TOWARDS A STRONGER COVALENT BOND: PEDAGOGICAL CHANGE FOR INCLUSIVITY AND EQUITY

Milo D. Koretsky[1], Devlin Montfort[1],
Susan Bobbitt Nolen[2], Michelle Bothwell[1],
Susannah C. Davis[1], and James D. Sweeney[1]
1 Oregon State University • Corvallis, OR 97331
2 University of Washington • Seattle, WA 98195-3600

In this article for the special section on diversity in chemical engineering, we provide a "snapshot" view of progress through two years of a comprehensive program-change initiative to shift the culture of the School of Chemical, Biological, and Environmental Engineering (CBEE) at Oregon State University (OSU). We have two related goals: (1) to create a culture where everyone in the CBEE community feels valued and belongs and (2) to create a learning environment that prompts students and faculty to meaningfully connect curricular and co-curricular activities and experiences to each other and to professional practice. This work is resourced by a grant from the National Science Foundation's REvolutionizing engineering and computer science Departments (RED) program, but is really owned by the CBEE community. The work leverages several projects initiated prior to this grant, and draws upon a departmental community with a collective commitment to address the difficult and important work of change.

Shifting culture is a complex goal and our design is multifaceted. We have previously described four elements that we believe need to act in concert for our culture to change.[1,2]

1. *Advancing faculty and staff capacity to engage issues of equity by shifting their* ***cognitive and affective knowledge of power and privilege*** *through an intensive, immersive 60-hour summer workshop followed by faculty working groups;*
2. *Curricular redesign and implementation focusing on second- and third-year studio courses to include more* ***meaningful, consequential work*** *via situated pedagogies like model-eliciting activities and problem-based learning;*
3. *Implementation of* ***student professional development 'PODs'*** *(self-forming student teams designed to be highly inclusive) where students can convene to better*

Milo Koretsky *is a professor in the School of Chemical, Biological, and Environmental Engineering at Oregon State University. He received his B.S. and M.S. degrees from UC San Diego and his Ph.D. from UC Berkeley, all in chemical engineering. He is interested in integrating technology into effective educational practices and in promoting the use of higher-level cognitive and social skills in engineering problem solving. His research interests particularly focus on what prevents students from being able to integrate and extend the knowledge developed in specific courses in the core curriculum to the more complex, authentic problems and projects they face as professionals.*

Devlin Montfort *is an assistant professor in the School of Chemical, Biological, and Environmental Engineering at Oregon State University. He received B.S., M.S., and Ph.D. degrees in civil engineering from Washington State University. His research focuses on describing engineering practice and engineering education as interrelated social systems and contrasting those systems, particularly in terms of how people talk about and understand knowledge.*

Susan Bobbitt Nolen *is a professor in and chair of Learning Sciences and Human Development in the College of Education at the University of Washington. She received her Ph.D. in educational psychology from Purdue University. Her main research interests are in designing environments to support engagement and in how motivation to learn develops over time in social contexts. Current projects include creating inclusive, engaging environments in university engineering programs and studying engagement in rigorous, project-based high school courses and how it might be supported. Nolen is a fellow of the American Psychological Association.*

Michelle Bothwell *is an associate professor in the School of Chemical, Biological, and Environmental Engineering. She completed engineering degrees at Purdue University (B.S.) and Cornell University (Ph.D.) before joining Oregon State University with teaching and research interests in bioengineering. She has contributed to new program development and improvement to engineering curricula, leading efforts to integrate professional engineering ethics, social and political responsibilities, and social justice topics in innovative and compelling ways. Her more recent research interests have centered on the interrogation of engineering culture using feminist and critical disability theories, and the transformation of academic institutions toward equitable, inclusive, and socially just workplaces.*

Susannah Davis *is a research associate in the School of Chemical, Biological, and Environmental Engineering at Oregon State University. She received her B.A. from Smith College and her M.Ed. and Ph.D. from the University of Washington. Her research focuses on individual and organizational learning and change in higher education with particular attention to the individual, social, cultural, and political factors that shape people's engagement in organizational change efforts.*

James Sweeney *is a professor in and head of the School of Chemical, Biological, and Environmental Engineering at Oregon State University (OSU). He received the Sc. B. in engineering (biomedical engineering) from Brown University and the M. S. and Ph.D. in biomedical engineering from Case Western Reserve University. His research interests in engineering education include engineering design pedagogies and practice, and academic organizational change for sustained impacts. He is also the Kuse Endowed Chair in Chemical Engineering at OSU and a fellow of the American Institute for Medical and Biological Engineering (AIMBE).*

understand their curricular and co-curricular experiences in relation to future professional practice; and

4. *Formal changes in* **governing policies and procedures** *in order to recognize less-traditional work that values and advances equity, inclusion, student success, and school community.*

Our approach to this change initiative is grounded in design-based implementation research (DBIR).[3] In DBIR, ongoing analyses are used to inform ongoing design decisions. Implementation problems and successes provide important information for redesign and elaboration decisions. Central elements to DBIR include: a focus on persistent problems of practice from multiple stakeholders' perspectives; a commitment to iterative, collaborative design; and a concern with developing theory and knowledge through systematic inquiry. Figure 1 shows the DBIR process with its continually interacting set of components.

