Program Level Curriculum Reform at Scale:
USING STUDIOS TO FLIP
THE CLASSROOM

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Recently chemical engineering programs nationwide have shown significant growth.[1] With the increasing student populations, many programs have struggled to maintain effective learning environments. Such a tension is not new. For example, Houze described alternative approaches of four large chemical engineering programs to growth in the 1970s.[2] Traditional management approaches include establishing program enrollment limits, increasing the intensity of gateway courses to "weed out" the lower-performing students, or delivering the required courses in multiple sections. Each of these solutions has a significant economic or social cost. This article reports an alternative approach in which larger lecture courses are punctuated by smaller studios. Studios, like recitation, break up lecture classes into smaller sections; however, unlike a typical recitation, they are learner-centered and activity-based where students are afforded the opportunity to interactively engage the content presented in the large lectures. The activities and social processes in the studio learning environment essentially provide for students a "flipped" classroom.[3]

This article presents a description of a comprehensive, program-level implementation that comprises the incorporation of studios in 10 core courses at Oregon State University, including: chemical engineering orientation, numerical methods, material and energy balances (two courses), process analysis, transport phenomena (three courses), and thermodynamics (two courses). The article provides a description of the studio approach, an analysis of student perception, and discussion of the administrative support and department culture needed for this type of curricular innovation. The aim, in part, is to contribute to the general discussion of critical elements to consider in instructional design for flipped classrooms and their curricular integration. The description and analysis are based on three years of experience implementing studios, and build on an earlier report that described the first term of implementation.[4]

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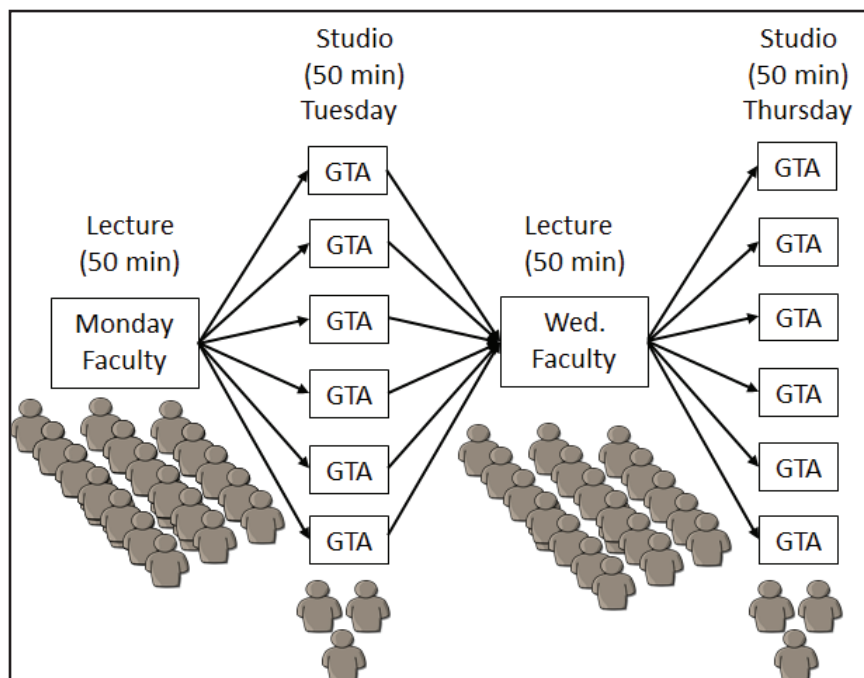
Figure 1. Weekly class structure for a junior-level studio course. Each class period is 50 min. The icons are proportional to the number of students in each portion of class.

BACKGROUND

The foundation of the studio architecture is based on the demonstrated effectiveness of interactive learning pedagogies from the education research community. These methods seek to promote a substantially higher level of engagement from students during in-class times. Deslauriers and colleagues[5] studied the effectiveness of interactive learning reform pedagogies using a split design among 538 students. For the control group, an experienced professor with a record of high student evaluations taught a 1-week unit on electromagnetic waves using a traditional lecture format. In the experimental group, an inexperienced, but trained, postdoctoral fellow led a parallel class but based instruction on interactive learning pedagogy. The instructional design was intentional and constructed for students to "spend all their time in class engaged in deliberate practice at 'thinking scientifically' in the form of making and testing predictions and arguments about the relevant topics, solving problems, and critiquing their own reasoning and that of others," (p. 862). These activities were embedded in a social environment where the students worked interactively with their peers and the instructor. Performance on an identical examination showed the average of the experimental group was 2.5 standard deviations above the control group. In addition, student attendance and engagement were reported to be significantly higher in the experimental group. Other, more comprehensive studies similarly find increased learning gains in courses that use interactive pedagogies.[6-10] For studios described in this article, we define interactive

learning in much the same way: when students engage in the deliberate practice of thinking scientifically supported by social interactions with peers and an instructor. A more complete description of what constitutes interactive learning is given by Chi.[11]

