a statistically significant positive outcome	3	1

There is limited evidence from the introductory statistics and general chemistry course case studies on innovations that improve course outcomes for Black, Latinx, first-generation students, and students who are economically disenfranchised. The ECoach study with Tier 1 (strong) evidence for statistically significant positive outcomes overall, did not find any statistically significant differences in the treatment effect between males and females, among students of different racial groups, among students of different class standings, and between low- and high-performing students (Chen et al., 2017). This outcome suggests that the intervention is equally effective for all of these student groups. Wesleyan University's Passion-Driven Statistics course found statistically significant positive outcomes for Black and Hispanic students when comparing treatment and comparison groups, but the study's outcome measure was self-reports of perceived learning (not an objective measure) and the study groups were non-equivalent (Dierker et al., 2016, 2018).

In chemistry, a study of the University of South Florida's general chemistry course innovation found statistically significant positive outcomes overall (Tier 3) but statistically nonsignificant positive outcomes for underrepresented students identified as Black, Hispanic, or American Indian (Wang et al., 2021). The University of Arizona and Western Research University shared preliminary data on studies of the effectiveness of their general chemistry course innovations on DFW rates. The course innovations at both institutions showed large reductions in the percent of DFW rates for females and underrepresented minority students, but the statistical significance of these improvements was not determined.

Key Takeaways

Case studies of innovative introductory statistics and general chemistry courses identified a range of approaches taken by individual faculty and departments for improving student course completion rates. The interventions targeted course curriculum, instructional pedagogy, or (most often) both). Key outcomes from the innovative course case study research are outlined below.

- All five of the five statistics course innovations and two of the three chemistry course innovations involved a shift away from computational approaches toward teaching focused on concepts and reasoning and the application of the discipline to students' lives and future goals.
- Peer-based active learning is a central activity for both statistics and chemistry innovations that receive grant support and qualify for publication. Both of these features are congruent with recommendations made in recent consensus study reports from the National Academies of Sciences, Engineering, and Medicine (HPL II; NASEM, 2022; NRC, 2014).
- Student opportunities to work with interactive data visualizations (in statistics) or simulations (in chemistry and statistics) were emphasized in some courses, reflecting their increasing prominence in professional practice in these fields.
- The University of Michigan's ECoach web platform provides evidence of how technology can mediate the implementation of the evidence-based teaching practice of supporting students' use of metacognitive and self-regulation practices. Similarly, Loraine County Community College's use of statistics courseware provided underprepared students with opportunities for formative skills practice.
- Most of the case studies combined a pedagogical intervention with a curricular intervention, and none implemented an intervention that only involved changes to the curriculum. This suggests that trying to identify one of these intervention types as more impactful than the other would make little sense to educators.
- Structure innovations were less common, suggesting that even when an individual faculty member has developed an innovative approach with evidence of positive impacts for students, barriers to adoption on a departmental or institutional level remain.
- There is insufficient research focusing on equity to identify multiple course-level innovations with positive impacts for the foundation's focal student subgroups. While the case studies provided some data on outcomes for minoritized learners, the majority reported overall course outcomes or disaggregated outcomes by general student subgroups without testing for interactions. Additional large-scale rigorous research is needed on the impact of introductory statistics and general chemistry course innovations on outcomes for minoritized students and students who are economically disenfranchised.

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Appendix A: Statistics Case Study Courses

Statistics Course Case Study: Lorain County Community College

About the Institution

Lorain County Community College (LCCC) is a public community college in the city of Elyria in Lorain County, Ohio. The college offers Associate degrees, Bachelor's degrees, and certificates for students seeking credentials. Total undergraduate enrollment in fall 2020 was 10,138. Enrollment by race/ethnicity in fall 2020 was 9% Black/African American, 10% Hispanic/Latinx, and 73% White.

About the Course

LCCC's course innovation, MTHM 168-Statistics, is offered by the mathematics department with around 15 different instructors teaching sections for close to 600 students each fall. The course provides a non-calculus-based introduction to statistical thinking and statistical methods. Statistical topics that are taught include: data collection, data description, basic probability, sampling distributions, probability distributions, confidence intervals, and hypothesis tests. The course emphasizes the use of technology to solve problems involving real data, and hands-on projects are used throughout the course. To take the course, students must have a satisfactory score on a mathematics placement assessment or concurrently take MTHM 068, Statistics Co-Requisite. The corequisite course was the result of a policy change as in the past, students who entered LCCC without college-level math skills took a developmental math course first and entered statistics only after passing it.

Course Innovation Elements

The central innovation element in MTHM 168-Statistics is the addition of WileyPLUS Adaptive Assignments. When the prerequisite policy changed and students entered statistics without taking a developmental math course first, the department was concerned that course success rates would drop and became interested in using adaptive courseware as a support for students taking the corequisite course. In fall 2019 four instructors from the Statistics department began using the WileyPLUS courseware in their classrooms. To avoid students having to do computations by hand, students used Excel and StatKey along with the StatKey associated textbook *Statistics: Unlocking the Power of Data.*

Making course content relevant to students' everyday lives. One of these early adopters was interviewed about her use of evidence-based teaching (EBT) practices in her MTHM 168-Statistics classes. To make the course interesting for students, the instructor uses real-life examples to illustrate the relevance of statistics to everyday life. For example, students learned about the difference between a population proportion and a sample proportion using real data on the rate of COVID infection in Ohio. Similarly, students were taught about the meaning and implication of statistically significant p-values after watching a video clip of Dr. Anthony Fauci in the White House discussing the efficacy of the antiviral medication Remdesivir.

Supports for students in need of additional skills practice. The course instructor described supports that were provided that were particularly helpful for students who had gaps, weaknesses, or experienced anxiety in terms of their math skills. Before assignments were due the instructor sent students reminder emails about upcoming due-dates and directed them towards resources that address the same statistics concepts addressed in the assignments. Generally, these resources took the form of videos created with the Kaltura video portal that explain challenging statistics topics that students have struggled with in the past.

Video explanations were also created for the exam study guide, along with an answer key for the most frequently missed questions from the WileyPLUS adaptive practice quizzes. The instructor noted that while assignment reminders and content reviews were also provided to students taking the on-campus version of the course, she provided more one-on-one support to students taking the online version, particularly for those simultaneously taking the corequisite course.

Techniques for supporting students' mastery of statistics concepts. The instructor described techniques to foster deep engagement with statistics concepts and their application in the course. After reflecting on topic areas where prerequisite students have typically had knowledge gaps, the instructor created a booklet that included only the math concepts that are foundational and necessary for succeeding in the course. Presentation of the statistics content in the corequisite course was timed so that students would be exposed to foundational concepts just prior to learning the material taught in MTHM 168-Statistics.