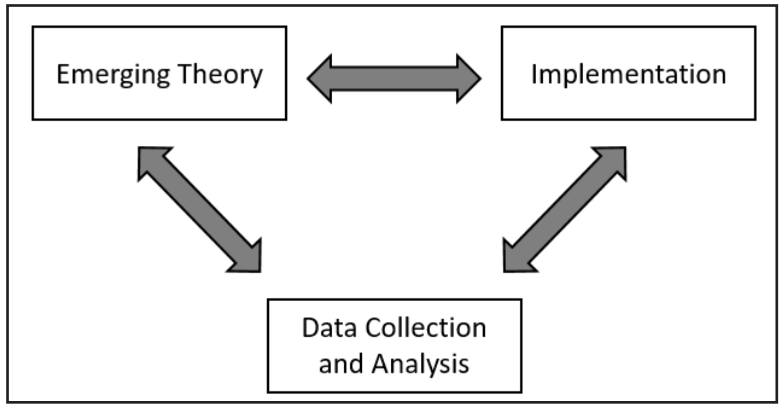


Figure 1. *Interacting components in our DBIR approach.*

In this article, we first present our emergent theoretical framework that was informed by insights from across the collaboration. Second, we provide a description of implementation activity in one of the four elements above: the core curricular change. We show how that work both informed and was informed by the emergent collaborative theoretical framework and by work on other elements of the project (knowledge of power and privilege; student PODs; governing policies and procedures). Through the framework, we connect issues of inclusion to the core chemical engineering curriculum by relating a students' identity as a chemical engineer to their multifaceted personal identities and to their professional competencies. While the work reported here focuses on inclusivity, it has a direct bearing on diversity because more inclusive environments foster a more diverse community. Finally, we describe how data collected during implementation informed future design cycles and led to a re-imagining of our emerging theoretical framework. We argue that, like in technical work, theory does not drive practice but rather evolving understandings of theory help address emerging problems of practice and, simultaneously, experiences from practice generatively drive theory development.[4]

AN EMERGING, INTEGRATED THEORETICAL FRAMEWORK

Our integrated theoretical framework connects aspects of the RED initiative centered on pedagogical reform to the driving goal of inclusive practices that foster diversity and social justice. Drawing from theories of learning[5-7] and systems of oppression,[8-10] we consider institutions such as chemical engineering departments to exist within larger interlocking social structures. We use situated learning and social practice theories to understand the "landscape of practice" that the CBEE community and affiliated participants (*e.g.*, students, engineers, employers, faculty) navigate as they develop personally and professionally.[7] In particular, we borrow from Holland's notion of "figured worlds" to juxtapose the norms, practices, and values as community participants act within the figured world of "engineering school" and the world of "engineering practice" that we invoke in our curricular change.[11,12] "Figured worlds" are the jointly constructed social systems of identities, relationships, positions, and valued practices in which participants live and work. The reform effort as a whole is situated in "engineering school world," where students and faculty members enact roles and engage in practices (lecturing, taking tests, conducting research, studying) valued in research universities. Our curricular change attempts to emulate aspects of "engineering practice world," in which engineers design products and processes to serve human needs and wants. By creating a kind of hybrid space, students have the opportunity to learn to be engineers by using engineering principles and practices to make progress on meaningful tasks. This conceptualization of an "engineering practice world" provides a structure to support the inclusion of all students by centering human societal needs as the value-orientation for engineering work and by reinforcing engineering practices that seek out multiple perspectives and competencies. However, the activity also resides in "school world" where tasks have an exchange value: successfully completed work can translate into a desired grade.

In conceptualizing the figured worlds of "engineering school" and "engineering practice," we must also account for features of those worlds or interactions within them that unjustly and unintentionally exclude some people from engineering.[13] Such exclusion can be understood in terms of systems of oppression (*e.g.*, racism, heterosexism, ableism) that are fundamentally about social, political, and economic power. Importantly, from this perspective, exclusion is not viewed as the direct result of intentional individual acts, but rather as the systematic result of interactions that reinforce undesirable hierarchies based on social and cultural differences.[8-10]

From this theoretical framework, we have distilled four guiding principles:

1. *Increasing inclusivity, diversity, and social justice in engineering education requires active cultural changes at organizational/departmental and interpersonal levels that affect the experiences and perceptions of students and faculty to increase the degree to which diverse individuals* ***identify as chemical engineers****.*
2. *Organized cultural change leads to inclusion when it reflects and affirms the lived experiences of all members of the community* (e.g.*, students, staff, faculty, administrators) as people with complex,* ***multifaceted identities****.*
3. *These changes should align with our community's core shared mission of developing students' chemical engineering* ***knowledge and skills****.*
4. *Explicit pedagogical and social supports for students and faculty will help to transition their identities, knowledge, and skills* ***from engineering school world to engineering practice world****.*

As we expand on these four principles next, the inseparable relationship between student learning and inclusive culture in our approach to reform is clarified. In developing a robust set of guiding fundamental principles, we wrestled with perspectives from very different intellectual traditions (*e.g.*, women and gender studies and the learning sciences). Despite their differences, these perspectives are mutually enriching: the curricular transformation element fundamentally aligns with the goal of moving towards a more inclusive and diverse community. This aspect is schematically captured by the diagram in Figure 2, which shows how learning through meaningful, consequential work and an inclusive culture are mutually constitutive in our vision of change where each is a defining component of the other.