Use of interactive learning methods has greatly increased in engineering over the last two decades, as advocated by Richard Felder and colleagues.[10, 12] Additionally, curricular reform of introductory physics and mathematics courses has demonstrated how to successfully incorporate interactive learning methods into large lecture classes. In some cases, the entire class time is based on an active-learning design.[13, 14] Recently, these efforts have been expanded to include design of technology-enhanced classroom architectures to support interactive learning, such as with the SCALE-UP architecture developed at North Carolina State University[15] and the Technology Enabled Active Learning (TEAL) project at the Massachusetts Institute of Technology.[16] SCALE-UP has recently found its way into engineering statics and dynamics classrooms.[17] Another curricular model focuses the reform methods by incorporating active-learning pedagogies to help students learn concepts and problem solving in small studios that accompany larger lecture classes, such as Tutorials in Introductory Physics,[18] and the Emerging Scholars Workshop Program in mathematics.[19] The implementation of studios reported in this paper is based on this latter model and is described next.

Studio architecture and implementation design

The design objectives of the studio implementation include:

1. *Provide an environment where all students are engaged in interactive learning.*

2. *Design a structure that allows strategic and tactical implementation of interactive learning pedagogies and which allows relatively easy scaling to meet changing enrollments.*

3. *Provide a scaffolded support structure for graduate teaching assistants (GTAs) that allows them a) to effectively integrate into the class structure to help students achieve the course learning objectives, and b) to develop their own teaching skills and knowledge of how students learn, and to better value contributions to teaching.*

In our implementation of the studio-based curriculum design, classes are divided with studios interspersed between lectures. Figure 1 shows a weekly schedule for a typical three-credit course with a capacity for 150 students, such as the

junior-level courses reported here. Previously, these courses had a 2-hour recitation in the same room as the lecture, so the contact time for students remains the same. In the 50-minute studio period on Tuesdays and Thursdays, students are provided worksheets where they are required to answer a series of conceptual and numerical questions designed to either reinforce content from the previous lecture and/or foreshadow the following lecture. Sometimes activities involve "virtual laboratories" where students collect data on their computers.[20] Students each fill out an individual worksheet, but are often allowed to work in groups for all or part of the class period. The studios are designed to be small enough (around 25 students), that a GTA or instructor can circulate around the room, interact with students and groups, and ask "facilitative" questions to help them get unstuck and promote learning. The social interaction between students themselves and the student and instructor is critical and is strongly encouraged.

What is the difference between a studio and a traditional recitation? One primary difference is in the nature of the roles that the students and instructors are assigned, and in the expectations that follow. In the canonical recitation model, the GTA or instructor typically "models" solutions to example problems by working problems in front of the group, provides tips on the homework, or extemporaneously answers student questions in front of the entire section from the vocal minority who ask. Students seldom witness or encounter what to do when they are "stuck" and cannot see a clear solution path. On the other hand, studios are designed to engage all students in the classroom. They are activity based where students spend the majority of the studio time in action to answer conceptual questions, solve problems, explain phenomena from in-class demonstrations, work on virtual laboratories, and reflect on these experiences. The GTAs or instructors interact with students in a facilitative mode where they ask probing questions with the intent to prompt students to reflect on appropriate procedures and concepts so that the students themselves can identify what to do next. These interactions are largely unscripted and an important aspect of studio implementation is to develop this perspective and ability in the GTAs. The intent is to shift emphasis from having students obtain the "correct" answer to developing their thinking process and skills about the concepts and problems and to relating their activity to the content in lecture. Directive feedback is used only as a last resort.

The implementation of the studios is executed by a coordinated team effort. There are regular biweekly meetings between the entire studio team including faculty, graduate students, and one or two studio coordinators and weekly meetings between personnel in a given course. These meetings cover a broad array of topics, including worksheet design; effectiveness and assessment; troublesome cases; and uniform delivery, formatting, and grading. One intention is to align the design and delivery among studios and between courses. In this way,

The foundation of the studio architecture is based on the demonstrated effectiveness of interactive learning pedagogies from the education research community.

we hope to create a consistent expectation among students in a studio, lowering the cognitive demand that would be used in interpreting different formats and allowing strong student focus. Such alignment also allows more coordinated and effective graduate student training. Another intention is to create a community of practice among the instructional personnel.[21] We have found that GTAs are eager to participate in the community and crave to learn how to be a successful teacher.

