

Back to the Future: Learning Chemical Engineering through Engagement in Disciplinary Practices¹

Milo D. Koretsky
School of Chemical, Biological, and Environmental Engineering
Center for Research on Lifelong STEM Learning
Oregon State University

Introduction

I am greatly honored and more than a little humbled to be invited here to Oklahoma State University to present the 52nd ConocoPhillips Lecture on Chemical Engineering and the afternoon plenary for the ASEE Midwest Section meeting. For those of you in the room who do not know about the Phillips lecture series, the themes of the talks tend to address broad issues in the trajectory of engineering education. While OSU has enlisted chemical engineers for this Lectureship, more often than not they are generally applicable to engineering. I hope that is the case today. And if you are not a chemical engineer, please forgive me in an occasional excursion into the discipline.

Today I would like to focus on student *engagement* – that is, how students take up the challenging and complex work that we ask them to do as they form into professional engineers. The title of the talk, “Back to the Future” refers to one of two models I will present of engagement. These models both build on recent work from the learning sciences about how students learn. Model I looks at engagement for conceptual understanding. The second model addresses engagement in disciplinary practices. If you look at the history of chemical engineering, when it evolved out of industrial chemistry, it very much focused on engineering practice. In the mid-20th century, motivated in part by the 1955 ASEE Grinter Report², there was a shift in emphasis towards the engineering sciences. This shift transformed the field into the “science based discipline” we know today and formed the foundation for the modern ChE curriculum, including material and energy balances, thermodynamics, transport processes, reactors, etc. I imagine many other engineering disciplines can see similar trends. By going “Back to the Future,” I seek to discuss the ways that engaging in engineering practice actually helps students learn the foundational principles in these classes.

Following the theme “Back to the Future,” I want to begin this story back when I was a newly minted PhD and first stumbled across the Phillips Lectures in Chemical Engineering. I did not travel to Stillwell³; in fact, this is my first visit here. Rather, in my box was this intriguing pamphlet authored by Rich Felder, “the

¹ I am very grateful to Susan Bobbitt Nolen who made me aware of the important links between engagement, learning, and equitable opportunities for participation. I am grateful to the Oklahoma State University School of Chemical Engineering and the ConocoPhillips Company for providing me with an opportunity to contribute to this historic series of Lectureships on Chemical Engineering Education.

I acknowledge support from the National Science Foundation under grants ERC 1519467 and DUE 1245482 and the productive, collaborative interactions with my colleagues working on those projects. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

² Grinter, L. E. (1967). Report on evaluation of engineering education (1952-1955). *Journal of Engineering, Education*, 58(1).

³ It strikes me how much this place reminds me of Corvallis, OR. Both are college towns about 90 miles from the cultural hub of the state that house a land grant, sun grant, sea grant research intensive university whose colors are orange and black and go by the name “OSU.”

Myth of the Superhuman Professor”⁴. Prof. Felder challenged several core premises of the university system – Is it realistic for the same individual to excel at both teaching and research? Is there even a synergy between the two? As a radical alternative, he proposed a system which would recognize and celebrate the outstanding researcher and recognize and celebrate the outstanding educator, but a system where a single individual not need to be both. Although I am not sure that Rich did convince me he was not superhuman!

The following year, another pamphlet showed up, “Technological and Societal Change in Chemical Engineering Education”⁵. This time Stan Sandler looked into a future with “the traditional blackboard being replaced by video screens, multimedia computers and simulation equipment” (p. 20). And to quote Prof. Sandler, “such simulators will later appear in our universities, perhaps in design courses and instructional laboratories. Providing practical experience is a goal of our instructional laboratories; however, there is an enormous difference between using small bench-scale and frequently outdated equipment in a university laboratory and working with a modern pilot plant or production equipment used in industry. Multimedia simulators could bridge this gap inexpensively, giving students a “virtual” experience with chemical plant equipment that universities cannot afford” (p. 21). In this idea, we see an implicit value placed on realistic engineering practice, and a vision for how technology might create this type of engagement.

If I look at the themes of the two Philips’ lectures – immersion into the learning processes of our students and, specifically, how technology-based learning systems can provide students opportunities they would not otherwise have - I land squarely in the work in which my group has been engaged active. In Figure 1, I show two industrially-situated processes that we have developed and have our students work with in the senior laboratory to provide a practice-based experience - strangely combining ideas from Profs. Felder and Sandler. I only recognized this connection as I prepared for the talk today. It seems those early CP Lectures might have influenced me more than I want to think! And all these years, I thought this was my original idea. I will discuss these technology-based learning systems in the chemical engineering seminar tomorrow. But for today’s talk, this realization has left me in a quandary about what I might present.

So to address it, I went to more recent CP lecture – that of 2013 and Mike Prince⁶ that focused on pedagogical practice in the chemical engineering classroom. In that talk, Prof. Prince advocated for active

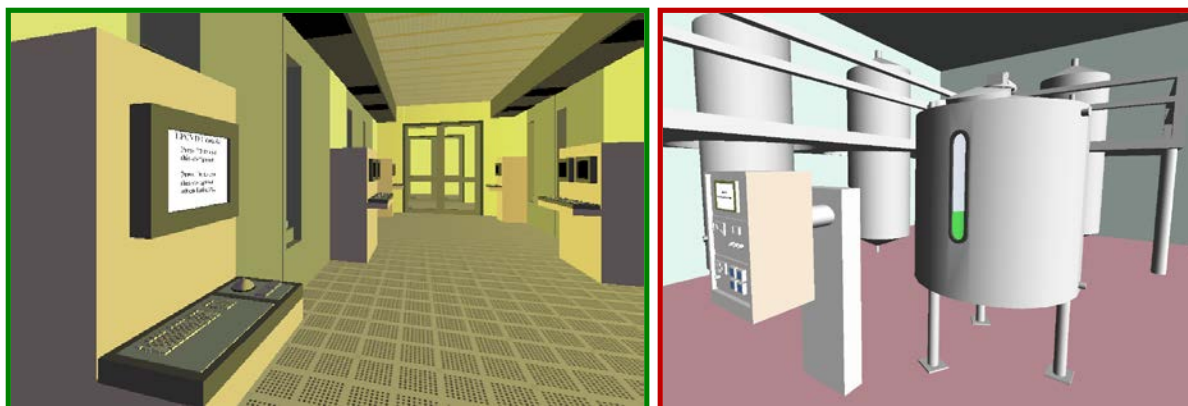


Figure 1. Screenshots of two *Industrially Situated Virtual Laboratories* developed by the Koretsky research group.

