
Theory of Change to practice: How experimentalist teaching enabled faculty to navigate the COVID-19 disruption

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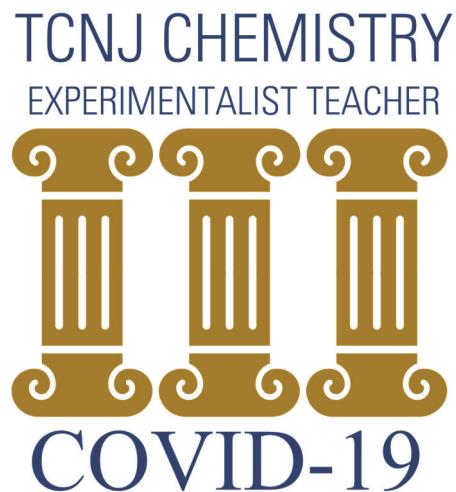
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ABSTRACT

The College of New Jersey's Chemistry Department and School of Science have been strategically transforming our teaching, learning, and mentoring environments for over a decade through programs that are targeted towards "new majority" students: low-income, first generation, and historically marginalized races and ethnicities. Recently, we have shifted from programs that target a small number of students to focus on systemic and structural changes to create inclusive excellence. We formalized our work in a Theory of Change (ToC) that emphasizes mechanisms for our faculty to depart from traditional pedagogy to become experimentalist teachers who use evidence-based practices and data to support our student success. The ToC is built on three pillars: (1) gaining empathy and understanding of our students, (2) a changing toolkit of acceptable pedagogical practices, and (3) a process to create shared language and values and an understanding of our responsibilities to our students. By focusing on mechanism, we do not prescribe a single pedagogy but instead are flexible for different course contexts. Department work on the ToC allowed our faculty to pivot instead of panic during the shift to online instruction. The students noted smooth transitions to remote learning and, more importantly, departmental discussions regarding pedagogy helped faculty to support each other with suggestions and sharing of best practices. As a department, we learned a great deal during the pandemic that furthers our collective work towards inclusive excellence and believe our ToC is transferable to other institutions.

GRAPHICAL ABSTRACT



KEYWORDS

General Public; First-Year Undergraduate; Second-Year Undergraduate; Upper-Division Undergraduate; Distance Learning; Collaborative/Cooperative Learning; Problem Solving/Decision Making; Computer-Based Learning; Chemical Education Research

The College of New Jersey (TCNJ) is a public, selective primarily undergraduate institution with approximately 7,000 undergraduates that has earned recognition for its commitment to excellence. However, careful evaluation shows that efforts are needed to support our “new majority” students,¹ including those who are first generation, low income, and come from racial and ethnic backgrounds historically marginalized in the sciences. TCNJ’s School of Science has been working strategically to address this over the past decade via student support programs and—more recently—through efforts to enact sustained institutional change. Additionally, we have seen a shift in the number of students of color graduating from the TCNJ Chemistry Department (5% in 2004 to 30% in 2019, based upon cohorts of 25-30 graduates). Our long-term goal is for our faculty to make a pedagogical shift; instead of educating based on traditional pedagogy, we want *experimentalist teaching* around student success to become the norm. We aim for this shift to happen both individually and collectively, and for this to be supported by a pedagogical culture of questioning, testing, and reflective revision. A key part of this effort involves collective conversations at every level to create *common language, values, and*

understanding of our students and our responsibility, leading to a new *toolkit of acceptable pedagogical practices*.

We formalized these principles within a larger Theory of Change (ToC), which serves as a guiding framework and highlights key mechanisms (or ‘pillars’) that we believe will drive change at our institution:

- **Pillar 1**, an *empathic, predictive understanding of students in their whole selves*, will prime faculty members to interpret student actions with empathy, and, in turn, yield faculty new heuristics by which to judge student performance and to assess their own performance in the classroom.
- **Pillar 2**, a *changed toolkit of acceptable pedagogies*, requires faculty to (a) share successes, failures, and new practices, and (b) emphasize faculty development and reduce fear of trying new pedagogy.
- **Pillar 3, common language, values, and understanding of our students and our responsibility**, will create shared, locally relevant meaning-making central to a robust culture and provide touchstones and guide decision-making for other practices, such as promotion and tenure.