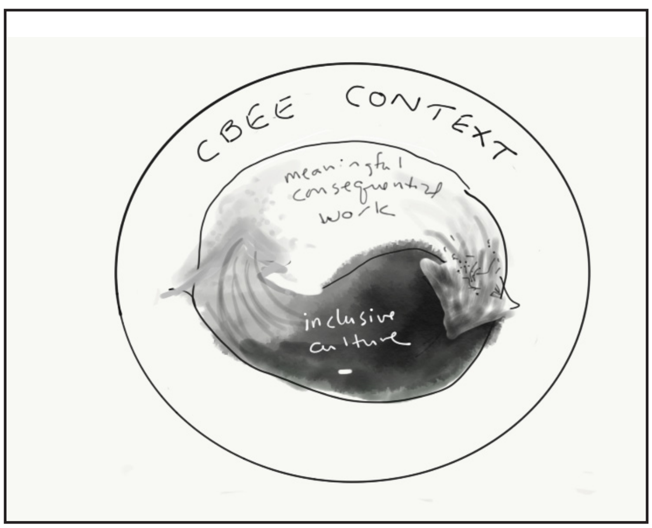


Figure 2. *Engagement in meaningful, consequential work and an inclusive culture are mutual constituents that feed one another.*

Identifying as Chemical Engineers

Essentially, chemical engineering education seeks to help people to become engineers. To do this, students must learn about chemical engineering, learn to do chemical engineering, and learn to see themselves as belonging to the engineering community. Students learn about steam tables, for example, not as an end in itself but rather to serve as a data resource for the analyses and designs they will perform as chemical engineers. In a situative view of learning, using steam tables in engineering work is a "practice,"[14,15] an intentional activity that has a meaning and value in a professional context or "community of practice." In this model, learning serves to increase one's integration into a professional community of practice.[14] Through fostering students' valued participation in and identification with the relevant communities of practice, we align approaches between what we teach and how to increase inclusivity and diversity in chemical engineering. The situative approach requires both change in opportunities for student learning and change in the culture in which that learning takes place. Engineering schools have historically been the realm of a privileged subset of people [13]; expanding opportunities to become engineers requires an expansion of the extent to which students with different identities—particularly those historically underrepresented in engineering—feel welcome.

Multifaceted Identities in Systems of Power

Our situative perspective of learning addresses the complex nature of students' developing identities as engineers. Students are more than just students; they are also members of families, workplaces, social groups, and religious organizations. In each of these communities, they express different aspects of themselves to different degrees. Identities are complex dynamic systems in themselves, and "chemical engineer" is only one component of any individual's nexus of identities.[16] A woman's experience as a woman is interleaved with her experience of race, class, and sexuality,[8,9] for example, and all are involved in the ways in which she develops an engineering identity. While it is common to separate discussions of diversity from pedagogy, our theoretical framing considers them inherently linked. Thus, we explicitly consider the systemic structures that inhibit students' developing professional identities as a core pedagogical issue.

Developing Knowledge and Skills

In engineering education communities, assessments and accountability focus on students' abilities and knowledge, while diversity, inclusivity, and social justice are often considered secondary. We argue that because inclusivity, diversity, and social justice are integrated into engineering practices (which require technical and social knowledge), learning to solve problems or design processes entails both aspects.[17] That is, students must learn to engage productively with diverse stakeholders, multiple perspectives, and others with different strengths and weaknesses. This framing highlights diversity as an asset, providing a natural opportunity for people with marginalized identities to see themselves (and others) as engineers. Student learning, persistence, and academic success are all improved by increased identification with engineering.[18] Pedagogical practices that support inclusive teaming on tasks that position students as engineers doing meaningful, consequential work can help students identify diversity, equity, and social justice as central aspects of engineering. This approach reinforces and broadens notions of authentic academic rigor, and we believe it will lead to more qualified engineering graduates.

Engineering School World and Engineering Practice World

Research using situative learning theory finds learning is deeply bound to context; understanding a concept in one setting does not necessarily mean the learner will be able to apply it in another, even closely related, setting.[6] In engineering school, students learn to use concepts and technical skills as part of school practices like studying for exams and answering decontextualized homework problems. Often the use of those concepts and skills in engineering work is separated from this initial learning and put off until more advanced courses or internships. Students can find themselves struggling with prerequisite material and having to "re-learn" concepts and skills along with their new uses. Students who are successful at "school world" uses of knowledge and skills may excel in earlier courses where others struggle and drop out or are eliminated through poor grades. Thus, in school world, a lot of energy can be expended learning practices that do not translate well to real engineering contexts, while some students who might do well in engineering contexts are excluded. However, school world competencies are likely insufficient for engineering practice. A process engineer's work, for example, often depends on appreciating the practices, goals, constraints, and values of operators, managers, vendors, and regulators, as well as engineers with different backgrounds, knowledge, and skills.