The heart of the studio learning process centers around the directed student activities, which are done individually and in groups. The activities are focused by the use of studio worksheets. Development of the worksheet content is based on the reform pedagogies described above. We have found that it is important that students engage in questions that directly relate in context and content of the material presented in the previous lecture. The structure of each worksheet varies by intention, but a common approach is for the student to make a qualitative prediction, discuss their predictions in a small group, solve a quantitative problem (usually in a group) and then reflect on how the answer compared to the prediction. There is sometimes an open-ended design component at the end of the worksheet, which helps moderate students who work at different paces. Each worksheet is generally developed by the faculty member instructing the course. It ideally is completed by the GTAs who will be facilitating the studios prior to delivery. The group of instructors and GTAs can then meet to revise the worksheet before delivery in the studio (time permitting). Detailed content knowledge of the studio activity allows GTAs and instructors to focus on facilitating learning during delivery.

An example worksheet for the topic entropy of mixing is shown in Figures 2 (next two pages). The content is identical to how it was delivered in the studio; however, it has been reformatted to reduce space. This particular worksheet shows an "inverted" structure that starts with a set of quantitative problems and ends with qualitative predictions. It is conceptually progressive. Part C of problem I can be answered by superposition, which helps students construct understanding of the effect of the mixing process on entropy (in a sense the

Example Studio – Entropy of Mixing
**Oregon State University**

Name: _____

Studio Time (circle one):   12:00   1:00   2:00   3:00   4:00   5:00

I.   *Calculations of Entropy Change*

A.   Consider the adiabatic, rigid container shown below. Initially (State 1) 0.21 mol of O_2 gas (species A) on the left is separated from vacuum by a partition. The partition is then removed. You may assume ideal gas behavior.
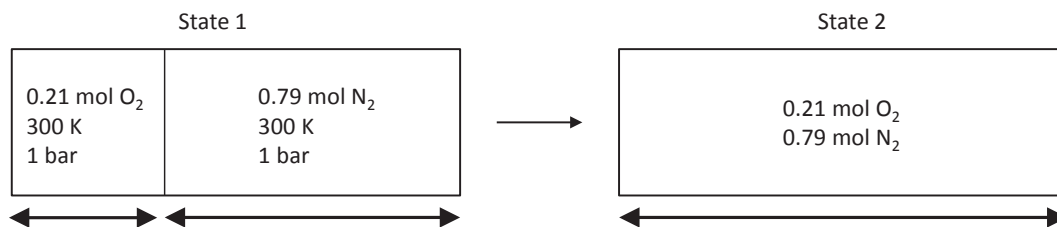
State 1   State 2

| 0.21 mol O_2
300 K
1 bar | Vacuum | | 0.21 mol O_2 |

    21 cm   79 cm   1 m
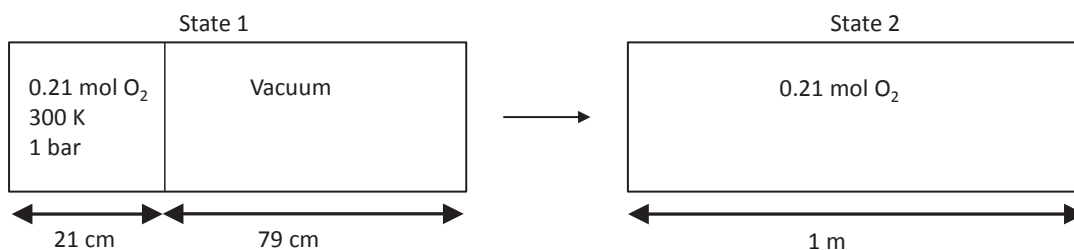
a.   Develop <u>an expression</u> for the entropy change of this process, ΔS in terms of P_1, P_2, T_1, T_2, c_P, n_A and R

b.   Calculate the value of ΔS.

B.   Consider the adiabatic, rigid container shown below. Initially (State 1) 0.79 mol of N_2 gas (species B) on the right is separated from vacuum by a partition. The partition is then removed. You may assume ideal gas behavior.

State 1   State 2

| Vacuum | 0.79 mol N_2
300 K
1 bar | | 0.79 mol N_2 |

    21 cm   79 cm   1 m
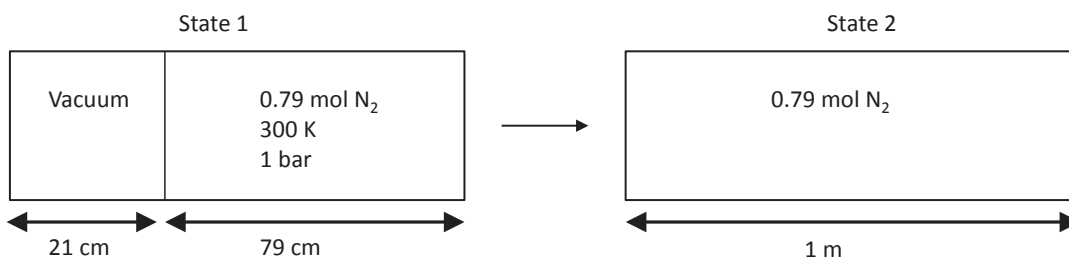
a.   Develop <u>an expression</u> for the entropy change of this process, ΔS in terms of P_1, P_2, T_1, T_2, c_P, n_B and R

b.   Calculate the value of ΔS.