The instructor's pedagogical approach included efforts to encourage students to complete their homework assignments by sending them regular reminder emails. The emails remind students of what the assignment is and what content videos will be helpful for completing the assignment. After an assignment deadline passes, the instructor emails students who have not submitted the assignment and asks if they need an extension. When students do complete their assignments on time, the instructor sends positive reinforcement messages to students.

Use of evidence-based teaching practices (EBTs) for cultivating an inclusive classroom. Both peer-based and individual forms of active learning are part of the instructor's pedagogical toolkit. In the in-person version of the course students work in pairs on practice problem sets, after which pairs are chosen at random to present their answers to the class. In addition, when the instructor asks a question during a lecture, students are routinely asked to discuss the answer with a peer before responding. In the online version of the course, students are encouraged to answer each other's questions in the discussion forum and are awarded a small amount of extra credit for doing so.

A number of supports are used in the classroom that help cultivate a sense of belonging among students taking MTHM 168-Statistics. The instructor is aware that LCCC does not have on-campus housing and that many students have families, full-time jobs, and other responsibilities to fulfill while simultaneously taking college courses. As a result, the instructor reaches out personally to students who are struggling with the course to ask if they need an assignment extension or other accommodations. These kinds of supports are particularly needed by students enrolled in asynchronous, online sections of the course, who tend to be non-traditionally aged students who have dependents and demanding work schedules.

Evidence of Effectiveness

A study on the effectiveness of the WileyPLUS Adaptive Assignments examined course completion data over time from course sections taught by the instructor who was interviewed for this case study. The analysis compared student course outcomes in fall 2019 (N = 102) to those for fall 2020 (N = 88) when the instructor was in her third term of using the courseware in MTHM 168-Statistics.

The model in the analysis adjusted for differences in the students enrolled in fall 2019 and fall 2020 based on the following variables: prior academic achievement, race, gender, age, enrollment status (full-time vs. part-time), and repeater status (whether the student was previously enrolled in the course). The findings from this analysis are shown in the table below.

Course Outcomes for Introductory Statistics Innovation

Semester	Course grade	Confidence Interval (low, high)
Fall 2019 (N = 102)		
All students	1.398	0.973, 1.823
Pell-eligible	0.944	0.370, 1.517
Part-time	1.492	0.940, 2.043
Fall 2020 (N = 88)		
All students	1.519	1.087, 1.951
Pell-eligible	1.420	0.871, 1.970
Part-time	1.931	1.323, 2.538

Summary

The use of adaptive courseware for learning introductory statistics can have positive effects on student learning outcomes. Specific findings from the Lorain County Community College case study including the following:

- Courseware can provide students with additional skills practice at a level that is appropriate for each individual student.
- Student course outcomes improved as the instructor gained experience using adaptive courseware in her class. This was particularly the case for students who were Pell-eligible and students who were taking the co-requisite course.
- The courseware provided students with additional skills practice at a level that was appropriate for each individual student, which was particularly important for students taking the corequisite course, as noted by the instructor
- The instructor of MTHM 168-Statistics employed a number of evidence-based teaching practices in her classroom, including opportunities for formative practice with feedback, individual and peer-based active learning, and promoting a sense of belonging for all students.
- The coupling of courseware with the instructor's use of EBT practices makes it difficult to disentangle the effects of each on student course success.

Statistics Course Case Study: Portland State University

About the Institution

Portland State University is a four-year public university in the city of Portland, Oregon that offers bachelor's and graduate degrees as well as graduate certificates. Portland State University had an enrollment of 18,045 undergraduate students in fall 2021. Enrollment by race/ethnicity was 52% White, 10% Asian, 17% Hispanic/Latinx, 6% Multi-Ethnic, 4% Black/African American, 1% Native American, and 1% Native Hawaiian/Pacific Islander.

About the Course Innovation

Portland State University's CATALST introduction to statistics course is intended for non-majors to fulfill their terminal mathematics credit. The course uses the Change Agents for Teaching and Learning Statistics (CATALST) curriculum. The CATALST curriculum focuses on models and simulations and is paired with TinkerPlots™, a technology that allows students to create visualizations of statistical models. Students use the statistical models to answer statistical inference problems.

Innovative Course Elements

How the course differs from the way statistics is usually taught. The CATALST statistical course is a pedagogical and curricular innovation incorporating collaboration, project-based learning, and Tinkerplots™ software to teach student statistics. In the CATALST course, the instructor assigns open-ended activities to students and provides scaffolding to support students' understanding of statistical concepts. Students use the Tinkerplots™ software to create visualizations of data (which aids in their understanding of statistical concepts) and to learn how to apply statistical techniques to various situations. Tinkerplots also allows students to customize simulations for their preferences and needs. Students work in groups of three or four throughout the semester and have the opportunity to work deeply on one to two projects to apply the statistical concepts they have learned. Student groups change periodically throughout the semester, allowing students to build rapport with one another and providing them with opportunities to experience the ideas and perspectives of different students.

Techniques used to elicit student interest and engagement to achieve competency. Students have the opportunity to work on projects that are of interest to them. Instructions try to bring in topics that are of high interest and relatable to current events and students' lives. Some examples of topics students have investigated include examining traffic stop data from the Ferguson, Missouri police department to see if biases exist in the drivers who are pulled over and examining data from Airbnb rental rates to see if there is prejudice in how properties are rented. During class time, students are able to gain insights from the instructor and their peers. Students use class time to collaborate with peers on their projects and engage in discussions on their interpretation of the simulations. Class discussions are structured to allow students to get feedback from the instructor and peers on the projects they are working on and to ask project-specified questions related to challenges they are encountering in their statistical interpretation and analyses.