Engineering practice has its own problems, however. Many contexts in which engineers work replicate and reinforce structural issues of power and privilege. Our aim, then, is not to imitate engineering practice in its (current) entirety, but to create a figured world, engineering practice world, that teaches to the possible. Such a figured world can help students develop the practices and identities of engineers who consider social justice as an important engineering issue and who have the skills and inclinations to create equitable and inclusive teams to do engineering work. Imagining ways to provide opportunities to learn engineering practices in this way is complicated by the fact that such learning is necessarily embedded in school world. This has been the focus of our core curricular change, described next.

IMPLEMENTATION: RE-SITUATING LEARNING FROM STUDIO 1.0 TO STUDIO 2.0

The majority of CBEE core engineering science courses utilize a studio structure[19] where large lecture sections (100 - 350 students) are interspersed with smaller studio meetings (approximately 24 students). In studios, students work together in mostly three-person teams, facilitated by trained graduate student teaching assistants (GTAs) or the course instructor. Studios are designed to extend students' thinking and problem-solving techniques while simultaneously reinforcing core content and developing teamwork and communication skills. The core components of this structure—well-designed pedagogical activities and productive student teamwork—are a common goal in engineering programs.

In its original manifestation, Studio 1.0, the activity relied on sequestered, worksheet-based problems. These problems helped students identify and practice key conceptual and procedural knowledge, and connect that understanding to lecture,[20] but the activities were clearly of school world, limiting students' abilities to both connect the activity to professional practice and to develop value systems corresponding to the profession.

Figure 3 shows an example of part of a Studio 1.0 activity in which students perform a regression analysis (and use other statistical methods) to determine the value and measurement error for the first order rate constant of a sugar reaction from data. The work is presented as a set of step-by-step instructions that the students must complete successfully. The formatting of the worksheet (headings, titles, and step-by-step instructions) unintentionally invites a "school world" approach, which may include "divide and conquer" strategies rather than thoughtful collaboration, or focusing on "getting the right answer" rather than considering how to capitalize on the diverse perspectives of team members. Assessment practices also contributed to a school world framing: while students worked in teams during studio, each student was held accountable by turning in an individual worksheet solution. Finally, the activity culminated in a reflective comparison of the least squares fit of the linearized kinetic equation to its exponential form—an abstract task that many students were unlikely to connect to engineering practice.

In the Studio 2.0 reform, our intent is to shift activity and re-situate learning by engaging students in meaningful, consequential work that directly and clearly relates to professional practice and desired professional attitudes and behaviors. The intent for these experiences is to provide a foundation for development of students' chemical engineering identity. Rather than attempting to direct students procedurally to a "correct" solution, a Studio 2.0 memorandum might explain a situation where a company is seeking to optimize a particular process and ask students to collaboratively decide on and perform calculations to make a design recommendation. Assessment is formative and immediate, focused on whether teams are "making progress" in grappling with the task. In this framing, as learners struggle with difficult concepts and may even sometimes fail to accomplish their short-term goals, they are continually positioned as engineers seeking meaningful progress towards a viable solution, rather than students following directions to get a grade. These opportunities to engage in chemical engineering practices, in a context designed to act as a hybrid space between school world and engineering practice world, support students' professional formation as engineers.

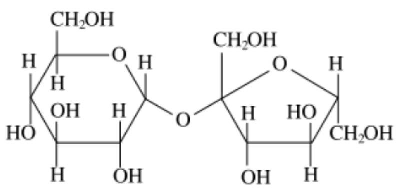
Figure 4 (next page) shows the analogous Studio 2.0 activity (regression analysis of sugar kinetics) to the Studio 1.0 activity shown in Figure 3. The form has shifted from a sequestered set of declarative tasks to an integrated assignment for the student team to complete. A memorandum from a fictional engineering manager places students in the role of engineers in industry, and, consistent with that framing, an individual work product is produced by the team. Most importantly, the nature of the activity has shifted. As part of the Studio 2.0 activity, the team needs to make a recommendation of process time to the production floor to achieve a minimum conversion. In this task, their understanding of variation becomes central in doing the engineering work itself. To determine a reasonable process time, they must recognize that the rate constant is best represented as a distribution and that if they choose the average value for k, the conversion would fall short

Computer lab 6: Regression Analysis

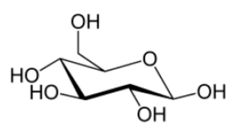
ChE, BioE, EnvE 213

Prof. Milo Koretsky

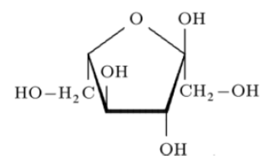
You are responsible for determining the reaction rate constant, *k*, for the hydrolysis of sucrose ($C_{12}H_{22}O_{11}$) to glucose ($C_6H_{12}O_6$) and fructose ($C_6H_{12}O_6$) in aqueous solution (0.5 M HCl).



Sucrose



Glucose



Fructose

The hydrolysis reaction is monitored by a polarimeter. In this technique, the angle of plane-polarized laser light is measured as it is passed through the solution. The change in angle can be related to the concentration of sucrose.