C.   Consider the adiabatic, rigid container shown below. Initially (State 1) 0.21 mol of O_2 gas (species A) on the left and 0.79 mol of N_2 gas (species B) on the right is separated by a partition. The partition is then removed. You may assume ideal gas behavior.

Figure 2a. *Example studio assignment from thermodynamics – page 1. The assignment has been reformatted to reduce its size.*

## Example Studio – Entropy of Mixing
Oregon State University

State 1 → State 2

State 1		State 2
0.21 mol O_2 300 K 1 bar	0.79 mol N_2 300 K 1 bar	0.21 mol O_2 0.79 mol N_2

a. Determine the value of ΔS_{mix}.

b. Develop <u>an expression</u> for the entropy change of this process, ΔS_{mix} in terms of P_1, P_2, T_1, T_2, c_P, n_A, n_B and R

c. Develop <u>an expression</u> for the entropy change of this process, Δs_{mix} in terms of P_1, P_2, T_1, T_2, c_P, y_A, y_B and R

A. Describe in your own words, what gives rise to the "entropy of mixing"
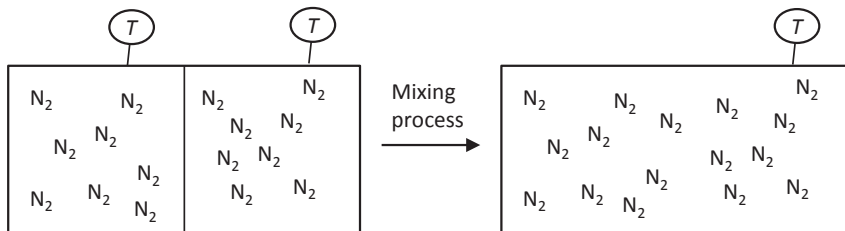
I. *Qualitative Reasoning Entropy Change of Mixing*

A set of mixing processes is shown below. The volumes are represented by the size of the boxes. For each process, determine whether Δs is greater than zero, less than zero, or equal to zero. Explain your reasoning.
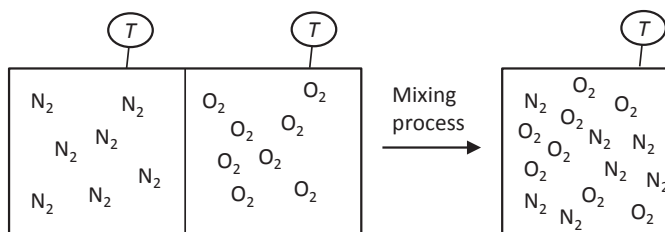
A.
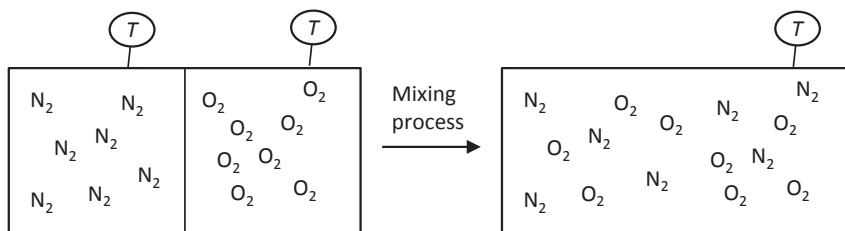
B.

C.

**Figure 2b.** *Example studio assignment from thermodynamics – page 2.*

sum of parts A and B is a hypothetical path). Part D asks them to reflect and generalize. Finally in problem II, they are asked to apply the core principle to new situations to qualitatively reason and predict outcomes. Figure 3 shows a screenshot of one frame of a virtual laboratory that is used in studio. This activity is quite different from the one shown in Figures 2. Each student completes the virtual laboratory on a laptop, but all still interact in groups of three. Two analogous versions of hypothetical path virtual laboratories delivered in different studios allow students to identify similarities between the approach to phase change (shown) and to chemical reaction.

FRAMEWORKS TO CONSIDER FOR EFFECTIVE DEVELOPMENT AND IMPLEMENTATIONS OF STUDIOS

In considering development and implementation of the studios, it has been useful to consider multiple theoretical perspectives. Two such perspectives, as they relate to studios, are described in this section: 1) studios as a bridge from concrete to formal reasoning and 2) studios as an opportunity to address threshold concepts.