At its core, our ToC connects collective meaning-making around our values and responsibilities to the cultural norms we create regarding which pedagogical techniques are ‘acceptable’ to use in our classrooms. Crucially, it emphasizes the mechanisms for change, but not the modalities of those mechanisms. For example, we argue that creating a *changed toolkit of acceptable pedagogies* requires faculty to share successes, failures, and new practices. However, it leaves open how and when that sharing should occur. By deliberately cultivating shared meaning-making and norms around teaching, faculty were able to choose new techniques to serve the original pedagogical intentions of their courses when, due to the COVID-19 closure at mid-semester, the remaining 8 weeks of these courses were performed using emergency remote teaching. Emphasizing experimentalist teacher mechanisms and not interventions allowed Chemistry faculty members to pivot and not panic (much) when asked to quickly transform our courses.

In the TCNJ Chemistry Department, the transformation in its teaching culture has been spurred in part through a variety of grant funded programs since 2008, from the National Science Foundation (NSF)

Scholarships in STEM (S-STEM) Program,^{2,3} and the NSF Improving Undergraduate STEM Education (IUSE) Program to improve TCNJ's Summer Scholars Program.⁴ These programs facilitated progress toward creating an empathic understanding of our students (Pillar 1) by having faculty observe, support, and teach new majority students. This empathic understanding led many of the faculty to change teaching styles to support students in these programs, but more importantly, to also support new majority students who were not identified for these programs. This change in our toolkit of pedagogical practices (Pillar 2) incorporated active learning strategies and research activities, such as CUREs⁵ (Course-based Undergraduate Research Experiences). Early progress in Pillar 2 arose from our participation in the IONiC (Interactive Online Network of Inorganic Chemists) group⁶ to develop learning objects using backwards design and active learning. The online community of IONiC⁷ helped to develop national level language and values on teaching (Pillar 3) to bring back to TCNJ. In 2018, TCNJ School of Science was awarded the Howard Hughes Medical Institute (HHMI) Inclusive Excellence grant⁸ to fund teams of faculty to overhaul the first two years of science curriculum. In Chemistry, teams began work to develop toolkits for general and organic chemistry. Critical to all three pillars and central to developing a culture of Inclusive Excellence, the HHMI grant funded the Mobile Summer Institute on Scientific Teaching⁹ in Summer of 2019.

General Chemistry performance by new majority students is critical to STEM retention.¹⁰ After extensive experience and experimentation within the NSF-funded programs, particularly the Summer Scholars Program for new majority matriculating students, Dr. Chan overhauled General Chemistry 1 (CHE201) in the Spring of 2017 and Fall 2018 into a high structure¹¹ guided practice (HSGP) model. The course leverages a highly structured course that also gives students a space to practice the skills required for successful class completion. The revised course contained active learning, group problem solving, careful balance of assessments, and development of college-level study and metacognitive skills (Pillar 2). In order to create time for active learning without sacrificing content, the instructors created pre-class video and readings. Subsequent to guiding the students through problem solving activities, students reinforce their learning through the application of the skills they have practiced to homework problems. This cycle then repeats. In accordance with our ToC, the pilot data and model were shared

with a small group of faculty including two new hires, Drs. Hunter and Ekanger, to acculturate them to the practices and TCNJ values undergirding the course design. Drs. Hunter, Ekanger, and Baker implemented the course design in Fall 2019 with resounding success.¹² The results were presented to the Chemistry Department in March 2020 to cultivate this understanding among faculty who did not participate in teaching the revised course (Pillar 3). The presentation shared our successes, concerns, and provided a mechanism for faculty to access this new toolkit and use some of the best practices in their classrooms. Three additional adjunct faculty members taught CHE201 with Dr. Chan in Spring 2020. The course design included an online, asynchronous component that translated well to online teaching. Synchronous online meetings facilitated group work and questions for the instructor, while maintaining progress toward inclusive excellence.