1. Write the stoichiometric equation for the overall reaction.
2. The kinetics for this irreversible 1st order reaction can be described by the following ordinary differential equation:

$$\frac{dC_S}{dt} = -kC_S$$

where C_S is the sucrose concentration in [mol / m^3], k is the 1st order reaction rate constant in [hr^{-1}], and t is time in [hr]. Solve this equation assuming you know the initial concentration (i.e., the initial condition at $t = 0$, $C_S = C_{S0}$). Get the TA to verify your solution. Hint: use separation of variables.

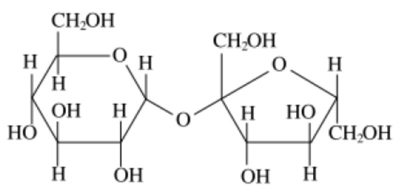
3. To determine the rate constant, concentration vs. time data are needed. Draw a rough schematic of what the experimental equipment would look like. Show it to one of the instructors.
4. Go to the link http://jimi.cbee.oregonstate.edu/statistics/rate/ and run the experiment.

Figure 3. *Part of the Studio 1.0 example for sucrose kinetics: regression.*

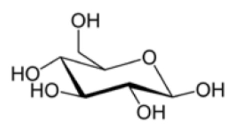
INTEROFFICE MEMORANDUM

TO: ENGINEERING PROCESS DEVELOPMENT TEAM
FROM: BENITO BEAVER, VICE PRESIDENT OF ENGINEERING, BEAVER DAM SWEET TREATS
SUBJECT: BATCH PROCESSING RECOMENDATION
DATE: MAY 4, 2016

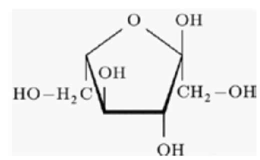
Our new OrangeCandy product line needs to go into volume production. For the process,, we need a source for glucose ($C_6H_{12}O_6$) and fructose ($C_6H_{12}O_6$). We will produce these sugars through a hydrolysis reaction using sucrose ($C_{12}H_{22}O_{11}$) as a reactant in aqueous solution (0.5 M HCl) with our proprietary RateEnhancer additive that is believed to catalyze the reaction.



Sucrose



Glucose



Fructose

The hydrolysis reaction is monitored by a polarimeter. In this technique, the angle of plane-polarized laser light is measured as it is passed through the solution. The change in angle can be related to the concentration of sucrose in solution.

The quality we provide to our customers is of utmost importance at Beaver Dam Sweet Treats. The process design team reports that it is critical that at least 70% of the initial sucrose has reacted to make the final product acceptable. Conversion less than 70% requires reprocessing the entire batch. Due to production bottlenecks, we also need to run the process for as short a time as possible. Due to process flow requirements, our two batch reactors need to use the same process time.

Please determine the rate constant and use it to make a process recommendation that you are confident will reach the 70% conversion requirement. I suggest you do the following analysis prior to experiments.

- First, the equation above must be solved to get a relationship between concentration and time.
- Second, concentration vs. time data are needed. It is helpful to draw a rough schematic for your supervisors of what the experimental equipment would look like.

Figure 4. *Part of the Studio 2.0 example for sucrose kinetics: regression.*

approximately half the time. Thus students see the understanding of statistical concepts as a tool to do the engineering work at hand, rather than something they need to learn for a grade.

We next describe three aspects of the development of Studio 2.0 that have emerged during implementation to inform our theory and catalyze changes.

Studio 2.0 Community of Practice

The deep integration of the studio model into our school complicates change efforts because it means developing a shared understanding and shared goals from approximately a dozen faculty members (as well as their instructional teams and the students in the courses). Moreover, each of these players bring different histories and prior knowledge to bear. We have approached this challenge through an ongoing and growing Studio 2.0 Community of Practice (CoP) where faculty work together towards these goals.

In the first iteration, selected studio course instructors (considered central participants, albeit with different perspectives) convened regularly for a quarter to develop a set of Instructional

Design Principles for Studio 2.0 in alignment with the goals of the greater change initiative (Figure 5). However, just as important as this product was the process whereby faculty were able to discuss critical issues such as assumptions about teaching and learning, who has access to the curriculum, and what counts as ability and competency.

The Studio 2.0 CoP expanded the following summer, when all studio instructors were invited to participate in a week-long intensive workshop that was facilitated by two learning scientists with deep knowledge in instructional design for ambitious, equitable instruction.[21,22] Instructors from eight studio courses were able to attend, some of whom had taken the 60-hour systems of oppression and privilege seminar (element 1). The co-facilitators aimed for a collaborative approach in which the many resources faculty participants brought to the workshop, including the Studio 2.0 design principles, together with new perspectives, would inform studio design and pedagogical implementation. The workshop was designed to collaboratively create a shared understanding of why and how a shift towards more meaningful, consequential studio activities would benefit student learning and engineering identity. It also provided the necessary time and scaffolding for participants to redesign one or more studio activities and receive feedback on the proposed changes from peers and workshop facilitators.