Studios as a bridge from concrete to formal reasoning

Jean Piaget's theory of intellectual development consists of four stages. While his theory was formed to explain developmental stages in children, it is useful to consider the progression of students in their engineering education in terms of the final two stages, concrete reasoning and formal operations.[22,23] In the lower-division courses, one sees a full range of concrete reasoning and formal operations with concrete (object/number-oriented) problems being easier to solve than abstract problems. Many students have a tendency to try to cope by using concrete skills with an emphasis upon memorization, picking the right equation, using numbers instead of symbols, and focusing upon getting the answers instead of using formal processes to just "figure it out." One of the primary goals of the studio architecture is to help students transition from concrete reasoning to applying formal operations as they engage with the course content to predict and explain phenomena and to solve problems. The controlled environment of the studio supports this transition as students must openly confront an array of different conceptual and numerical problems while they interact with their peers and the instructors.
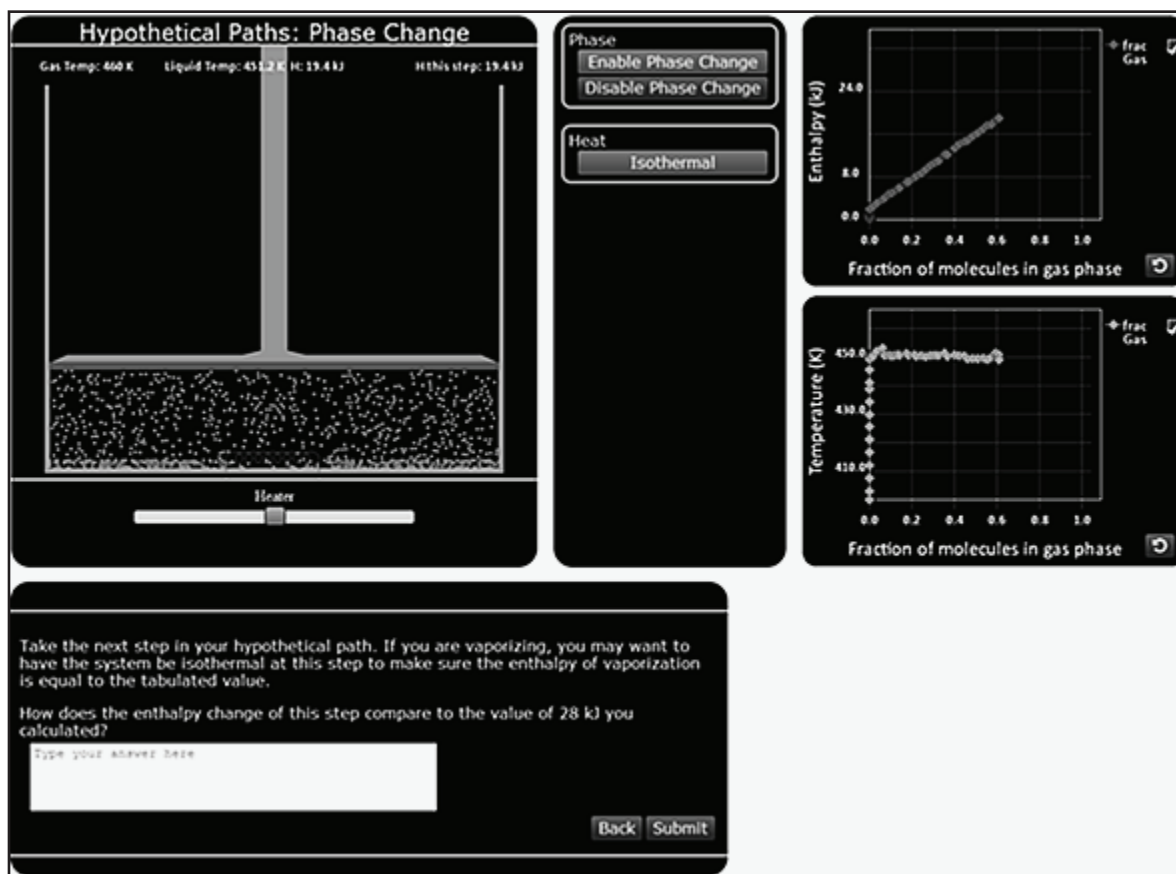
Figure 3. *Several hypothetical path virtual laboratories allow students to explore the ideas behind hypothetical paths while constructing one to solve a problem. The case of phase transition is illustrated above. Students also have a virtual laboratory to construct a hypothetical path for a chemical reaction.*

Studios as an opportunity to address threshold concepts

Meyer and Land[24] pose threshold concept theory as a lens through which to view learning, assessment, and curriculum development. In their application, the term "concept" should be viewed broadly to include both the concepts and the capabilities that are core to understanding and progressing in a discipline. Meyer and Land identified four qualities of threshold concepts: troublesome, transformative, irreversible, and integrative. By troublesome, they mean the concept or capability is difficult for students to learn; for example, it may be conceptually complex. It is transformative in that once understood, it changes the way the student views the discipline and knowledge of the subject. It is irreversible in that once the student "sees" this new view, she/he will not revert to the more naïve perspective previously held. Finally, it is integrative in that it allows the student to see connections between elements that were previously disjointed.