⁵ Dr. Stanley I. Sandler, [Technological and Societal Change and Chemical Engineering Education](#) (1993).

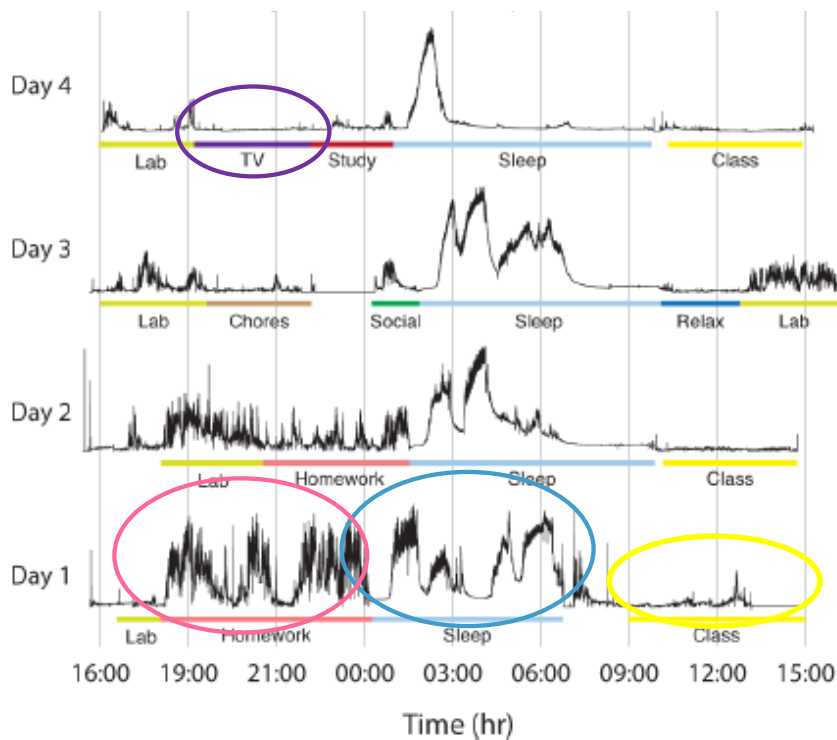
⁶ Dr. Michael J. Prince, ["Introduction to Active Learning for Busy Skeptics"](#) (2013).

learning which he described as “anything that you have your students do in class that gets them to actively engage with the material you’re trying to teach” (p. 1). Well this says what you shouldn’t do (talk at students like I am talking at you now), but it leaves a wide berth for what you might do. So today, I would like to explore some fundamental questions about student engagement in the active learning classroom: Engagement in what? What kinds of engagement? I propose two models that might be productive in thinking about the active learning classroom:

1. The first model examines engagement in terms of conceptual understanding towards building expertise, or I should say the knowledge structures that experts have.
2. The second model examines engagement in terms of disciplinary practices, where students use the concepts and discourses of engineering to “get somewhere” on an engineering task.

Like the technical models we use as chemical engineers, I do not view either of these as inherently more correct or better, rather they are representations of learning that might provide useful ways to make design choices within a certain context.

In this talk, I focus on engagement and think about the ways that engagement mediates between the



activities we ask our students to do and their learning. To begin to think about this, let’s look at a study which measured the biological responses of a student over seven days as reported by an electrodermal activity sensor (Poh et al., 2010⁷). In Figure 2, we see a display of the first four days of continuous skin conductance measurements in a student’s natural home environment. The measure of biological activity in a lecture class is very low (yellow circle). In fact, if we compare it to when this student is sleeping (blue grey circle), we see that there is more activity when sleeping than in in lecture. Think of the implications of this. The next time you see a student sleeping through a lecture, it may actually be a disservice to wake her up! The only lower activity than lecture turns out to be watching TV (purple circle). But if we look

at homework (red circle), we see plenty of biological activity. From the perspective of learning, I will posit that more activity means more engagement. And more engagement might be a good thing for learning.

Figure 2. Biological activity as measured by skin conductance measurements. Date taken from Poh et al. (2010)⁵. ©2010 IEEE. Reprinted, with permission, from *IEEE transactions on biomedical engineering*.⁵ Colored circles added.

⁷ Poh, M. Z., Swenson, N. C., & Picard, R. W. (2010). A wearable sensor for unobtrusive, long-term assessment of electrodermal activity. *IEEE transactions on biomedical engineering*, *57*(5), 1243-1252.

So we might conclude that instead of transmitting information to passive students, we might want activity in class to more resemble homework. We call this approach active learning, and research consistently shows higher learning gains with active learning than passive lecture⁸. So now as an instructor, as an educator, I say active learning might be a good thing! But now I have to consider how to design these activities. So I want engagement, but engagement in what? Are there ways to think about how I engage my students? Clearly, there is no single answer or “right” way to engage students, but there may be productive ways to think about student engagement. In the remainder of talk I would like to address two approaches to this question. They are quite different and I hope there is something in there that resonates with you and this can maybe provide you a way to approach instruction and student learning.

Model I: Engagement for Conceptual Understanding

Following the theme of back to the future, I would like to go back to kindergarten where they say you can learn everything you need to lead a full and successful life. The book *Fish is Fish*^{9,10} tells a story of a friendship between a fish and a frog who have known each other since back when they were a minnow and a tadpole. Well, when the frog is able he leaves to discover what is out *on land* and returns to describe to the fish what he has seen. The frog describes birds, cows, and people. But the pictures that the book shows is the fish’s conceptions of each of these. In each case, the fish conceives a modified fish like form with the attributes that the frog describes¹¹. So that birds become these fish with wings and many colors and cows become big fish that eat grass and have big pink bags of milk. So what does *Fish is Fish* say about engaging our students in complex concepts and procedures of chemical engineering? Well like the fish, our students construct new knowledge from prior knowledge. So just like the fish and the frog, they may be “seeing” the content in the ways that are different than we imagine.