Issues of diversity and inclusivity were incorporated into the workshop, through: (1) an emphasis on valuing and incorporating inclusive teamwork skills as important professional skills for engineers; (2) setting team norms to facilitate effective and equitable team participation; (3) identifying and building on different perspectives and resources students bring to teams; and (4) designing "group-worthy tasks" complex enough to benefit from the multiple perspectives and different knowledge that team members bring. Participants also discussed the formation of student teams as an instructional (as opposed to purely logistical) practice, considering ways to address issues of status that might arise within teams, including how those relate to social identities (*e.g.*, gender, race, nationality, English language proficiency, disciplinary identity within engineering). Participants who had taken the 60-hour workshop focused on difference, power, and privilege in higher education (element 1) and talked about and raised issues about inclusivity and equity more frequently and in different ways than participants who had not attended the 60-hour workshop. For example, one such instructor noted that the students in a videotaped studio team were only using male pronouns when referring to hypothetical people in the problem.

Ideas about how to capitalize on the prior knowledge and experiences students brought to studio teams became more complex and nuanced as the workshop progressed. On the first day, one participant commented about the challenges of getting students with "type A personalities" to collaborate and what students' "different levels of curiosity and confidence" might mean for students' learning and contributions to studio teams. By the fifth day, with scaffolding from the facilitators, participants and facilitators had a long discussion about status issues in group work in which participants were talking in more asset-oriented ways about "multiple abilities" and using "different areas of competence [as] a way for everyone to think they're a valuable member of the group." Participants considered ways in which instructors might help facilitate students' appreciation of the multiple forms of competence and perspectives that team members bring, and how that might relate to teamwork in the context of engineering practice world. Facilitators encouraged participants to think about what students bring as forms of expertise that can be developed given opportunity, rather than fixed or innate competencies or personalities. A student panel provided their perspectives on issues of teaming, collaboration, and the kinds of studio tasks that were most realistic and engaging.

Instructional Design Principles
Studio 2.0

- ***Practice First***: Move the focus of student work from concept first to practice first. Start with work that has meaning towards an engineering goal and have the practice incorporate core concepts that are needed ("a time for telling") and also other desired engineering skills. (Learn principles by doing; "How does this prepare me for practice?")
- ***Group Worthy Problems***: As much as possible, make problems challenging enough so that multiple perspectives become valued. Include some problems that have multiple solution paths. (There are multiple ways to contribute productively to a team; Engineering problems have multiple solution paths; Progress despite Incomplete knowledge).
- ***Cooperative Learning***: Retaining the framing of the problem (roles, purposes, context), create a safe learning space that celebrates confusion and shared meaning making. In support, prepare instructors (including GTAs and undergraduate LAs) to facilitate inclusive interactions and "situated" learning.
- ***Looping***: Provide students opportunities to revisit concepts and practices in new contexts. Looping is key to deepening (complicating, differentiating, and integrating) their evolving understandings. Identify threads for vertical integration (*e.g.*, MATLAB skills, variation and statistics).
- ***Revisit Context***: Weave the same context into studios for multiple courses and hold students accountable to practice and further develop previously learned knowledge and skills.
- ***Assessment***: Assessment and instructional practices should be considered as a system; they need to reinforce the learning goals of the activity. Emphasis should be placed on the process of making progress and less emphasis on getting the answer.
- ***Formatting for Cognitive Load***: As much as possible align studio delivery so it is as similar as possible between sections (common memo formats, team forming practices, grading).
- ***Manageable Change***: Take baby steps in transitioning from Studio 1.0 to 2.0.

Figure 5. *Working document of Studio 2.0 instructional design principles developed by the Studio 2.0 faculty Community of Practice.*

TABLE 1
Instructional elements to support Studio 2.0

Program element	Activity
Graduate Teaching Assistant (GTA) professional development program	• A half-day workshop before the academic year • Eight one-hour seminars over the year • Content includes group-worthy problems, facilitating teamwork, feedback to teams, and the role of status in teams
Undergraduate Learning Assistant (LA) Program	• Modeled after program from the Colorado Learning Assistant Alliance[25] • Undergraduate students provide additional support in studio to facilitate learning and also provide a "near peer" for teams' reference • LAs have been used in six studio courses over the last four terms
Dedicated classroom space for Studio 2.0	• With support from the registrar and the University Space Committee, two dedicated adjacent classroom spaces for studio delivery were developed • Movable tables and large workspaces where students can write and have computer or text resources • Course instructor can visit two studios simultaneously

At the end of the workshop, participants made commitments about the concepts, ideas, and practices they agreed to incorporate the following year. Among these commitments, five out of the six participants agreed to set norms for small group work and to strategically assign teams, rotating once during a term.

Instructional Support

In studio, we use the floating facilitator model[23] where the instructor moves from team to team during class, asking questions and probing for understanding. The instructor emphasizes the need for students to articulate their knowledge and reasoning processes.[24] In this model, key aspects of practice include: establishing classroom norms that allow everyone access to opportunities to learn; encouraging sense-making as stepping stones for learning (*i.e.*, making progress in understanding as the goal); and modeling and creating an environment for productive conversations that support understanding significant engineering concepts and practices. The latter practice can include: making student thinking visible; noticing where members of the team are and how they are working together; and asking questions that guide learners from their initial understandings towards the designed learning objectives of the authentic task. Thus, studios require complex instructional practices that fall, in large part, to student instructors.