As an example of a threshold concept, consider hypothetical paths in thermodynamics. A hypothetical path is a path that is used for calculation when it is different from the path the system actually undergoes. The broad applicability of thermodynamics lies in the concept that the change in any property, $e.g.$, Δu, for a hypothetical path is the same as for the actual process as long as the system starts and ends up in the same states as that process. The utility of this threshold concept is that it enables the use of data that are available to solve many different problems of interest. Recognition of the possibility and development of the ability to construct hypothetical paths between states allows for efficient collection and organization of experimental data. Once the students' conceptualization has been "transformed," they recognize when they can appropriately construct a hypothetical path and have the ability to develop the path and execute such a calculation based on the data. This realization is also irreversible and integrative; once students "get" hypothetical paths, the idea sticks and it allows them to understand the context for many different calculations that they are asked to perform.

Development of curriculum based on the identification of threshold concepts has recently been enacted in engineering by Male and Baillie.[25] We suggest that identification of threshold concepts and capabilities is a useful framework for identifying content for the studio workshops. While initial implementation described in this paper has focused more on structural and logistical details, we suggest that there is a long-term opportunity for studios to focus on the threshold concepts. However, there is still work that needs to be completed to realize such a vision. First, threshold concepts central to each of the 10 courses need to be identified, and then activities need to be developed that effectively promote student learning of this content. The virtual laboratory depicted in Figure 3, intended to help students learn the hypothetical path threshold concept, is a step toward this vision.

STUDENT PERCEPTION OF STUDIO IMPLEMENTATION

Method

The studio structure was implemented in nine courses beginning in the 2011-2012 academic year, and a tenth course was added in 2012-2013. In each course, students are asked to complete a survey to provide their perceptions of the studio experience at the midpoint of the term. Two weeks later, they are asked to complete a survey about the effectiveness of the GTA or instructor in their studio. About 80% of the studios are led by GTAs and 20% by a faculty member, although the lead faculty in the course often attends parts of other studio sections as well. The surveys were developed in an open and iterative process by the studio team, and then administered to a small set of students who were then interviewed about their interpretation of the questions. Results are presented for the Fall term over a three-year span, but similar results were found in Winter and Spring terms. Fall term is chosen since that is the only term that an entire complete set is available for the three-year study.

In the Fall term, studio courses include a sophomore-level material balances course (CBEE 211), a junior-level thermodynamics 1 (ChE 311), and transport phenomena 1 (ChE 331) courses. The two surveys consisted of five Likert-scale questions and four free-response questions. The five-point Likert-scale questions ranged from strongly disagree (=1) to strongly agree (=5) to a statement. Only results of the Likert-scale items are reported here; coding and analysis of the free-response questions show perceptions consistent with the survey results and are provided elsewhere.[4]

Survey Results

Tables 1 and 2 (next two pages) present survey results for the Likert-scale statements for studios and GTAs/instructors, respectively. Both questions show generally consistent results between questions, with positive responses significantly greater than negative responses. The perceptions for the junior-level courses and the distributions between the two courses are very similar despite being implemented by entirely different personnel. Such a result is a positive indicator of the benefits of the systematic, program-level implementation plan described above. While the majority of student responses for all three courses are positive, a lower fraction of the sophomores perceives value than of the juniors. There are several plausible factors that may contribute to the difference between sophomores and juniors. As the complexity of subject matter increases, students may assign more value to engaging in the interactive structure of the studio. The attrition between the sophomore and junior year may disproportionately encompass less-satisfied students. Finally, the junior students may be more mature, and see the value in engaging in and struggling with the course content themselves. The GTAs and instructors are perceived to be a good resource, although some students felt they are not able to