Evidence of Effectiveness

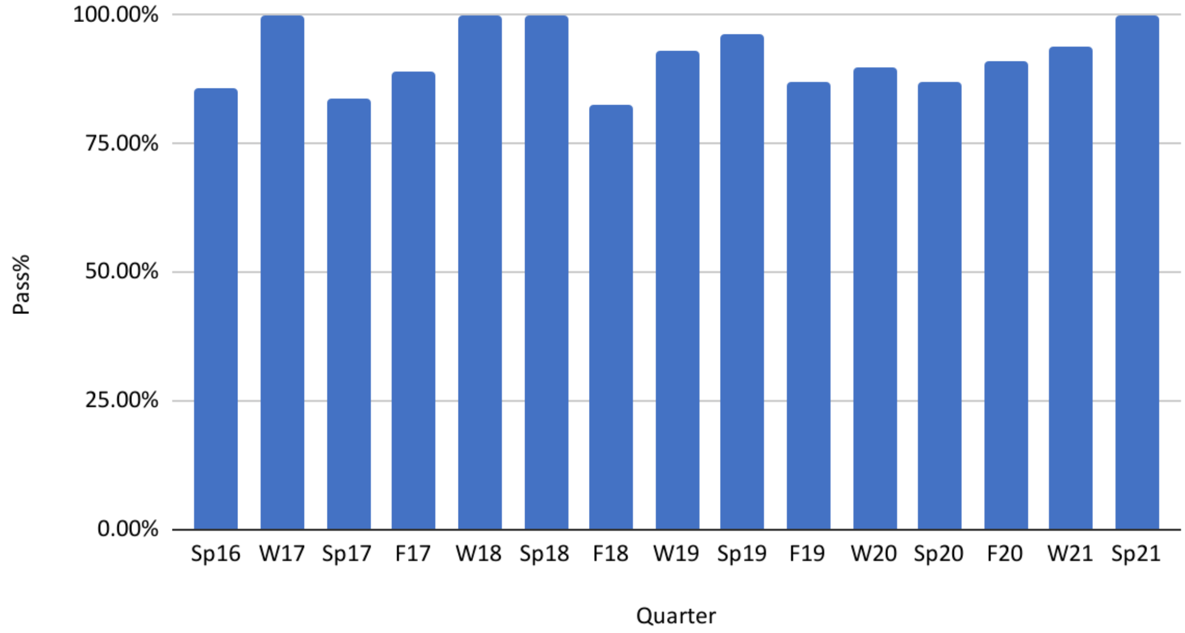
The average student pass rate for students taking the CATALST Introduction to Statistics class between Spring 2016 and Fall 2021 was 91.92%.

Comparison of Introduction to Statistics Pass Rate (Traditional vs. CATALST)*

Term	Traditional Class	CATALST
Fall 2017	87.18%	88.89%
Spring 2018	89.47%	100.00%
Spring 2018	89.47%	-
Fall 2018	97.50%	82.76%
Fall 2018	89.47%	-

*Comparison is from instructors were teaching both the traditional and statistics classes during the semester.

CATALST Percent Pass Rate: Spring 2016-Spring 2021



Summary

- The CATALST introduction to statistics course is just as effective if not more effective than the traditional statistics course for students attending Portland State University.
- The CATALST course is student-centered. Students have the opportunity to work on topics they have an interest in and to collaborate with peers on statistics inquiry activities.
- Students use TinkerPlots™ to create visualizations of statistical models.

Statistics Course Case Study: Skyline Community College

About the Institution

Skyline Community College is a public community college in the city of San Bruno, California. Skyline College is a Hispanic Serving Institution (HSI) that offers associate's degrees, bachelor's degrees, and certificates. In the fall of 2020 total undergraduate enrollment was 9,359. Enrollment by race/ethnicity was 32% Hispanic/Latinx, 19% White, 18% Asian, 16% Filipino, 8% Multi Races, 3% Black/African American, and 1% Pacific Islander.

About the Course Innovation

Skyline's course innovation, MATH 200: Elementary Probability and Statistics (Data Path), is a non-calculus-based introduction to probability and statistics that provides students with the opportunity to learn how to code with SAS as they learn to apply statistical reasoning and methods to solve real-world problems. The Data Path course serves as both a terminal math course for general education requirements and as a gateway course for the data science program. Students work on projects throughout the semester, and instructors use a flipped classroom to engage students in the curriculum. Students watch a video lecture prior to coming to class, and class time is used to support students as they work through their projects.

Innovative Course Elements

How the course differs from the way statistics is usually taught. Before starting their project, students conduct a literature review about their selected topic, examining existing research on the topic and related variables. Students use existing data to gain a deeper understanding of the variable they are working with and to enable them to look at variables from different perspectives. Students' complete write-ups of their literature review and use information from the literature review to create research questions and make recommendations for future studies. Students work on the same project for the duration of the semester and apply newly learned statistical techniques to advance their projects. Additionally, as students are learning new statistical concepts, they also learn how to code in SAS to support data visualization and analysis. Unlike their counterparts in traditional statistics courses, students enrolled in the Data Path course do not have regular exams or final exams. Rather, students' grades are based on project checkpoints dispersed throughout the semester and a final presentation on their project.

Techniques used to get students to deeply engage with statistical concepts and their application. The Data Path course takes a flipped-classroom approach to instruction. Students watch lecture videos before attending class, and class time is used to provide direct support to students to increase their conceptual knowledge, apply statistical concepts, and code in SAS. When the instructors recognize that students lack conceptual understanding of concepts, they build in additional activities during class time to support student learning.

Instructors have access to multiple data sets and use these data sets to select examples that are relatable to students, further reinforcing student learning of statistical concepts.

Students can select the topics of their semester-long project from a large public health data set with over 5,000 subjects and 200 variables. Examples of topics students have researched are associations between mental health and internet use; religion and alcohol use; health and education; and sexuality and smoking. Statistical concepts are taught and practiced in the context of the project as well as through analyzing the Flint Water crisis, the decline in cars' values once they are purchased, and other topics related to how statistics is used in the news.

Student supports that promote success and a sense of belonging. The Data Path course is student-centered, which contributes to student success and engagement. The course structure allows students to collaborate with one another on the statistical concepts they are learning, approaches to applying these concepts to their projects, and feedback on coding in SAS. Each Data Path section has a tutor who attends all classes. During class time, students have the opportunity to work with either the instructor or a peer tutor in small groups to support their learning of statistical concepts and coding in SAS. Additionally, tutors are available for both drop-in and appointment tutoring sessions through the Skyline College Learning Center.

Evidence of Effectiveness

Only preliminary course effectiveness is available for this course. Sample sizes for specific race/ethnic groups other than Latino and Filipino are too small to provide reliable estimates in some semesters (indicated by a dash in the table below). In addition, the first course offering for the Data Path course was during COVID restrictions. Course instructors initially prepared for this course to be face-to-face but made last-minute adjustments to offer the course online. An additional challenge to the first implementation of this course was that instructors were learning to code as they were teaching the course.

Course Outcomes: Spring 2021

Outcome	All (n=196)	Asian (n=24)	Black (n=9)	Filipino (n=39)	Latino (n=64)	Multi Race (n=25)	Pacific Islands (n=2)	Un-known (n=5)	White (n=27)
Success rate	55.1%	-	-	61.5%	42.2%	-	-	-	-
Non-Success rate	19.9%	-	-	33.3%	48.4%	-	-	-	-
Withdrawal Rate	25.0%	-	-	12.8%	34.4%	-	-	-	-

Course Outcomes: Fall 2021

Outcome	All (n=506)	Asian (n=60)	Black (n=11)	Filipino (n=117)	Latino (n=178)	Multi Race (n=39)	Pacific Island (n=6)	Un-known (n=6)	White (n=89)
Success rate	54.5%	73.3%	-	66.7%	39.3%	56.4%	-	-	57.3%
Non-Success rate	22.7%	23.3%	-	32.5%	55.1%	41.0%	-	-	41.6%
Withdrawal Rate	22.7%	10.0%	-	16.2%	30.3%	23.1.0%	-	-	25.8%

Students (n=69) completed a pre- and post-survey about their experiences with statistics overall and with the MATH 200 course. The data indicate that they "had a high level of understanding" of statistics (85%) and liked having the opportunity to choose their own topics for their projects (strongly agree, 47%; agree, 38%). Students also reported they liked the interaction they had in the class with their instructors, tutors, and peers (46%), and agreed that the instructional approach increased their understanding of different ways statistics can be used (85%).