To support this work we have implemented GTA professional development, initiated an undergraduate learning assistant (LA) program, and created a dedicated studio space, as described in Table 1. Central to both GTA and LA development programs is work around inclusive teaming practices that allow the LAs and GTAs to identify and address status interactions of team members as described next.

Inclusive Teaming

Engineering work relies on effective collaboration and communication among diverse groups of people in many roles, including: engineers, scientists, managers, technicians, end-users, and others. While all engineering educational programs require student teamwork, instruction on effective and inclusive practices is often sparse. When present it may be ad hoc or only addressed in the senior year. Moreover, inclusivity outcomes are rarely assessed. With Studio 2.0, we seek to design and implement a scaffolded and progressive approach to growing students' capacities to engage in inclusive teaming, where diverse perspectives are encouraged and valued. By coordinating student team experiences in these courses in the Studio CoP, we aim to develop productive interaction practices. We have been paying particular attention to identifying: (i) the role status plays in group interaction, *i.e.*, to what degree does an idea depend on who is saying it rather than the idea itself; and (ii) providing work that is "group-worthy,"[26] *i.e.*, where the task presented to the student team is complex enough to benefit from multiple perspectives and various slices of understanding.

Studio 2.0 assignments are designed to use real-world uncertainty to encourage students to seek out multiple perspectives on systems and problems. Without the explicit direction of what to calculate next, students depend on each other to co-construct their plans and are less likely to be able to do it alone. By making space and devoting time to these interactions, Studio 2.0 structures align with the explicit messaging about the value of teamwork and communication. Perspective-seeking is supported and guided through various means to help make students' diverse thinking visible and valuable to each other. For example, in two recent studio courses, teams have been provided with small table-top whiteboards and each student is assigned a different color marker. Students are encouraged to explain their understanding of a system or problem[27] and to elicit and build on one another's thinking. The different colors capture the extent to which this is happening and provide in-the-moment assessment data. Together these practices encourage students to see the worth of others' viewpoints and, consequently, the value of their own individual understandings. We see the Studio 2.0 CoP as critical in expanding this type of inclusive practice beyond an individual instructor to programmatic use so that

TABLE 2
Exemplar free responses to the prompt "write down one thing that you learned from the studio activity" for Studio 2.0

Code	Response
Integration into chemical engineering practices	I learned that there isn't always a right answer. In fact, in many cases there are no right or wrong answers. However, you MUST be able to provide an answer with sufficient evidence and support. I think that this studio helped me realize that the real world isn't perfect after school, and that troubleshooting and problem solving are more important than a plug and chug mentality.
Chemical engineering identity	I had such a great time in studio this morning. I feel like a real chemical engineer for once. I'm proud of my new ability to attack these problems by using my math skills and intuition. I love solving these kinds of problems and am excited for my future.

all students are afforded opportunity to develop their identity as chemical engineers.

DATA COLLECTION, ANALYSIS, AND INTERPRETATION

In the spirit of DBIR, we constantly collect data on processes and implementation from all elements of the change initiative and use them for ongoing modification of those efforts (Figure 1). We present some of our data collection efforts briefly, emphasizing how they inform our emerging theory and our implementation strategies and activities. This research was approved by the OSU Institutional Review Board and all participants provided informed consent.

Student Perceptions of Learning in Studio

Measures: We collected student responses from a survey in a sophomore-level studio class in CBEE. The survey was delivered after each of nine studio activities; four were Studio 1.0 versions while five were Studio 2.0. We asked students to respond to two items: (1) write down one thing that you learned from the studio activity [free response]; (2) the studio activity helped you learn the course content [Likert scale (1 = strongly disagree to 5 = strongly agree)]. Two-hundred and twenty four students participated.

Analysis: There were no statistically significant differences in Likert ratings of learning between the Studio 1.0 and 2.0 approaches. However, analyses of free responses revealed that students saw the work differently in two of the Studio 2.0 activities. Emergent coding of item (1) showed that in two Studio 2.0 activities, significantly more students wrote answers where they integrated what they learned into more general engineering practices and connected the work to their emerging engineering identity. Table 2 provides exemplar responses for each code category. Interestingly, in the two Studio 2.0 activities that showed more integrated responses, significantly more students also referenced the specific engineering task at hand. This analysis aligns with our emerging theoretical framework that relates inclusion and learning to students' developing chemical engineering identity. It also illustrated some cases of Studio 2.0 that were more effective by this measure. This information provides fodder for future re-design.

Clinical Video Study of Studio Activity

Based on the results of the survey data above, we used video interaction data to seek a better understanding of the ways that three student teams took up work in one Studio 2.0 activity.

Measures: In this clinical study, we analyzed video data of three teams engaging with a realistic Studio 2.0 task: the design of a heat exchanger system for a microfluidic device to automate a bioreaction process for point-of-care use. The teams were selected for analysis based on their varying orientations toward school world vs. engineering practice world. An emergent coding process was iteratively developed as a collaboration between a learning scientist and two chemical engineering educators.