EXAMPLES OF HOW WE ADAPTED TO ONLINE INSTRUCTION

The examples herein demonstrate our ToC in action. Each faculty member had direct or indirect experience with the HSGP model of General Chemistry and its attendant values, teaching philosophy, and the understanding of students that guided the design, and many had already begun to change their teaching by drawing on this student-centered, active learning pedagogical toolkit. As the pandemic took off, the department quickly moved to sharing ideas and strategies via a Google chat, which facilitated the ongoing teaching conversation previously conducted in informal hallway chats and in-person meetings. While the courses vary widely by content, student level (first-year to seniors), number of students (11-48), and place in the curriculum (foundation, mid-level, in-depth), the imprint of the nascent teaching culture can be seen in each example.

General Chemistry 2 (CHE202)

While Dr. Ekanger taught CHE201 in Fall 2019 using the HSGP format, CHE202 did not yet undergo a systemic redesign within the Department. The high structure of CHE201's asynchronous content delivery coupled with synchronous practice was quickly used by all CHE202 instructors, including Drs. Bunagan and Ekanger, to restructure their course sections for emergency remote teaching (Pillar 3). A key part of HSGP requires students to submit a digital copy of notes written while watching pre-recorded videos (Pillar 2) for a grade. When students fell behind on submitting notes, they were messaged to check in on their wellbeing. Reaching out to students, especially students struggling

with difficulties created by the pandemic, kept them engaged with the class and continued the faculty's development of empathic understanding (Pillar 1). In addition to asynchronous activities, the high structure format also helped with CHE202 synchronous meetings.

Each CHE202 recorded synchronous online meeting became a space for students to work through a problem set in structured groups, aligned with the format for group work conducted in CHE201. After each round of 2-3 questions, student volunteers described their rationale for solving a problem to the class while Dr. Ekanger took notes on their solution using a shared screen visible to all participants. When needed, Dr. Bunagan also used some synchronous meeting time to emphasize pre-class content, finding that students were more apt to ask questions and engage via the chat than they had been in face-to-face meetings, likely due to their pre-class preparations. Moving forward, the Department plans to facilitate a systemic redesign of CHE202 to a HSGP format.

[Analytical Chemistry \(CHE310\)](#)

Prior to the transition, Dr. Hunter redesigned CHE310 to incorporate small group active learning exercises (Pillar 2), rather than content delivery via traditional lecture. She drew on her understanding of students to guide how to transition to a remote environment, focusing on maintaining a synchronous active learning component, while also being empathetic to the unique challenges faced by each student at home (Pillar 1).

During the transition, initial attempts to replicate group work using breakout rooms were unsuccessful due to slow check ins. If a group struggled with how to approach a problem, they felt abandoned without instructor feedback (Pillar 1). As class recordings did not capture breakouts, students unable to attend missed out on important discussions. To pivot, more structure was created with separate pre-class and in-class components for each active learning exercise (Pillar 2). Students were assigned a short, recorded lecture or reading to review along with the pre-class activity, and would submit their notes and/or work via the learning management system prior to attending class synchronously. The pre-class questions primed students for the in-class activities, which were restructured to include more guiding questions, allowing students to be more productive independent of the instructor. With more efficient breakout sessions, there was time for robust, whole class discussion, which was recorded to share with students unable to attend synchronously. Additionally,

these students could earn participation credit by engaging with the pre-class questions and recorded content, and then submitting notes and a reflection. Going forward, Dr. Hunter plans to shift some discussion to an asynchronous format to allow for more equitable participation.

Organic Chemistry 2 (CHE332)

Dr. Triano redesigned a section of CHE332 in Spring 2020 to include structured independent student pre-class activities (Pillar 2); these centered around learning goals that involved either lower-tier Bloom's taxonomy goals¹³ or topics from first-semester organic. The student activities consisted of 2-3 short pre-lecture videos that the students took notes on and answered questions on prior to class. Class time involved short lectures and structured problem sets centered around the higher-level Bloom's taxonomy learning goals, particularly those that integrated multiple concepts (Pillar 2). Class time was designed to be flexible so that activities could focus on student understanding of the course material (Pillar 1).