So let’s think about what the fish and the frog can tell us when it comes to problem solving and engagement. I will show a straw dog of two potential approaches. In many lecture-based classrooms, the instructor may take a procedural approach to problem solving, as shown in Figure 3. Let’s say students are working with state functions in thermodynamics. The instructor may first go through an example where the property T is given and the instructor shows how you can apply the laws of thermodynamics to find the unknown P. The instructor then gives the students a similar problem on

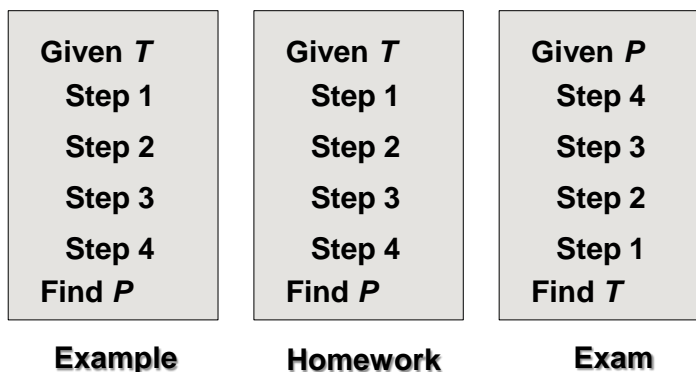


Figure 3. Schematic of a procedural approach

⁸ Freeman, S., S.L. Eddy, M. McDonough, M.K. Smith, N. Okoroafor, H. Jordt, and M.P. Wenderoth, *Active learning increases student performance in science, engineering, and mathematics*. Proceedings of the National Academy of Sciences of the United States of America, 2014. **111**(23): p. 8410-8415; Hake, R.R., *Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses*. American Journal of Physics, 1998. **66**(1): p. 64-74; Deslauriers, L., E. Schelew, and C. Wieman, *Improved Learning in a Large-Enrollment Physics Class*. Science, 2011. **332**(6031): p. 862-864.

⁹ Lionni, L. (2015). *Fish is fish*. Random House Books for Young Readers.

¹⁰ Inspired by National Research Council. (2000). *How people learn: Brain, mind, experience, and school: Expanded edition*. J. D. Bransford, A. Brown, R. Cocking, Editors, National Academies Press: Washington, DC.

¹¹ For an illustration see http://www.shorttales.net/wp-content/uploads/2013/06/DSC_0648.jpg (accessed 09/27/2017).

the homework, maybe changing from SI units to English units. Then to assess whether the students understand the material, the instructor gives a test with the same procedure but maybe with a little twist, perhaps starting with P and finding T. The assumption is that if the student can reproduce the procedure, then they understand the underlying thermodynamics concepts. So the teacher has taught and the student has learned. All is happy in Mudville. Until of course, we consider the fish and the frog. Just like the form of the bird, the cow, and the humans, the instructor has been “on land,” and can see how the work connects to the core concepts of the discipline. To students on the other hand, this chemical engineering topic becomes reproducing a set of procedures – they are putting wings on a fish.

So what’s an alternative to the procedural approach? Well we need to take learners “on land” so to speak where they can engage in sense-making by working with the concepts themselves. Let’s call this a conceptual approach. I will illustrate it with an alternative model as shown in Figure 4. You might consider a topic you are teaching let’s say Topic 1 that has several core concepts. You might first define the concept α and then show an example related to how you apply it to solve a problem. Next you do this for another for concept β with an example. Then you define a third concept γ , but now you have the student *figure out* how to use it to solve a problem in homework using some of the ways that they have seen in examples 1 and 2. To solve the next homework problem, students might need to connect concepts α and β . With this instructional practice, you are cultivating the ability to operationalize concepts to solve problems. When you approach instruction this way, and make it an explicit outcome to students, then it is fair for you to ask (and for them to expect) to connect two

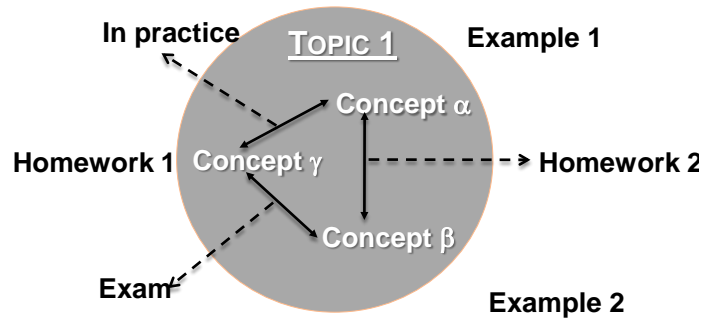


Figure 4. Schematic of a conceptual approach

different concepts (say β and γ) on an exam. The beauty here is that they are now engaging in concepts in adaptable and flexible ways – ways that allow them to identify different permutations in practice. The expert-novice literature¹² suggests that a central difference between experts and novices is not just that experts know more, but that the experts’ knowledge is connected and flexible. In the conceptual approach, you push students towards building towards integrated knowledge structures. From the view of the fish and the frog, we can say that students come with prior knowledge and beliefs. Learning requires rearrangement of mental schema. Rearrangement takes effort and activity by the student and that requires them to engage actively in learning.

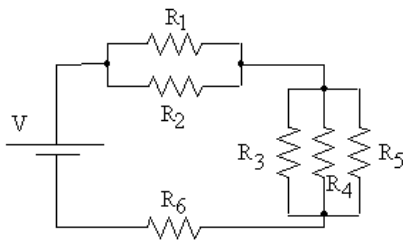
Let’s contrast a couple of questions, as shown in Figure 5. Question 1 is a problem similar to one that many 1st and 2nd year engineering students have solved over the years. Take a moment and think about how you would go about solving this question. Next let’s look at Question 2 which refers to the same schematic representation in the middle. Take a moment and think about how you would go about solving this question. Let’s think about one thing both these questions have in common – they are about topic of passive electric circuits. But how are they different? Well the first one contains a numerical calculation – perhaps it can be solved with applying a set of procedures. In the second one, the numbers are taken away from the problem and students need to think through how current flow through one part of the circuit responds to a change in another part. We might argue this leads to reasoning and sense-making. I want to be clear, I am not saying Question 2 is better than Question 1, it would be useful for engineers to

¹² e.g., National Research Council. (2000). *How people learn: Brain, mind, experience, and school: Expanded edition*. J. D. Bransford, A. Brown, R. Cocking, Editors, National Academies Press: Washington, DC.

Question 1

In the circuit on the right,
 $V = 25V$, $R_1 = R_2 = 10\Omega$,
 $R_3 = R_4 = R_5 = 15\Omega$,
 $R_6 = 50\Omega$.

What is the current through resistor R_3 ?



Question 2

In the circuit on the left, when the value of R_6 increases, the current through R_3 _____.

- A) Increases
- B) decreases
- C) remains constant?