Course	Likert Statement	Year	1	2	3	4	5	Average
CBEE 211 (Mat Bal)	Studios help me to learn the class material.	2011	9	16	51	75	23	3.50
		2012	9	16	55	105	45	3.70
		2013	1	6	46	127	37	3.87
	For the same total class time per week, I would rather have part Studio and part Lecture than all Lecture.	2011	18	26	29	62	39	3.45
		2012	31	28	52	65	54	3.36
		2013	5	21	47	62	83	3.90
	The Studio worksheets are too long to complete in 50 min.	2011	9	7	33	58	66	3.95
		2012	8	7	38	78	98	4.10
		2013	2	20	32	65	98	4.07
ChE 311 (Thermo)	Studios help me to learn the class material.	2011	3	1	5	33	19	4.05
		2012	1	4	19	54	42	4.10
		2013	1	2	10	64	56	4.29
	For the same total class time per week, I would rather have part Studio and part Lecture than all Lecture.	2011	1	5	8	23	23	4.03
		2012	3	5	16	36	60	4.21
		2013	4	4	21	34	70	4.22
	The Studio worksheets are too long to complete in 50 min.	2011	2	17	18	20	3	3.08
		2012	5	22	37	38	18	3.35
		2013	5	28	63	24	12	3.05
ChE 331 (Transport)	Studios help me to learn the class material.	2011	2	3	11	57	51	4.23
		2012	0	3	25	81	53	4.14
		2013	1	2	19	55	55	4.19
	For the same total class time per week, I would rather have part Studio and part Lecture than all Lecture.	2011	3	13	18	41	49	3.97
		2012	5	8	20	54	75	4.15
		2013	5	9	19	29	70	4.11
	The Studio worksheets are too long to complete in 50 min.	2011	2	27	53	31	11	3.18
		2012	5	22	44	49	42	3.62
		2013	3	14	49	35	31	3.56

spend enough time with students during studio. We are investigating an undergraduate learning assistant model to provide more instructional resources during studio.

In developing studio assignments, there is a balance toward accommodating students at different ends of the spectrum of prior knowledge, preparation, and quickness of thought. Table 1 shows the responses of students to whether they perceive the studios to be too long. The distribution for both the junior-level courses is symmetric (*i.e.*, just as many students agree as disagree). Our interpretation of this result is that the studios are appropriate in length. On the other hand, the majority of the sophomore-level students feel the studios are too long.

DISCUSSION AND CONCLUSIONS

We report in this paper about the first three years of a coordinated effort to implement interactive reform-based pedagogies in 10 core courses in the chemical engineering curriculum through the studio approach. In this endeavor, we have sought to create a community around the studio instruction, a community that not only includes faculty and instructors teaching these courses but also the GTAs working with the students in the studios as well as other faculty in the unit. We view both cognitive and social components to be important. Cognitively, we seek to have our students take a greater ownership of their learning and, for those who need to, to transition from concrete reasoning to formal operations. Socially, we seek to provide a collaborative environment where students can develop and test ideas with their peers, but also get punctuated support in the form of coaching from the instructors. We believe the studio structure will be particularly useful to develop struggling students who would otherwise seek to "hide" in large lecture courses.

While there is overwhelming evidence in the literature that this type of reform method is critical to improved student

Course	Likert Statement	Year	1	2	3	4	5	Average
CBEE 211 (Mat Bal)	The TA is a good resource for you to complete the Studio Worksheets.	2011	8	6	32	72	77	4.05
		2012	1	9	35	93	109	4.08
		2013	3	9	28	108	87	4.12
	The TA is able to spend enough time with you during the Studio to help with your questions on the Worksheets.	2011	6	10	42	83	54	3.87
		2012	10	23	48	88	78	3.69
		2013	3	30	36	80	86	3.90
ChE 311 (Thermo)	The TA is a good resource for you to complete the Studio Worksheets.	2011	0	2	8	22	31	4.30
		2012	0	0	10	44	65	4.46
		2013	0	6	10	37	68	4.34
	The TA is able to spend enough time with you during the Studio to help with your questions on the Worksheets.	2011	2	11	6	21	23	3.83
		2012	2	8	24	53	32	3.88
		2013	1	4	25	39	52	4.10
ChE 331 (Transport)	The TA is a good resource for you to complete the Studio Worksheets.	2011	0	1	5	42	59	4.49
		2012	0	3	12	56	50	4.26
		2013	0	2	16	34	68	4.33
	The TA is able to spend enough time with you during the Studio to help with your questions on the Worksheets.	2011	0	10	18	53	26	3.89
		2012	4	15	26	52	24	3.64
		2013	2	10	30	37	41	3.81

learning, we have reported here only student perception. There seems to be evidence from the student perceptions that is consistent with our intent. The transition from concrete reasoning to formal operations can be uncomfortable. For example, when asked the open-ended survey question about how the studios can be improved, there are several responses like: "I would recommend instead of a worksheet that the TA would teach additional material and review problems and answer questions, more like an O'chem recitation," and "I think we should go over an example before studio starts especially for the studio assignments that are really challenging." This type of response is interpreted as coming from students who are comfortable with concrete reasoning and seeking to learn in a pattern recognition mode. Thus, they are being challenged by the aspect of the studio structure that is intended to stretch their conceptions of thinking. We view such opinions as reflective of a productive friction.[26] This juxtaposition between student expectations and authentic practice is illustrated in the following excerpt. When writing what could be improved in the studios, one student wrote:

> I'm going to be completely honest, we work in groups on these worksheets and the people in the group always seem to be confused on what to do. Eventually we will come to what appears to be the right answer, but it takes so long that the worksheet ends up feeling far harder than it really is. The TA is fairly helpful with questions. I don't find myself learning anything new in studio, though.