After the transition, Dr. Triano maintained both the structure and student-centered approach. Asynchronous videos were expanded to include all lecture content, including the problems that were done during in-person meetings. Recorded synchronous meetings focused on solving the problems from the pre-class material and answering student questions. Additional lab sessions were dedicated to problem solving in small groups, where observation of student work was easier. Two key components to remote instruction were real-time feedback from students (Pillar 1) and other faculty members trying similar approaches to their classes (Pillar 3). Student feedback indicated that students appreciated the asynchronous lectures but really valued the synchronous meetings – problem solving with other students in an environment where questions could be asked was central to their ability to construct an understanding of organic chemistry. Students also indicated that they felt that the course was designed in a way that valued them as learners, regardless of the method of delivery of the material.

Quantum Chemistry (CHE371)

Based on Dr. Baker's experience in Fall 2019 with CHE201, CHE371 was redesigned to be HSGP (Pillar 2) and flexible to student needs (Pillar 1) by combining both synchronous and asynchronous components. The general scheme was to first watch 3-4 short (~5-10 minute) videos and submit PDF notes on Canvas before synchronous Zoom session, then attend optional recorded synchronous online meetings during class time (50% attendance) to discuss videos, work problems, etc., and finally perform

a short follow-up online quiz after class. Several tools were used to maintain student/instructor communication including a message board, chats, video conferences, and email. Two computational chemistry activities (focusing on geometry optimizations, coordinate scans, and reactivity predictions) were integrated in place of in-lab experimentation. Dr. Baker produced additional videos demonstrating the quantum chemical calculations using the WebMO¹⁴ interface as a front end to Gaussian16¹⁵ software, which is installed on TCNJ's Electronic Laboratory for Science and Analysis (ELSA) high performance computing cluster. This high-structured approach will be continued in future offerings of CHE371.

Advanced Option (CHE476)

Dr. O'Connor developed CHE476 as a course on green and sustainable chemistry. The face-to-face classroom involved lecture, in class activities/work, and homework. The key to a successful transition to online learning was maintaining high structure, flexibility, and connection with the students. Although not formally involved in the General Chemistry experiments, the Department and School were actively discussing and sharing findings from experimentalist approaches (Pillar 3); thus the pivot to remote learning for Dr. O'Connor's CHE476 course was straightforward. Before preparing lecture materials, learning goals that the students should achieve by listening and studying the lectures (Pillar 2) were developed. Each asynchronous lecture video started with the learning goals explicitly written/said. Assignments that directly assessed these learning goals were written for students to practice cues. The LMS was useful to organize the week's work; students could complete each listed required assignment. Recorded synchronous class time was reserved to clarify topics, review assignments and due dates, and for group work. Each synchronous session included an agenda slide; students were reminded of assignments/due dates by a task list. Twitter and GroupMe were critical to engage with the students. The class used Twitter to share news articles or papers pertaining to sustainable chemistry, and class time was used to discuss findings. GroupMe helped the class and instructor to remain connected throughout remote instruction.

The lab component also pivoted smoothly to online instruction. The first two experiments were conducted on campus; the final lab was converted from a CURE to a written proposal project, still involving elements of the research and discovery process (Pillar 2). The students designed a greener

synthesis of a class of new molecules provided to them and used literature to propose an application for these molecules. Weekly meetings supported their research and proposal writing. The students created 5-minute “shark-tank” style videos to mirror the NSF review process to convince reviewers to fund the work.