Figure 5. Questions that elicit different types of engagement.

be able to do both. It just elicits a different type of engagement. And by engaging students in reasoning and sense-making it brings concepts to the surface, brings the fish “to land” so to speak.

If we think back to the skin conductance measurements, we learned that there is more biological activity when students are doing things – actively engaged. And thinking about how the fish envisions birds, cows, and people, we learned that students fit in pieces of understanding to the prior knowledge that they bring. So we want to engage students in reasoning and sense-making around critical concepts in the course and the discipline and in that way provide them with closer experience to “being on land.” Next I put forth that class is a great place to engage students in this manner. Here students can compare their conceptions with their peers and it can be moderated by the instructor.

But many of our programs are getting larger and larger, so we need to consider scale. This is a place where technology can be a productive tool. In the picture shown in Figure 6, you see a 2nd year MEB class at Oregon State University. Students have their computers out, because they are individually answering a question like Question 2 above on the computer. It almost looks like an advertisement for one of the major manufacturers, no? In this case, they also need to individually provide written justifications of the answer they selected. By initially answering on their devices, each student has opportunity to participate and commits to an answer.

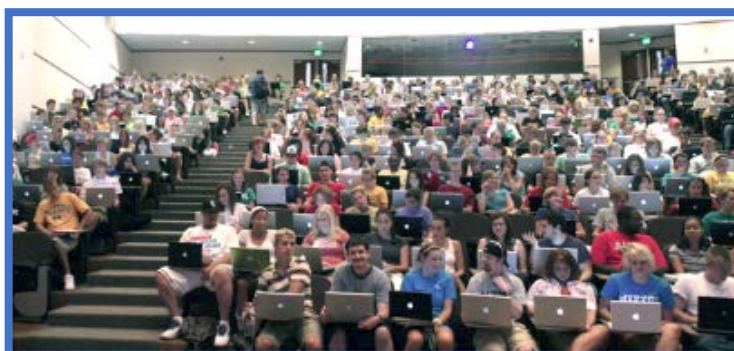


Figure 6. Students actively engaged responding to a conceptual question using the *Concept Warehouse*.

So this sounds good, you might say, but it seems like a lot of work. Where do I get content and how do I deliver it in class? Fortunately for chemical engineering faculty, there are resources. I have been involved in one such project, the *Concept Warehouse*.¹³ The overall goals of the *Concept Warehouse* are:

1. To create a community of learning focused on concept-based instruction and
2. To lower the activation barrier to promote implementation of concept-based instruction and active learning.

¹³ Go to <http://cw.edudiv.org/>

Kudos to the group chemical engineers at Oklahoma State University (Karen High, Rob Whiteley, Josh Ramsey) who have been involved from the get go. Another terrific resource is the LearnChE website¹⁴.

Time for a short video break to learn about the Concept Warehouse: go to <https://youtu.be/Nf5w0kG3asY> to see the video that was played.

Model II: Engagement in Disciplinary Practices

To this point we have conceptualized engagement in terms of developing conceptual understanding by building towards the connected knowledge structures that experts have. I would like switch now and think about another model: engagement in disciplinary practices. By disciplinary practices I simply mean the way engineers think and act in the real world.

To illustrate, I would like to talk next about an anecdote of Edison, Ohm, and the Electric Light, as best I can figure it out. This story is inspired by some of my summer reading – Bruno Latour’s *Science in Action*¹⁵. This is a story of an engineering design problem and how conceptual tools were critical to make progress. It also marks one of the defining technological transformations in human history!

Edison wanted to replace oil lamps with a newly discovered technology, electricity. But there were some challenges. The cost of electricity was high and in early attempts to build a prototype the filaments kept blowing. Also the brightness of the electric lamp, which was determined by the power dissipated in the filament, P_{fil} , needed to match oil (or at least be suitable). Edison recognized that electric technology needed to match the cost of oil to be competitive. Undertaking a systems analysis, he concluded the primary cost was in the materials for the copper conductor to pump the electrons a line distance, L , from the power source to the user. That cost was proportional to the volume of the copper conductor, V_{Cu} , which is just the length times the cross-sectional area, A ¹⁶:

$$V_{Cu} = AL \approx \$\$ \quad (1)$$

This far, the engineering constraints included a fixed cost of oil, a fixed cost of copper, a fixed distance from source to users, and also the materials properties of copper were fixed, such as a fixed resistivity, ρ_{Cu} . Here Edison brought in Ohm and utilized some conceptual tools from circuits as well as materials.

First the resistance in the line is governed by:

$$R_{line} = \frac{\rho_{Cu} L}{A} \quad (2)$$

and the current that travels is given by Ohm’s law:

$$I = \frac{V_{line}}{R_{line}} \quad (3)$$

where V_{line} [different than the volume (V) above] is the voltage drop across the line. Assuming the user is in series with the line, the current available for the user is determined by that delivered by the line:

¹⁴ Go to <http://www.learncheme.com/>

¹⁵ Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Harvard university press.

¹⁶ What is an engineering talk without equations!

$$I_{fil} = I_{line} = I \quad (4)$$

And finally, the power dissipated by the filament is equal to the square of the current times the resistance:

$$P_{fil} = I^2 R_{fil} = \text{const} \quad (5)$$

Eqn. (5) represents the energy (per time) that is available to produce light. So how does Edison decrease the cost and make the electric light viable? Since the cost of copper is fixed, and the line distance is fixed, the only way to use less copper (reduce the volume) is to decrease the cross-sectional area [See Eqn. (1)]. However, a decrease in A leads to a higher line resistance, R_{lin} [Eqn. (2)]. And a higher resistance decreases the amount of current that flows [Eqn. (3)].

To get an acceptable brightness, while decreasing the cost, Edison recognized he needed to *increase the resistance of the filament* [Eqn. (5)]. This is a key result from his application of conceptual tools. So while everyone else was looking for a low-resistance filament since they believed that it would not burn out as readily, Edison had his team switch and pursue a high-resistance filament. This was a critical design choice and it was enabled by applying conceptual tools of engineering within the context of the constraints of a design problem. Well you know the rest of the story. After about one year of trial and error, Edison's team produced the high-resistance incandescent lamp, and changed the way we humans lived.

If we go back to our two problems on circuits (Figure 5), we might ask is there something missing? What can we take away from the anecdote of Edison, Ohm, and the electric light? What's the moral of the story?