Summary

- Students liked getting to choose their own topics for investigation and liked having access to peer tutors for support.
- The majority of students reported they had a high level of understanding of statistics in the MATH 200 Data Path class.
- In its initial implementations online, the Data Path course had Filipino course success rates higher than the course average while success rates for Latino students were lower than average.

Statistics Course Case Study: University of Michigan

About the Institution

The University of Michigan, Ann Arbor, is a selective 4-year public university that offers bachelor's, master's, and doctoral degrees as well as postbaccalaureate and post-master's certificates. Total undergraduate enrollment in fall 2020 was 31,329 and of these 1,305 (4%) were transfer-in enrollments. Undergraduate enrollment by race/ethnicity in fall 2020 was 4% Black/African American, 7% Hispanic/Latinx, and 55% White.

About the Innovation

The ECoach system described in this case study is unique because it is a web-based coaching platform that gives students tips about how to best approach their course, personalized feedback on their performance, and tools to help them succeed including to-do lists, exam playbooks, and a grade calculator. ECoach helps students learn by prioritizing the most important tasks for each week, tracks their progress on grades and study habits, and provides tailored strategies to help them improve their grade. Aside from being used in introductory statistics, ECoach is also used in other introductory courses with high enrollments (introductory chemistry, biology, and physics).

Course Innovation Elements

The main student-facing features of ECoach are the exam playbook, grade calculator, and 'Name that scenario.' Faculty-facing features include the ability to send tailored messages, texts, and emails to students, and tools for conducting surveys and research in classrooms. In the exam playbook students see a list of course resources chosen by the instructor up to 10 days before their exam. Students are asked to think about what they expect to be tested on in the exam, select the resources they plan to use to study, and write about why they chose those resources. Students then make a study plan that outlines how, when, and where they will use the resources and sync the plan with their Google Calendar.

The grade calculator shows students the grades they have earned to date and lets them estimate what they will do in the rest of the course to see what might happen to their final grade. Faculty can assign grade cutoffs to make the calculator match the course grading scale, add multiple grading methods, and assign course-specific grade category rules, such as dropping the lowest quiz score. Faculty can turn the calculator on or off for each of their courses. One faculty-facing ECoach feature that is currently being developed is the 'Behavior data manager' that enables faculty to use behavior data and analytics from other sources, such as online homework programs, autograders, and learning management systems.

Evidence of Effectiveness

In 2017, two randomized controlled trial studies were conducted that focused on the exam playbook as a stand-alone support (i.e., before it was incorporated into ECoach). The playbook was used as a 'Strategic Resource Use' intervention that students could self-administer online, and the effects were tested in two cohorts of a college-level introductory statistics class. Across both studies students were randomly assigned to the treatment intervention condition (N = 179) or the control condition (N = 182). Random assignment happened automatically when students started their first pre-exam survey, which they received approximately 10 days before each exam. Students in both conditions received the same message in the survey that reminded them of their upcoming exam and asked them to write down their desired grade and answer three questions about how motivated they were to receive that grade. In both studies students in both conditions were presented with the intervention twice during the course, with each survey taking 10-15 minutes to complete.

After the pre-exam survey students in the control condition received a regular exam reminder that their exam was coming up in a week and that they should start preparing for it. Treatment students received the same exam reminder and then a brief strategic resource use intervention. The intervention prompted students to consider the upcoming exam format, which resources would facilitate their studying, why each resource would be useful, and how they were planning to use each resource. After considering the types of questions that they expected on their upcoming exam, students then indicated which class resources they wanted to use (from a list of 15 available) to maximize the effectiveness of their learning. The checklist of class resources included lecture notes, practice exam questions, text- book readings, instructor office hours, peer discussions, and private tutoring, among others.

Across the two studies there was no statistically significant difference between the treatment and control groups in students' high school GPA, college GPA before the intervention, students' desired grade, or their motivation to receive their desired grade. Using final course grade as an outcome measure, the researchers compared the course performance between the two groups along three parameters: all students in both conditions (regardless of whether or not they completed the pre-exam surveys), students in both conditions who received the full intervention (i.e., they completed a survey before each exam), and differences among students based on how many pre-exams were taken (treatment dosage).

The analysis found that students in the treatment condition performed better on final course grades than all students in the control condition in Study 1 ($d = 0.33$) and Study 2 ($d = 0.37$). Considering only those students who completed the full intervention (i.e., completed two pre-exam surveys), treatment students again outperformed control students in Study 1 ($d = 0.38$) and Study 2 ($d = 0.47$). Finally, a treatment dosage effect was found between students who took the pre-exam intervention twice (full intervention) and those who took the intervention only once ($d = 0.81$). Moderation analyses for Studies 1 and 2 showed that there were no statistically significant differences in the treatment effect between males and females, among students of different racial groups, among students of different class standings, and between low- and high-performing students. In a recent correlational study of ECoach (Matz et al., 2021), researchers found significant positive relationships between students' use of specific ECoach features and their final course grade.

A randomized controlled study of the treatment effects of ECoach features on course success rates was recently published in *Nature Publishing Group (npj), Science of Learning* (see Chen et al., 2022).

Summary

- Findings from the University of Michigan ECoach case study showed that a web-based intervention designed to develop students' metacognitive self-regulation skills can result in higher final grades for students taking introductory statistics.
- The intervention has since been incorporated into ECoach as the Exam Playbook as a scalable, individualized way to reach and support students taking large first-year introductory courses.
- A now-retired instructor who has used ECoach for nearly ten years provided an anecdotal case report describing how the platform was used to provide personalized coaching that approximated one-on-one support.
- ECoach is an example of how technology and courseware can be used to support instructors' implementation of evidence-based teaching (EBT) practices in high-enrollment introductory courses.

Statistics Course Case Study: Wesleyan University

About the Institution

Wesleyan University is a private liberal arts university located in Middletown, Connecticut. Wesleyan University offers bachelor's and graduate degrees. Wesleyan University has an enrollment of approximately 3,000 undergraduate students with student demographics being 55% White, 11% Latino, 8% Asian, 7% Two or more races, 6% Black, <1% Native Hawaiian or Other Pacific Islander, and <1% Native American.