Independent Research (CHE493)

One of the more challenging pivots to remote course instruction was CHE493. Each tenure-track faculty member mentors students in research, which for most involves in-person experimentation. Therefore, traditional experiments could not be completed after online transition. However, the power of high structure, community building, and explicit cues (Pillar 2) was important for successfully transitioning research groups to remote learning. One strategy that worked well was to organize research-based activities with deadlines in the LMS, as students are familiar with the LMS from other courses. Assigning weekly assignments maintained the structure of in-person research activities (not involving hands-on experiments) and kept students engaged (Pillar 2). Examples included literature assignments with guiding questions, completing outlines with key references for an introduction, writing a comprehensive introduction to the experiment-based research project, reading assigned literature articles pertaining to the broad research areas studied in the lab, and presenting on the literature article. To keep other group members engaged in reading articles, students uploaded questions to ask the presenters and provided reflective answers about concepts learned from presentations. To maintain the lab community, group members shared news about what was going on at home, how we were feeling, and frustrations of the semester at weekly scheduled meetings (Pillar 1).

REFLECTION

Most critically, the adaptations highlighted worked for our students. In anonymous, post-semester student surveys administered in our courses, students identified common challenges, including finding quiet workspaces at home, avoiding distractions during synchronous sessions, and learning how to structure time outside of the college environment. However, the high structure yet flexible approach alleviated these challenges, e.g. videos allowed self-paced content consumption, note submission and regular assessment prevented falling behind, and multiple modes of communication with faculty provided flexibility. Several students identified that shorter videos were preferable to longer videos or

live lectures used in some courses. Comments suggest the high structure approach would be beneficial even in face-to-face instruction: “I was not sure how online learning would go considering when in-class instruction was going on I felt like quantum [CHE371] was extremely difficult to grasp. But the video lectures ended up being EXACTLY what I needed to succeed. Being able to pause the videos to absorb what was just said was really helpful in actually fully understanding the material.” Similarly, a CHE202 student wrote: “Moving from in person to an online teaching format was done so gracefully. He supplemented us with great videos, made sure we understood that content, and still held lectures at the time we would usually have them. During these Zoom meetings, he still enforced a collaborative learning environment by creating breakout sessions for us to work on practice problems.” The HSGP model supported the collaboration and community students missed from in-person instruction: “One aspect I like is that group discussions are still being made a part of the class [CHE310]. It is also nice to have this discussion part since if more people do not understand a subject, then we know what needs to be explained by the professor.” The pivot to remote laboratory instruction was more challenging for many of our courses. For example, student feedback for CHE201 indicated that the laboratories normally done in person were more difficult to accomplish in a remote environment even when data and detailed instructions were provided. Using the experimentalist teacher mindset, this group of instructors acknowledged the feedback and proposed a commercial solution, Lab Flow (www.labflow.com), which will be used and assessed in all CHE201/202 sections during the Fall 2020 semester.

Our ultimate goal of the ToC is to create *experimentalist teachers* who use data, best practices, empathy, and pedagogical literature to make curricular choices that best support a wide range of students. A culture shift towards a paradigm of inclusive excellence takes time, insightful conversation, and practicing different pedagogies. Having multiple faculty members attempting similar pedagogies simultaneously allowed for facile sharing of successes and failures in the classroom in ways that improved students’ experiences. Given the success described here using the ToC to intentionally guide our efforts during the COVID-19 pandemic, it should be transferable to other institutions. Not only were our efforts successful, but faculty and students gained valuable insights during this experiment that we can build on in the future: “I think having pre-class assignments was useful and better prepared me for class discussion. (I think it would be good even for in-person instruction.)”

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ACKNOWLEDGMENTS

The authors would like to thank those that have helped in work presented herein: the TCNJ Chemistry faculty and adjunct faculty, the TCNJ School of Science and Dean Jeffery Osborn, the TCNJ Education Opportunity Fund and Summer Scholars Program, Dr. Lynn Gazley's research students, and the wonderful TCNJ students who have enriched our chemistry courses. We also thank the National Science Foundation for Division of Undergraduate Education funding SSTEM-0807107, SSTEM-1259762, IUSE-1525109, integration of computational chemistry MCB-1817670, and the ELSA cluster at TCNJ funded in part by OAC-1826915, OAC-1828163. This research was supported in part by an Inclusive Excellence grant to The College of New Jersey from the Howard Hughes Medical Institute through the Science Education Program.

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