The concepts are similar to these questions we ask of our students, but the context is different in that Edison used his understanding of passive electric circuits to do engineering work, to "get somewhere." We can see that these engineering science concepts play a different role here; they are used as tools for engineering practice. I am next going to make a provocative statement. We can say the questions we ask of students takes a perspective that *knowledge* is an abstract entity to be "acquired" while the work of Edison suggests that *knowing* entails meaningful participation in activities situated within disciplinary practice. From this latter perspective, knowing and doing are intertwined, i.e., what is learned is not separate from how it is learned. Learning depends on content, context, and activity, and knowledge is situated in the experience¹⁷ This view fundamentally questions the notion that concepts are self-contained entities but rather positions concepts as tools, which can only be fully understood through use. In this case, Edison used concepts from electrical fundamentals to make progress on a design task. Thus, learning involves more than "acquiring" conceptual understanding, but rather involves having students build what Brown and Collins call an "increasingly rich implicit understanding of the world in which they use the (conceptual) tools and of the tools themselves"¹⁸. This understanding is framed by those situations in which the conceptual tools are learned and used.

This leads to a different way that we might think about student engagement. To understand this, I introduce the framework of Productive Disciplinary Engagement (PDE)¹⁹. Figure 6 shows a schematic of

¹⁷ See e.g., Barab, S., and Duffy, T. (2000) From practice fields to communities of practice. *Theoretical Foundations of Learning Environments*. 1(1), 25-55, and Dewey, J. (1938). *Experience and Education*, Macmillan, New York.

¹⁸ Brown, J., Collins, A., and Duguid, P. (1989) Situated cognition and the culture of learning. *Educational Researcher*. 18(1), 32-42.

¹⁹ Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, 20(4), 399-483.

two figured worlds²⁰, school world and engineering world. By the time undergraduate engineering students have reached their senior year, they have generally been successful in the world of engineering school, what I show as “School World” in Figure 7. However, these school abilities may function almost completely independently of the real life sense making abilities needed in the world of engineering practice. It is not uncommon to find a student in the engineering classroom who does well on exams but cannot operationalize that same material in project work. Alternatively, as Edison did, when one uses the knowledge and skills of engineering to achieve task specific goals, they are in *Engineering World*. From this perspective of engagement the challenge is to re-situate the curriculum more towards, engineering world (as illustrated by the arrow in Figure 7). The underlying premise is that thinking and acting like engineers (PDE) is more likely if students are immersed in professional contexts in engineering world rather than thinking like engineering students in school world. I will next examine some ways that school world and engineering world differ, then present an example of an activity using these concepts and finally look at two contrasting video examples of students working in teams within such an instructional design.

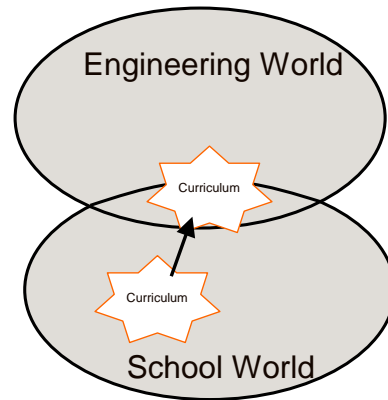


Figure 7. Representation of shifting the curriculum from school world to engineering world.

Next I present several aspects of the work we might ask students to do. I begin with a traditional view that is rooted in the historical and cultural norms of undergraduate engineering school. Then I contrast it with an alternative take from engineering world. The views of engineering world presented here are rooted in principles from the learning sciences and science and technology studies literature²¹.

1. A traditional curricular view tends to emphasize the technical aspect of engineering work – for example, some instructors might be enamored with rigorous mathematical analyses or derivations. They might also include social work – the so-called soft skills or professional skills – since ABET says they need to. But that aspect is backgrounded and largely separated from the technical work. In engineering world, engineering is viewed fundamentally a social profession, as the engineer designs processes and products to meet social needs. In addition, most engineering is done in collaboration with peers, other experts, and managers. So engineering work contains both significant social and technical components. Moreover, these two are “interlocked” – meaning that social practices influence the way we go about technical work – and vice versa.
2. A school world view might be that you need to have a solid understanding of the fundamentals before you can do real engineering work. This perspective leads to curricular designs where math, science, and engineering science are front loaded, leaving students little opportunity to

²⁰ Holland, D., Lachicotte, W., Skinner, D., & Cain, C. (1998). *Identity and agency in cultural worlds*. Cambridge, MA: Harvard University Press.

²¹ E.g., Bailer-Jones, D. (2009). *Scientific models in philosophy of science*. University of Pittsburgh Press; Cook, S. D., & Seely Brown, J. (1999). Bridging epistemologies: The generative dance between organizational knowledge and organizational knowing. *Organization science*, 10(4), 381-400; Ford, M. J., & Forman, E. A. (2006). Chapter 1: Redefining disciplinary learning in classroom contexts. *Review of Research in Education*, 30(1), 1-32; Lehrer, R. (2009). Designing to develop disciplinary dispositions: modeling natural systems. *American Psychologist*, 64(8), 759; Pickering, A. (1995). *The mangle of practice: Time, agency, and science*. Chicago: University of Chicago Press; Trevelyan, J. (2014). *The making of an expert engineer*. CRC Press; Vincenti, W. G. (1990). *What engineers know and how they know it: Analytical studies from aeronautical history*. Baltimore: Johns Hopkins University Press.

experience engineering work in a realistic context. In engineering world, we may take the approach that you learn principles better by applying them to real concrete engineering demands.

3. School world practice commonly gives students deterministic problems with single answers; in contrast real engineering problems often have multiple solution paths where the engineer is asked to be more creative and to work within competing constraints.
4. In school world classes convey that engineering is done with certainty and good students are able to find the correct answer; in engineering world, the curriculum would prompt students to make the best decisions they can based on what they know – and thereby understand that engineers need to progress despite incomplete knowledge.
5. School world reinforces the norm that there is one way to be smart and privileges a certain type of knowledge. When engaged in engineering world, students see there are multiple ways that they can meaningfully and productively contribute to a team – and therefore such an environment places value on diverse ways of thinking.
6. Finally many players in school world are oriented by grades while re-situating work in engineering world leads to valuing the knowledge and skills needed for professional practice.