About the Course

Wesleyan University offers a Passion-Driven Statistics course which is a multidisciplinary statistics course intended for all students and is a course that satisfies the statistics requirement for several majors. The course is titled "Applied Data Analysis" in the course catalog and is a project-based course where students have the opportunity to answer questions that they feel passionately about through independent research using existing data. Students taking the semester-long course meet 2 times a week for a total of 3 hours. And have access to an additional 2-hour help session staffed by peer tutors.

Course Innovation Elements

The central design feature of Passion-Driven Statistics is the collaborative project-based approach where students learn and apply statistics concepts through researching a topic of their own choosing using an existing dataset.

What makes the course interesting to students. The course takes a project-based approach to teaching statistics. At the beginning of the semester, students chose the project topics they will work on for the duration of the semester. Project topics are selected from publicly available datasets and codebooks that represent different disciplines. The data sets are used for the student topics and the research questions that students use to guide the semester-long project. Examples of research questions include What factors predict safe sex practices? Does childhood abuse increase the incidence of mental health issues? and Is there a relationship between migraine headaches and educational attainment?

Techniques to encourage students to engage deeply with course content. Students conduct a literature review to learn about their topic and the associated variable they will be analyzing. Students learn how to code using a statistical software package (e.g., SAS, R, Stata, Python, and SPSS) as they work through their project. Professors have the discretion to choose the statistical software used by students. Students perform data management and statistical analyses on their selected variables.

Supports for students in need of additional skills practice. Peer tutors are embedded as a part of the course. Peer tutors are students who have taken the Passion-Driven Statistics courses and they attend class to help students work through their projects applying the statistical methods they are learning. Students are exposed to a variety of statistical methods and learn to select the appropriate statistical method to answer their research question. Projects are presented at the end of the semester. Initially, the component assignments and final project presentation went into the grade for students, but due to student familiarity and comfort with exams, exams were reintroduced as a requirement for the course.

Use of evidence-based teaching practices (EBTs) for cultivating an inclusive classroom. Active learning approaches–both individual and peer-based–are a central component of Passion-Driven Statistics. The course uses a flipped classroom method where students watch videos lectures of course content prior to class. Time that would ordinarily be spent on lectures is then used for problem-based activities where students work directly with instructors and peer tutors. Peer-based active learning is further reinforced through a project-based approach that lasts for the duration of the semester.

Evidence of Effectiveness

- Dierker et al. (2016, 2018) and Nazzaro et. al. (2020) reported on the evidence of the effectiveness of the Passion-Driven Statistics course by comparing learning experiences and course outcomes between students enrolled in the Passion-Driven course (n = 295) and students enrolled in the traditional statistics course (n = 44), and by comparing the outcomes of underrepresented students and non-underrepresented students (Dierker et al., 2016).
- Course outcome measures included students' self-reports of perceived confidence in several data analysis and statistical skills that were evaluated with a pre/post-survey. Study findings showed that underrepresented students were significantly (p = .04) more likely that non-underrepresented to report that their interest in conducting research had increased following the course.
- Students' learning experiences were also measured with a pre/post-survey. Study findings from Dierker et al. (2018) showed that students taking the Passion-Driven Statistics course were significantly more likely than students taking the traditional course to rate their learning experience as more useful (p = .025) and more rewarding (p = .006), and that they accomplished more than expected (p = .008) relative to other courses they were taking.
- Students enrolled in the Passion-Driven Statistics course reported higher levels of understanding of the information they received from individualized support (p = .001) than did students in the traditional course.
- Engaging in greater preparation for class sessions: Students enrolled in the Passion-Driven Statistics course showed more signs of increased engagement based on their reports of more frequently preparing for class.

- Students enrolled in the Passion-Driven Statistics courseware more likely to report accomplishing more than they had expected in the course and that the course was more useful than other college courses.
- Increased confidence in a variety of data analysis and statistics applications: Students enrolled in the Passion-Driven Statistics course and the traditional statistics course both had increased confidence in their analytic abilities at the end of the course. Students in the Passion-Driven Statistics course, however, were more likely to report an increase in confidence with managing data, choosing the correct statistical tests, and writing syntax code to run statistical analysis.
- Passion-Driven Statistics also promoted further training in statistics. Using causal inference techniques to achieve matched comparisons across three different statistics courses, students originally enrolled in Passion-Driven Statistics were significantly more likely to take at least one additional undergraduate course focuses on statistical concepts, applied data analysis, and/or use of statistical software compared to students taking either a psychology statistics course or math statistics course (Nazzaro et al., 2020).

The following table shows the exam scores of underrepresented and non-underrepresented students enrolled in the Passion-Driven Statistics Course (Dierker et al., 2016).

Exam Scores Grades (% correct)

Outcome measure	Underrepresented Students (URM) (n = 75)	Non-underrepresented students (Non-URM) (n = 259)
Exam 1	86.9%	97.5%
Exam 2	83.7%	90.3%
Exam 3	85.6%	90.5%

Summary

- Students in Passion-Driven Statistics learn how to code using a statistical software package while also learning statistical concepts.
- The Passion-Driven Statistics approach to learning statistics does not focus on statistical equations. Rather, students learn the skills of statistical inquiry and how to select the appropriate method of analysis to answer their research questions.

Appendix B: Chemistry Case Study Courses

Chemistry Course Case Study: University of Arizona

About the Institution

The University of Arizona is a 4-year public research institution in the city of Tucson, Arizona. Total undergraduate enrollment in fall 2021 was 38,528. Enrollment by race/ethnicity in fall 2021 was 6.4% Black/African American, 25.6% Hispanic/Latinx, 10.0% Asian, and 65.5% White.

About the Course

The University of Arizona's course innovation, CHEM 151 and CHEM 152 (also called "Chemical Thinking I and II"), are integrated lecture-lab courses designed to develop a basic understanding of the central principles of chemistry. The instructors teach using a reformed curriculum implemented with active learning components (e.g., collaborative in-class activities, clicker questions). Additionally, students are introduced to modern laboratory techniques and participate in experimental activities that promote the development of basic and advanced science-process skills. To take the course students must have a satisfactory score on the university's mathematics placement assessment or concurrently enroll in an introductory mathematics course.

The development of the Chemical Thinking curriculum was led by a research faculty member in chemistry education and a teaching faculty member recognized as one of the best instructors in the department. Their close collaboration over several years resulted in a successful pilot test and garnered momentum for change. The curriculum was pilot-tested and refined over a six-year period. During the pilot-testing period, a variety of educational resources (e.g., textbook, class notes) were developed not only to support student learning but also to facilitate the work of other instructors who might want to implement the curriculum. Key components implemented for broader dissemination are: (1) common instructional materials and methods (e.g., use of lecture videos and whiteboards) (2) common summative assessments (3) faculty professional development, and (4) teaching assistant and peer leader training.