Analysis: While the Studio 2.0 activity was developed to provide an authentic context and the clinical setting enabled a low-stress and supportive environment, teams constructed an understanding of the task differently. Team 1 showed accountability primarily to school world norms; reasoning and sense-making processes were minimized by strategic thinking to "get an answer." Team 2 spent most of their time in engineering practice world, negotiating periods of confusion and contributing different perspectives, leading to constructive overt activities and accountability to engineering norms. Team 3 initially approached the task in school world, where significant periods of confusion led to a "jumping around" of procedural activity. With time their activity shifted more to engineering practice world. Across teams, we found that the richness of technical design discourse (*e.g.*, hypotheses, justifications, reflections), heuristics used, and social interactions were related to the figured world (engineering practice world or school world) in which the student team was situated. Moreover, inclination towards a figured world depended, in part, on the resources the students bring (*e.g.*, procedural competency, conceptual fluency) as well as the practices of the instructor. This study provided us with a richer understanding of the multitude of ways teams could take up the challenge of a Studio 2.0 task and provided a tool for the Studio 2.0 faculty CoP and for GTA and LA professional development. Beyond the design of group-worthy tasks, ensuring students' orientation toward engineering practice world may take multiple opportunities to engage in realistic work, support to learn inclusive teaming practices, and specific instructor moves to counteract well-learned school world approaches.

Student Focus Groups

Measures: Following the video of studio activity, two focus groups were conducted where the video participants provided their perspective on their curricular Studio 1.0 experiences and their responses to the Studio 2.0 activity just completed.

Analysis: Through the focus groups, we learned ways that Studio 1.0 was antithetical to our goals of developing teaming skills. Students described that they worked in groups because they were required to. The importance of teamwork and communication skills were explained and emphasized by the instructor, but the structure subtly contradicted this explanation: students' work was graded individually and therefore the collaboration of the group was focused on helping each individual complete their own copy of the assigned tasks. In addition, often individual students recognized they could do the work on their own, resulting in individuals competing with their teammates by "racing" through the worksheets. Students agreed there was status associated with being the first to complete the worksheet.

Although the connections among and applications of the concepts in Studio 1.0 were apparent to instructors, the focus groups suggested that many students saw studios as school world "worksheet activities," and some resented the required teamwork for interfering with their goals of completing the assigned work as quickly and correctly (according to the answer key) as possible. Although the content was directly relevant to engineering practice world, several students reported engaging in primarily school world practices like following directions and algorithmic calculations.

CBEE Climate Survey

Measures: As part of the overall change process, we have initiated an annual student climate survey. Measures include students' perception of how welcoming (vs. hostile) CBEE is for 14 different identity groups reflecting various social identities and histories; perceptions of peer relations; faculty, GTA, and advisor support; perceptions of bias and microaggressions; engineering identity; participation in CBEE and other extracurricular activities; and persistence in engineering.

Analysis: Initial results highlighted the importance of peer relations (both in and out of class) in mediating the effect of gender, climate, and faculty support on students' engineering identities and persistence. The studio environment, where students work in teams in a structured environment, can cultivate positive peer relations, especially for students who might otherwise be marginalized. The climate survey data, therefore, support further emphasis on strengthening inclusive teamwork in studio and integrating these practices into the capstone courses. The annual administration of this survey across all CBEE students will also provide a way for us to regularly assess the impact of the larger change initiative over time.

CONCLUDING REMARKS

With this "snapshot" view of our progress, we aim to provide insight into the process of change towards a more inclusive culture that promotes diversity and equity. Any such change project must account for a unique set of local histories, norms, and practices; there are no prescriptive answers to this "wicked" problem. Thus, we share our approach to the change process, design-based implementation research, where theory, implementation, and data collection and analysis continually interact towards building understanding and making progress. While we focus here on the pedagogical element, multiple interacting elements are needed to change the structures and practices that systematically exclude people. These various elements of the larger project are beginning to inform one another (*e.g.*, participants in the 60-hour workshop influencing shared understanding in the Studio 2.0 CoP). For example, a focus on inclusive teaming has resonated with the passions of several faculty members in the school, and there is active effort to extend and integrate these ideas throughout the curriculum. Resourced through a grant from the Difference, Power, and Discrimination (DPD) Academy,[28] three faculty members have completed the 60-hour workshop (element 1) and are participating in a faculty learning community around inclusive teaming. In a complementary effort, two senior-year instructors have received an Action Research Fellowship through the ESTEME@OSU Program[29] to develop and research functional teaming practices in the senior year in the chemical engineering and bioengineering programs. Such cascading of activity is an indicator of how the ideas of inclusive teaming are being taken up by the CBEE faculty.

Through our emerging theoretical framing, we connect issues of inclusion to the core chemical engineering curriculum by showing how identity, academic success, and professional formation are all closely intertwined: issues of inclusion are, in fact, issues of competence and vice-versa. While the curricular change focuses on inclusivity, it has a direct bearing on diversity because more inclusive environments lead to a more diverse community. To promote inclusivity, we are working to shift "engineering school world" to "engineering practice world" as a way to equitably incorporate and support the multiple identities and different competencies that students bring. This shift positions learners in the role of practicing engineers interacting on meaningful work while utilizing inclusive teaming practices. In this way, our change initiative seeks to provide access to professional formation for all students.

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