The consensus report, *How People Learn*²², led by John Bransford, Ann Brown, and Rodney Cocking, illustrates one of the problems associated with a curriculum associated with school world. As they write:

Sometimes, however, students can solve sets of practice problems but fail to conditionalize their knowledge because they know which chapter the problems came from and so automatically use this information to decide which concepts and formulas are relevant. Practice problems that are organized into very structured worksheets can also cause this problem. (p. 43)

They go on:

Sometimes students who have done well on such assignments – and *believe* that they are learning – are unpleasantly surprised when they take tests in which problems from the entire course are randomly presented so there are no clues about where they appeared in a text. (p. 43)

As there become greater shifts in context, such as the messy, open-ended work in engineering practice, these issues only become exacerbated.

Let's look briefly at a classroom activity that was designed as part of our NSF RED project²³ with the idea of engaging students in disciplinary practice. We have just recently gotten going on this project, and I would like to provide a taste of what we are up to. The activity shown in Figure 8²⁴ was developed for the sophomore level energy balances class and students complete it in the role of engineering teams in a studio learning environment. The students are placed in the role of development engineers for a start-up company designing a microreactor that uses a PCR reaction for point of care diagnostics. As shown by the

²² National Research Council. (2000). *How people learn: Brain, mind, experience, and school: Expanded edition*. J. D. Bransford, A. Brown, R. Cocking, Editors, National Academies Press: Washington, DC.

²³ Award abstract (https://www.nsf.gov/awardsearch/showAward?AWD_ID=1519467); see also Koretsky, M., & Bothwell, M. K., & Nolen, S. B., & Montfort, D., & Sweeney, J. D. (2016, June), *Shifting Departmental Culture to Re-Situate Learning* Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.26183; Sweeney, J. D., & Koretsky, M., & Bothwell, M. K., & Nolen, S. B., & Montfort, D. (2017, June), *Board # 140 : Re-Situating Community and Learning in an Engineering School* Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio. <https://peer.asee.org/27753>

²⁴ Problem and schematic developed by Adam Z. Higgins, Oregon State University.

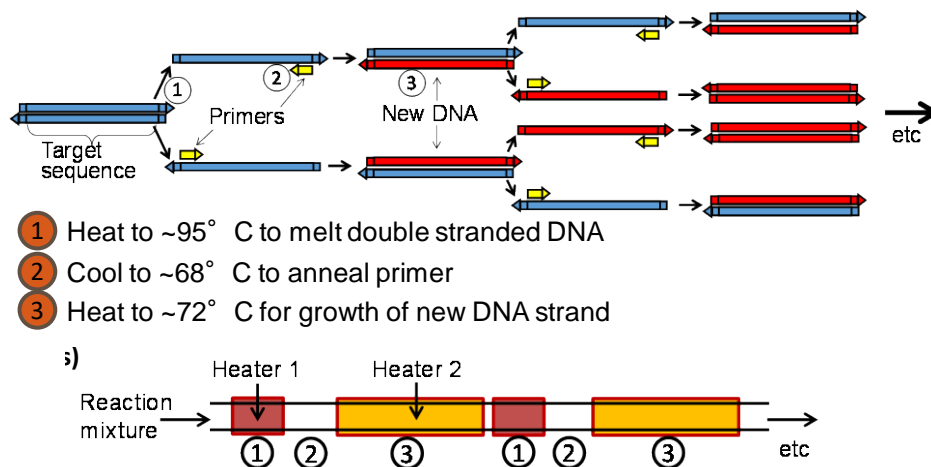


Figure 8. Energy balance studio problem intended to engage students in disciplinary practice.

schematic in Figure 8, in the PCR reaction, chains of DNA are reproduced through a three step sequence at three different temperature. This process is repeated several times to geometrically multiply the original DNA sequence for testing. Since each step occurs at a different temperature, teams need to operationalize their understandings of energy balances and use energy conservation as conceptual tool to design the system.

Our intent is that students who engage in this activity take on the roles of engineers in ways that resemble engineering practice. In the spirit of *design based research*, we would like to see the degree to which this occurs and seek to iterate on the design of the instructional system using this information. One way to determine this is to infer from the work they hand in. Even more useful is to collect process data, that is, observe teams as they do their work.

Next I am going to show video clips from two teams completing this studio activity (transcripts are available in Appendix A). It is useful to understand the context in which these students were recorded. Rather than in the class itself, we recruited a set of students who had already successfully completed energy balances. As you watch the videos (or read the transcripts), think about the ways the team's activity is characteristic of school world and of engineering world.

Both teams are engaged – but they are engaged in different ways. Team 1's work is focused on a shared work object. They are thinking within the system and using specific reasoning about the system and foundational disciplinary knowledge to build on or challenge one another's claims. They bring different perspectives and inclinations but all are clearly meaningfully participating. In short, they are mostly in engineering world. Students in Team 2 all have individual work objects. In fact, when student 1 (S1) holds up his notebook to focus on a common object, he is quickly rebuffed. They are mainly trying to figure out where the task fits within the context of school structure to decide what to do. They make claims without reasoned justifications ("...because that's what we assumed in mass transfer usually."). Let me be clear, I am not implying Team 1 is "good" and Team 2 is "bad." Rather they are engaging in this activity in ways they have been enculturated and in ways that makes sense to them. However, as educators, we might say

that the thinking and social processes of Team 1 will more resemble what they might do as practicing engineers.

In this context, we can see some characteristics of what productive team work looks like. These include shared work objects/representations, equitable participation patterns, group-wide engagement, collaborative thinking/co-construction, productive friction where the dilemmas and discrepancies teams face lead to new ideas, glorious confusion the necessary precursor to deeper learning, and immersion in engineering world where the group is thinking and acting like engineers by using engineering concepts and practices to do engineering work and making progress.

So thinking about student team engagement in disciplinary practices, we can see a spectrum of activity. On the one end, students are thinking and acting in ways that they have been enculturated into in school world. In this mode, the activity is seen for its transaction value and directed to “get the points.” At the other end of the spectrum, team activity aligns with applying concepts and practices of engineering to design, analyze, and optimize processes. In short, students are in engineering world. The premise here is that the ways of thinking and knowing in engineering world better align with the activity students will undertake in professional practice. So by eliciting this type of engagement, the work that we ask students to do will more likely result in adaptable, flexible, and transferrable knowledge and skills.

Clearly such engagement depends on what we ask students to do. That has been the focus of today’s presentation. But we need to make meaning of our video observations where the two teams responded quite differently. This leads us to consider instructional practices, as well. A generic conceptualization of the roles of activity design and instructional practices is shown in Figure 9a. Instructional practices include the whole class and individual team interactions between the student and the instructor(s). Within any class, there is a distribution of student engagement (represented by the bell-shaped curve) and that distribution depends on both the activity design and the instruction practices.