Course Innovation Elements

How the course differs from the way chemistry is usually taught. At the University of Arizona, there are one to two general chemistry course sections, with 50 to 200 students each, following a traditional lecture-dominant approach. The majority of the course sections, with 200 to 600 students each, follow the Chemical Thinking curriculum innovation with active learning components. The Chemical Thinking innovation is described as more "conceptual" and focused on critical thinking while the traditional course is described as more "quantitative."

The reformed course curriculum is structured around eight units addressing essential questions that chemical thinking allows us to answer:

- How do we distinguish substances?
- How do we determine structure?
- How do we predict properties?
- How do we characterize chemical processes?
- How do we predict chemical change?
- How do we control chemical processes?
- How do we synthesize substances?
- How do we harness chemical energy?

The Chemical Thinking courses are also structured differently in terms of how learning is assessed. Students are graded based on their class participation, quizzes, homework, laboratory, and multiple low-stakes exams rather than on the basis of a high-stakes mid-term and final exam.

Most of the students enrolled in the Chemical Thinking courses are not Chemistry majors, so the instructors strive to provide them with tools and frameworks of chemistry that they can use in other courses in whatever field they pursue.

What makes the course interesting for students. The course innovation teaches chemistry concepts in the context of relevant issues, such as energy sources, environmental issues, life and medicine, and materials design. In this curriculum, students actively engage with core concepts and ideas through instructional tasks (three to seven tasks per lecture) that ask them to analyze data, model chemical systems, and generate evidence-based arguments and explanations. The activities are implemented in small groups and create a sense of community within large classes.

Techniques used to get students to engage deeply with chemistry concepts and their applications. Students enrolled in these courses are given opportunities to process information in collaboration with their peers. The instructors encourage use of whiteboards in the classroom for peer collaboration. Students are supported by graduate student teaching assistants and undergraduate peer leaders who have taken the course successfully in the recent past. Both help clarify questions and concepts during classroom activities.

Additionally, students are provided with resources, such as reading materials and videos, that they can use outside the classroom. This provides students with opportunities to engage in conversations and activities inside the classroom.

Supports for students who have some gaps, weaknesses, or anxiety in terms of their chemistry skills. Instructors have intentionally created a classroom environment that is supportive and helps students engage with the content. Instructors integrate relatable analogies and students are intentionally placed in a working group to maximize their learning outcomes.

Instructors use student feedback and polls, especially from students who didn't come from a very strong chemistry background and have a lot of anxiety about the course. Based on the feedback, instructors modify the course constantly and generate resources (videos, reading materials, concept maps, practice problem sets, etc.) to support student learning outside the classroom.

Students are also given the chance to participate in practice tests prior to low-weight mid-term and final-exams. This practice gives students the opportunity to work on their content knowledge gaps and weaknesses.

Outside of the classroom, teaching assistants and peer leaders provide tutoring hours, and instructors encourage students to attend office hours to clarify any gaps in their chemistry skills.

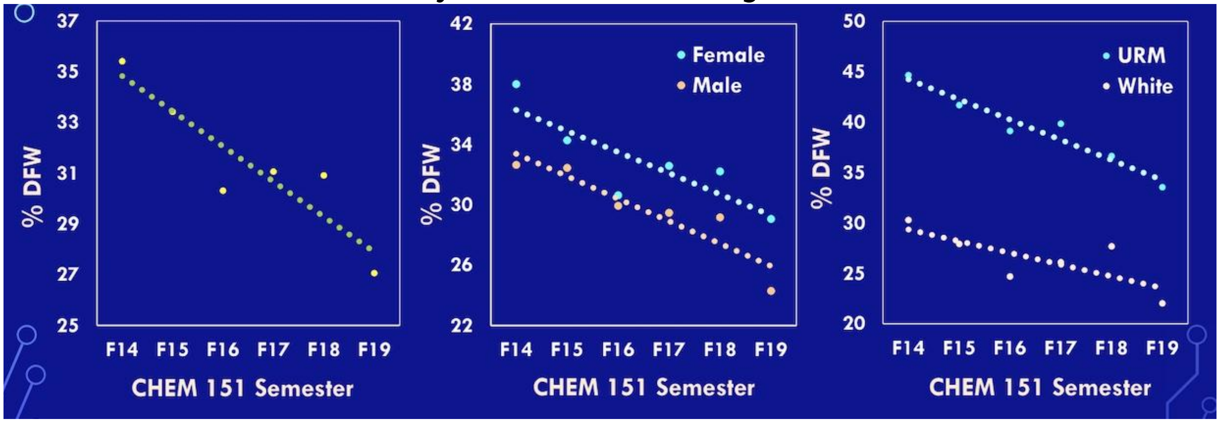
Techniques used to ensure that students practice chemistry methods enough to attain competency. The course is activity-driven and student-centered. Instructors generate resources (videos, reading materials, concept maps, practice problem sets, etc.) to support the students outside the classroom. Instructors also send emails or create posts on the learning management system on what to read and how to prepare for the next class. The emails and posts provide students with a structure for working consistently on their coursework.

Use of evidence-based teaching practices (EBTs). To support students' sense of belonging, the course instructors, teaching assistants and peer leaders create an inclusive environment in the classroom that is free of judgment and provides students with the opportunity to make mistakes without adverse consequences. Instructors use growth mindset feedback on both struggling and successful students. For example, the instructor provides feedback through individuals emails that that emphasize student's effort in the course. Instructors, teaching assistants and peer leaders also share their personal stories of struggle and success in a classroom environment. Students are also supported through heavy use of in-class group work, where students collaborate and share their approaches to solving chemistry problems.