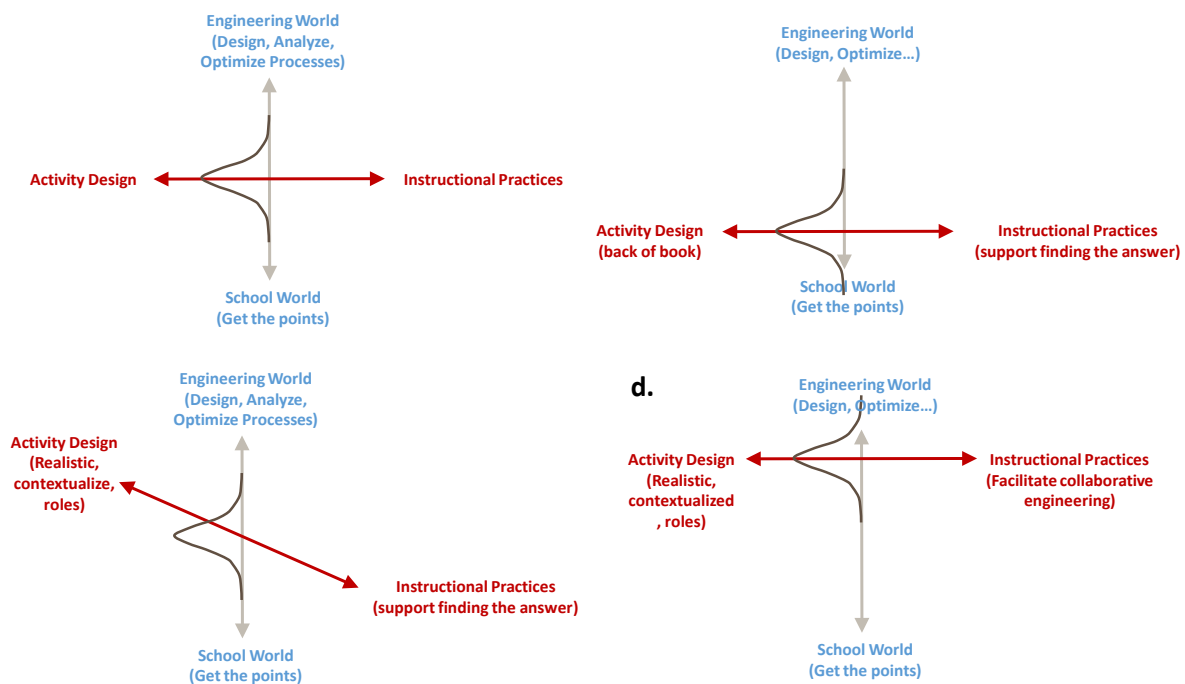


Figure 9. Roles of activity design and instructional practices in eliciting student engagement. a. general representation; b. traditional activity and instruction; c. realistic activity with traditional instruction; d. realistic activity with instructional practices that facilitate collaborative engineering.

For example, consider Figure 9b. If the activity is typical of many “back of the book problems” and the instructional practices focus on finding the answer as opposed to the sense-making and collaborative processes of thinking about the problem, the distribution of engagement is likely to shift to school world. Even with a well-designed activity that supports students in realistic, contextualized roles of engineering world (Figure 9c), if the instructional practices focus on answer finding over sense-making, we may see only partial engagement towards engineering world. We want to maximize the benefits of group work, where all students have opportunity to participate and learn. From the model presented today of engagement in disciplinary practices, we would say that we need both a rich activity design which places students in realistic, contextualized roles, and corresponding instructional practices that facilitate collaborative engineering and encourage sense-making (Figure 9d).

Summary

Active learning has been shown to produce higher learning gains than passive transmission based instruction. I have presented two models that may be useful to ground our work as we develop activities for the active leaning classroom. The first model of engagement deals with conceptual understanding where we seek to help students “see the land” and work towards developing the connected knowledge structures of experts. The second model of engagement considers disciplinary practice where we ask students to think and act like practicing engineers.

I will end this discussion where it started, by going “Back to the Future.” In his 1981 CP Lecture, Robert Pigford stated, “If their teachers present problems that require only mathematical skill the effect may be only to sharpen the students’ ability to solve mathematical problems. If the assignments and class discussions never refer to technical problems related to real processes or real equipment but always involve the derivation of equations representing highly idealized phenomena the students will have no practice in the art of making assumptions that are reasonable and useful... Even worse, the students will have no way of knowing what engineers actually do and why they perform a function that is an essential one for their employers and their companies” (p. 4-5).

My hope here today is that I have provided some perspective through which to consider these words.

Epilogue

An epilogue on the benefits of engaging students in disciplinary practice is that it has potential to fundamentally address issues of broad dissatisfaction with schooling and of inequitable participation and opportunity to learn²⁵. Because the wide array of engineering practices offers numerous avenues for legitimate engagement of learners, technologies and learning environments that engage students in engineering practice can provide access to a more diverse set of learners²⁶. Through subsequent participation in such activities, learning in engineering and identity development in engineering become linked and inseparable²⁷. As classroom practices and expectations align with how learners see themselves

²⁵ Sfard, A. (1998) On two metaphors for learning and the dangers of choosing just one. *Educational Researcher*. 27(2), 4-13.

²⁶ Windschitl, M., and Calabrese Barton, A. (2016) Rigor and equity by design: Seeking a core of practices for the science education community. *AERA Handbook of Research on Teaching*, 1099-1158.

²⁷ Dahlgren, M., Hult, H., Dahlgren, L., af Segerstad, H., and Johansson, K. (2006) From senior student to novice worker: Learning trajectories in political science, psychology and mechanical engineering. *Studies in Higher Education*. 31(5), 569-586.; Brickhouse, N., Lowery, P., and Schultz, K. (2000) What kind of a girl does science? The construction of school science identities. *Journal of Research in Science Teaching*. 37(5), 441-458; Pierrakos, O., Beam, T., Constantz, J., Johri, A., and Anderson, R. (2009) On the development of a professional identity: Engineering persists vs engineering switchers. *IEEE Frontiers in Education Conference*, 1-6.

as engineers, what is learned is valued more and has more meaning²⁸. Learners consequently become more ready to operationalize what they have learned in professional practice.

Appendix A: Transcripts of two teams approaching a Studio task

Transcript from Video from Team 1:

S1: Right like we only know our target temperature.

S1: We could set up...this is...this is...I mean...that's heat transfer right?

S1: We don't know that technically we're in 212 (Energy Balances) right?

S2: Yes but I want to use Heat Transfer.

S3: If you use heat transfer I think it will be a little bit easier but [mumbles] and if you remember from the Energy Balance

S3: we always start with two things. First thing we have to start with the assumptions (for the system)

S3: then we always, always start with the energy balance. Then we [indiscernible] the equations.

S3: Then I think we will end up by Q term and this Q term is going to be replaced with this (Fourier) equation [mumbles]

Transition, about 1 minute passes here.

S2: It shows theres a gap between heater 1 and heater 2 here, I dont...either decription ...by the decription it doesn't sound like there should be...

S3: I think it requires cooling. Because the cooling happens here.

S2: It doesn't say anything about cooling down. Between the...2 and 1

S1: Right like we only know our target temperature.

S1: We could set up...this is...this is...I mean...that's heat transfer right?

S1: We don't know that technically we're in 212 (Energy Balances) right?

S2: Yes but I want to use Heat Transfer.

S3: If you use heat transfer I think it will be a little bit easier but [mumbles] and if you remember from the Energy Balance

S3: we always start with two things. First thing we have to start with the assumptions (for the system)

S3: then we always, always start with the energy balance. Then we [indiscernible] the equations.

S3: Then I think we will end up by Q term and this Q term is going to be replaced with this (Fourier) equation [mumbles]

Transition, about 1 minute passes here.

S2: It shows theres a gap between heater 1 and heater 2 here, I dont...either decription ...by the decription it doesn't sound like there should be...

S3: I think it requires cooling. Because the cooling happens here.

S2: Yeah but it just says that the process cycles immediately after heater 2...

S2: It doesn't say anything about cooling down. Between the...2 and 1.

S1: That is step 2.

S2: Yeah right here. But between 3 and 1 there's...

S1: I think this is intended to be like ..this is just so small that it's just like..."bink"

S2: Yeah so we can ignore that? We can just say heater 2 and 1 are next to each other?

S3: Yeah because the temperature is not...I mean...it does not require the same cooling as that one so...

S1: Oh ok. Uhm...should we do individual, like...heater 1, heater 2, [mumbles]?

²⁸ Nolen, S., Horn, I., and Ward, C. (2015) Situating motivation. *Educational Psychologist*. 50(3), 234-247.

Transcript of Video from Team 1 (cont):

S1: Just like an energy balance for each step, and then combine them or can we do it over [mumbles]?

S3: The question is asking to find the temperature of the water within the microchannel...

Title Slide, "2 minutes later...": During these two minutes the group discusses the "thin-wall assumption" in addition to using the textbook reference to decide where to go next. S3 then references the memo to check design parameters requested by the memo.

S3: ...power delivered...so Q...size of the heater...so this is area which is πdl ...and distance or length...hmm...

Title Slide, "2 minutes later...": During these two minutes the group stalls out, with S1 working independently while S2 and S3 seem to puzzle over where to go next.

S3: Let's see what is the confusion part here. Is it...that we have three heaters?

S2: Yeah I think it's...Yeah we just have three parts. We should focus on one part first. Let's focus on heater 1 first.

S3: That's what I was thinking. So let's say system 1...

Title Slide, about 1 minute passes here.

S2: This is where we would use log mean temperature in Heat Transfer.

S3: I guess if you are going to use it with Heat Transfer it may be easier...but I'm not sure.

S3: [mumbles]...see what I'm saying?

S3: I said if we are going to use some information that we learned in heat transfer I guess it would be easier.

S1: Well...if we just...if we're breaking it into chunks all we're doing is heating it right?

S1: So, we're gonna have our heating element...which is gonna be our Q right?

S1: And then we just have $Q = mCp\Delta T$

S1: Yeah and then you've got...

S3: \dot{m} so "m" is the mass flow rate...so it is a function of flow rate.

S1: Yeah so we use the density and the volumetric flowrate to find that.

S3: And what is the second mCp?

S1: Cp which is the specific heat of...which is...probably assumed to be water, because it's gonna be in solution right?

S2: I wasn't thinking of the heater that way.

S1: Well this is going to be defined isn't it though?

S2: No I was...like you have a coil. So it's just delivering a set amount of heat.

S3: Yeah that's what I was saying it's power. It's power. Yeah.

S1: Yeah, and we have to take a step back like we don't know heat transfer yet so we aren't going to...

S1: ...there's no radial variability in your equation, it's just bulk flow rate.

Transcript of Video from Team 2:

S1: [indiscernible, regarding checking the book]

S4: And so, where we're looking [indiscernible]

S1: Yeah.

S4: So, we're essentially modifying the Q (heat transfer) equation?

S1: That Qdot fits into a bigger equation, and then we can just plug that chunk into the equation...is what I'm thinking.

S4: That's right, we have...[indiscernible]

S1: Sooo...we want "Part 3: Energy Balances"... we want page 356.

Title screen, "3 min later...": three minutes of facilitator led discussion regarding the students understanding of the memorandum, with a focus on context.

S2: So I guess what I'm saying is, is it gonna be at 95 degrees C for like half of this chamber...

S2: ...or like right when it gets to this point before it hits the anneal space?

S3: Do we need to know that?

S1: I think that that might be overcomplicating the situation.

S1: This is...this is a class where [indiscernible] ok it's in the heater and is at that temperature (target temperature) now.

S4: I think we could probably like assume that it's completely mixed and the temperature is uniform in the heating area...

S4: ...because that's what we assumed in mass transfer usually.

S2: So uniform temperature.

S1: And then ΔE_k (kinetic energy) and ΔE_p (potential energy) always go away, unless it's like pipes dropping a big distance.

S2: So are we assuming that the DNA mixture has the same properties as water?

S1: Unless told otherwise. You assume that always in this class.

Title screen, "10 min later...": ten minutes of student discussion regarding system analysis, including a few distractions.

Discussion focused on understanding the simplification of the energy balance and how to approach the piecewise nature of the process.

S2: I know it may make the problem more complicated, but...

S2: ...is it really super reasonable to assume that we have a constant temperature throughout each one of these spaces?

Because as it's moving through it's heating, cooling, then heating again...

S1: We didn't start doing anything transient like that until the last week or two of class...and this would have been much earlier than that.

S2: Was it you and someone else who had already done a studio similar to this?

S1: Uhm, I have never done this studio...but I took the class just last year.

S2: So you're our expert