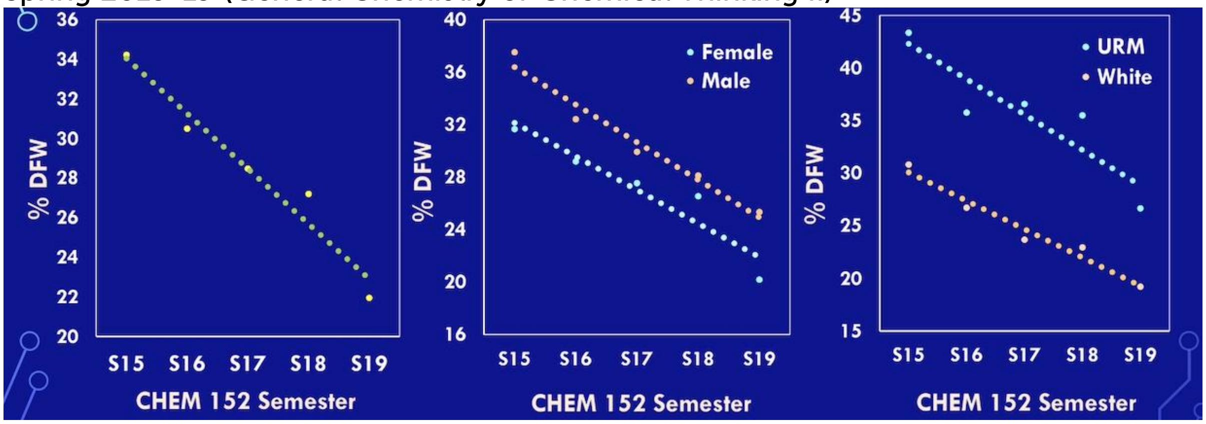
Evidence of Effectiveness

A study on the effectiveness of the Chemical Thinking courses was shared internally with the chemistry department at the University of Arizona. The analysis illustrated student course outcomes in terms of the percentage of students receiving a D/F or withdrawing from the course (%DFW) from Fall 2014-19 (General Chemistry or Chemical Thinking I) and Spring 2015-19 (General Chemistry or Chemical Thinking II). The data are shown in the graphs below. These findings show a significant drop in the DFW rate and a narrowing of the gap for students from underrepresented minorities.

Fall 2014-19 (General Chemistry or Chemical Thinking I)



Spring 2015-19 (General Chemistry or Chemical Thinking II)



Summary

The Chemical Thinking findings are very encouraging with respect to the positive effects of the combination of curricular, instructional, and assessment practices in this course innovation. Specific findings from the case study include the following:

- The Chemical Thinking courses are activity-driven and student-centered. The curriculum is guided by discussions that contextualize learning through the analysis of relevant issues such as energy sources, environmental issues, life and medicine, and materials design.
- The Chemical Thinking instructors employed a number of evidence-based teaching practices, including individual and peer-based active learning, opportunities for formative practice with feedback, and promoting a sense of belonging for all students.
- Students have multiple opportunities to demonstrate their learning through class participation, quizzes, homework, laboratory, and multiple exams rather than being graded predominantly on the basis of a high-stakes mid-term and final exam.

- The innovation seems to have benefitted female and underrepresented minority (URM) students, but further research is needed to determine if similar patterns are observed in other universities.
- The researcher and instructors acknowledge that they do not know the extent to which improvements in student performance are attributable to the new assessment and grading practices as opposed to curricular and instructional components of their innovation.

Chemistry Course Case Study: University of South Florida

About the Institution

The University of South Florida (USF) is a 4-year public institution in the city of Tampa, Florida. Total undergraduate enrollment in fall 2020 was 38,696. Enrollment by race/ethnicity in fall 2020 was 9% Black/African American, 20% Hispanic/Latinx, 7% Asian, and 48% White. Enrollment by gender in fall 2020 was 42% female and 58% male.

About the Course

USF's course innovation, a second-semester General Chemistry course, included almost 700 students participating in three classes taught by two instructors. The instructors revised the course experience by aligning the learning objectives, textbook, and syllabus across the three course sections. The course addressed topics such as intermolecular forces, solutions, thermodynamics, electrochemistry, and nuclear chemistry. The two-semester sequence of general chemistry is a requirement for STEM majors and for students pursuing programs in the health profession. Students from the latter group were predominant among course enrollees.

Course Innovation Elements

How the course differs from the way chemistry is usually taught. Traditional chemistry courses are taught in a lecture format. The key intervention strategies used in this course were active learning, peer-led learning, and utility-value and mindset interventions. Peer active learning included the use of active learning techniques that integrated communication skills and group work. The goal of peer active learning was to promote active discussion of chemistry topics and content. The utility-value intervention utilized prompts that allowed learners to establish how course content is connected to future goals. In effect, this allowed students to establish relevance of course content to their own academic and professional goals. Peer-led learning was also used to leverage small-group learning through problem-solving sessions. The peer-led support allowed students to receive immediate feedback, which is not feasible when one instructor is supporting a class of 250 students.

Techniques used to elicit student interest and engagement to achieve competency. Peer-led and active learning strategies specifically increased engagement and collaboration compared to traditional chemistry formats. The opportunity to collaborate and problem-solve together allowed students to deeply engage with content as they applied learning in collaborative tasks. As students co-constructed their learning, they were also able to establish the relevance of chemistry concepts to their future careers. This type of reflection allowed students to deeply think about how the content related to and supported their individual interests to increase motivation for learning about chemistry.

Student supports to promote success and a sense of satisfaction. The interventions used in this course supported social-psychological interventions. At the course level, students were able to receive immediate feedback and support through the peer-led and collaborative learning process. Further, students regularly engaged and extended their collaboration outside of class time using technology. Students who experienced the utility-value intervention experienced an increased sense of satisfaction. While these interventions are not designed to strictly promote a sense of belonging, they belong to a host of social-psychological interventions that explore how it can be operationalized. Students also had access to university-level supports which included tutoring support.

Evidence of Effectiveness

A study of the effectiveness of these interventions was published in the *Journal of Chemical Education*. An experimental design was used to test two types of social-psychological interventions and compared to a control group (Wang et al., 2021). The interventions, utility-value and growth-mindset involved three prompts embedded into course assignments throughout the semester. The study was conducted across three classes that consisted of 491 participants randomly assigned to one of the three course conditions (Wang et al., 2021).

The content summary group (control) students were asked to summarize key content addressed in the class (Wang et al., 2021). A second group experienced a utility-value course intervention, in which prompts asked students to reflect on how the content was relevant to them. The third group received a growth mindset intervention involving prompts asking students to reflect on a growth mindset approach in their studies. Wang et al. found that students receiving the utility value course intervention outperformed the students in the content summary and growth mindset groups. The performance achievement difference was significant in test scores in the latter half of the semester. While the interventions did not have a significant impact on underrepresented students' achievement (likely due to sample size limitations), the intervention's impact on underrepresented students was comparable to that of the entire cohort. Students in both intervention groups showed increased utility value for chemistry, and the utility value group also experienced increased emotional satisfaction (Wang et al., 2021).

Summary

Overall, pedagogical interventions that include active learning strategies and utility-value interventions appear to have a significant and positive impact on student performance in general chemistry.

- Utility value interventions are an effective method of developing chemistry content relevance to students' intended future careers
- Underrepresented students experienced a similar impact to utility value interventions compared to their peers
- Course design should incorporate some type of utility value prompt into course assignments periodically throughout a course

Chemistry Course Case Study: Western Research University[2]

About the Institution

Western Research University is a 4-year private research institution in western United States. The total undergraduate enrollment in fall 2020 was 19,786. Enrollment by race/ethnicity in fall 2020 was 5% Black/African American, 15% Hispanic/Latino, 19% Asian, and 30% White. Enrollment by gender in fall 2020 was 52% female and 48% male.

About the Course

Western Research University's course innovation, Chem 100, satisfies the university's general education requirement. A prerequisite for the course is concurrent enrollment in Chem 150 (General Chemistry Tutorial that emphasizes chemical mathematics and key concepts in general chemistry) or passing the university's placement tests in chemistry and math. The department is currently re-evaluating the prerequisite policy to reduce barriers and maximize student success rates. Students have to register for a lecture, lab and quiz to successfully complete the course.

Course Innovation Elements

How the course differs from the way chemistry is usually taught. General chemistry is typically taught in a traditional lecture format. A Chem 100 individual faculty has implemented a flipped classroom model incorporating various active learning methodologies. The students watch a short, pre-recorded video created by the instructor before attending the classroom lecture and answer a few questions about the content they watched. Students get two weeks to watch the videos and complete the pre-assignment or quizzes. This provides the students an opportunity to evaluate their understanding of the content and ask necessary questions to improve their conceptual understanding. During lectures students participate in small group work, including answering poll questions or solving problems, and they have the opportunity to ask questions to the experts.

The course is also structured differently in terms of assessment. Instead of high-stake exams (midterm and final exams), the course uses low-stake assessments (e.g., multiple quizzes and a final project instead of a final exam).

What makes the course interesting for students. The course encourages student agency. The ability to preview the course material prior to attending the classroom lecture and testing their conceptual understanding provides an opportunity for students to learn at their own pace, reflect and revise, and internalize self-efficacy. The interactive classroom environment empowers and encourages students to ask questions and minimize knowledge gaps.

[2] The institution and course name for this case study have been anonymized.

Techniques used to get students to engage deeply with chemistry concepts and their applications. Techniques include peer collaboration and student-centered activities. One of the active learning strategies implemented in the classroom is Think-Pair-Share. At the end of the class students have to answer a poll question or an open-ended question by collaborating with their neighboring peers.

The instructor of the course also conducts group quizzes. Students in groups of three work on quiz questions that are less mathematical and more conceptual. The group quizzes are administered a day before the individual quiz and are low-stakes assessments. This provides an opportunity for small group discussions where students agree on a consensual answer. In addition, there are also large classroom discussions on open-ended questions.

Supports for students who have some gaps, weaknesses, or anxiety in terms of their chemistry skills. The department offers a corequisite or companion course (Chem 150) that some students enroll in concurrently to help build math skills and work on key general chemistry concepts. Students work in small groups and get personalized help to learn the concepts and build their skills.

In the classroom, the instructor spends time each week on general study skills and techniques. Some of the techniques involve reducing test anxiety and study tips to build conceptual understanding.

Techniques used to ensure that students practice chemistry methods enough to attain competency. Students are expected to view pre-recorded videos and complete quizzes prior to attending the lecture on the same topic. Many of the activities involve collaborative active learning. These include in-class Think-Pair-Share, group quizzes, and classroom discussion on open-ended questions. Students are also encouraged to work informally with their peers outside of class on weekly homework assignments and classroom content.

Techniques used to promote a sense of belonging for all students. The instructor encourages students to adopt a growth mindset. According to the instructor, students value the open environment in the classroom that encourages them to ask questions without fear of being judged. Students work with their peers on group activities that create a sense of community. There are also office hours to discuss questions and/or problems 1:1 with the instructor.

Use of evidence-based teaching practices (EBTs) for cultivating an inclusive classroom. The instructor of the course employed a number of evidence-based teaching practices in the classroom, including individual and peer-based active learning, opportunities for formative practice with feedback, and promoting a sense of belonging for all students. Prior to attending the lecture, students view pre-recorded videos and complete quizzes. This provides an opportunity for students to learn at their own pace, reflect and revise, and internalize self-efficacy. Other peer collaboration and student-centered activities include in-class Think-Pair-Share, group quizzes (administered a day before the individual quiz), and classroom discussion on open-ended questions.

A number of supports are used in the classroom that help cultivate a sense of belonging among students. The instructor encourages students to adopt a growth mindset. Students also value the classroom environment that encourages them to ask questions. The instructor also reaches out to the students and conducts office hours to discuss questions and/or problems 1:1.

Evidence of Effectiveness

Preliminary data was shared with the interviewer on the effectiveness of the Fall 2020 flipped classroom. The flipped classroom model was taught by the instructor who was interviewed for this case study. The analysis compared student course outcomes or DFW rates in Fall 2020 for the Flipped Classroom (N = 215) and Traditional Classroom (N =307). The findings from this analysis are shown in the table below.

Final Course Outcomes for General Chemistry Innovation (Chem 100)

Course	Total Number of Students Enrolled	% URM Students	DFW Rates (Whole Classroom)	DFW Rates (URM Students)
Fall 2020 Flipped Classroom	215	6.5%	2.8%	7.1% (N=14)
Fall 2020 Traditional Classroom	307	5.9%	40.1%	61.1% (N=18)

Summary

Flipped models of instruction when used in gatekeeper chemistry courses have positive effects on student learning outcomes. Specific findings from the case study includes the following:

- The course encourages student agency. Students have the ability to preview short, pre-recorded videos created by the instructor prior to attending the classroom lecture and test their conceptual understanding by answering questions. This provides an opportunity for students to learn at their own pace, reflect and revise, and internalize self-efficacy.
- The instructor of the course employed a number of evidence-based teaching practices in the classroom, including individual and peer-based active learning, opportunities for formative practice with feedback, and promoting a sense of belonging for all students.

- Students have multiple opportunities to learn and perform in their coursework through multiple quizzes and a final project rather than high-stakes mid-term and final exams.
- Introduction of evidence-based instructional and assessment practices seem to have benefitted underrepresented minority (URM) students, but further research is needed to determine if similar patterns are observed in other universities.

Appendix C: Instructor Interview Protocol

1. How does this course differ from the way [Introductory Statistics/General Chemistry] is generally taught?
2. What supports are provided for students in the course who have some gaps, weaknesses, or anxiety in terms of their math skills?
3. What, if anything, about this course makes [statistics/chemistry] interesting for students?
4. What techniques are used in this course to get students to engage deeply with [statistics/chemistry] concepts and their application?
5. What techniques are used in this course to ensure that students practice [statistics/chemistry] methods enough to attain competency?
6. In what ways, if at all, do students collaborate with each other in this course?
7. What, if any, techniques are used in this course to promote a sense of belonging for all students?
8. What proportion of students taking this course succeed in earning a C or better? Is the course success rate higher for some kinds of students than for others?
9. Do you have any data on the effectiveness of this course in terms of learning measures or course grades for Black, Hispanic, and/or low-income students?
10. Do you have anything else to share?