Clearly to this student what "it really is" refers to the post-processed, clean presentation of a problem solution that he/she is used to; it is not the messy, indirect, and iterative problem-solving process that is authentic to engineering practice. A goal of the studio project is to influence the perspective of problem solving through direct and guided experience. Ultimately, we need to measure differences in student learning associated with the studios as well as the changes to students' approaches to learning and epistemologies as they progress.

These goals of student learning are difficult to obtain from one course in isolation, and implementing them in concert among the 10 courses is critical. This endeavor takes support from the unit faculty, and from the school and university administration. Faculty who teach these courses have been open to "buying into" the process, albeit, in some cases with a healthy dose of skepticism. This coordination requires a slight change in the model of what creative control of the classroom means. While studio faculty retained their rich and individual interpretations of what it means to know the subject that they are teaching (which manifest in quite different styles and pedagogies in lecture), they have all worked with the team to accommodate a uniform curricular architecture of the studio model.

At the administrative level, there has been full commitment to provide appropriate staffing for the first-year start-up of this initiative. However, by year three, only a slight increase in instructional staff is needed, and is aided by switching

a large portion of homework grading from GTAs to senior undergraduate students. For example, a junior-level course to 150 students requires one faculty member, two GTAs, and one undergraduate grader to deliver. There is also an added service requirement for the faculty coordinator. Additional unit administrative support was provided via time at the department retreat and at the industrial advisory board meeting, so that there could be an understanding among the broad community about the studio approach. We have also received support from the university administration with studio scheduling. At a team meeting in the first year, it became clear that the variety of physical architectures in classrooms created a disparity in how well the studios could be implemented. Classrooms with desks that move or larger tables where groups of students can work together (the latter is preferred), and enough room so that the GTA can readily circulate and interact with students, are critical. Additionally, electrical outlets for laptops and surfaces where a laptop and pencil and paper can simultaneously be used are desirable. With support from Academic Affairs, we have initiated a new course type (studio), and have priority for the subset of university classrooms that are appropriate. The new course type greatly reduces the disparity in delivery of studio. We are currently in the planning stages to systematically design a dedicated studio space.

As implemented, the studio curricular design and support structure also provide a rich educational experience for the GTAs involved. Not only are the GTAs tasked with an authentic teaching experience, but the bi-weekly meetings of the studio personnel provide a forum for TAs to freely discuss their experiences in the classroom with faculty and their peers. Topics included brainstorming solutions to classroom management, development of strategies for facilitating student learning (as opposed to just giving the answer), and an overview of pertinent educational theory that serves as a basis for the studio approach. In fact, much of the theoretical underpinning discussed above was first presented and discussed in the bi-weekly meetings of the studio personnel. It was clear from the discussions in these bi-weekly meetings that GTAs were deeply engaged in their assignments and learning a great deal about teaching and learning. We argue that the experiences of GTAs involved are not typical of the experiences of GTAs in more traditional assignments and represent a significant positive outcome.

Finally, while indicators appear positive, we have only begun and there is much work to do. The content and pedagogy of the studio worksheets are critical. With the studio structure now in place, we can more systematically explore different studio activity designs and their affect on student learning. Identification of a set of threshold concepts and capabilities that are critical for each of the 10 courses would help target that work. We have also begun to develop innovative instructional tools, like interactive virtual laboratories.[20] There

are also issues in implementation that are unresolved. For example, we need to determine what the best approach is to assign studio grades. Being too oriented toward performance creates a high stakes environment that is detrimental to the focus on "process" and the interactive social culture that we are trying to establish. On the other hand, we are concerned that if only participation counts, the level of genuine engagement will not be as great. We hope that iterative incremental improvement will assist us in dealing with such details.

ACKNOWLEDGMENTS

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ChE in memoriam

Tribute to Duncan Fraser
(August 23, 1946 – July 19, 2014)

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My good friend and colleague Duncan Fraser was scheduled to give a keynote address at a chemical engineering student conference in Manila on July 16, 2014. When he was felled by a stroke, the conference organizer asked me if I could step in via the Web, give a synopsis of Duncan's talk, and take questions. I was honored to be asked, and did it. I tried to give the attendees a sense of how Duncan was revered by the large number of his colleagues around the world who knew and valued his immense contributions to our profession. Sadly, he passed away several days after this event. Following is a synopsis of my tribute.

* * *

I first met Duncan Fraser at an engineering education conference in the United States, where I saw him give a talk on his efforts to improve education in the black townships of South Africa. This was still in the apartheid era, when doing anything like that could have caused him a great deal of professional difficulty and raised threats to his personal safety. I was struck by his obviously great sense of ethics and morality and his immense personal courage, and at the same time by his personal warmth, humility, and humanity. I sought him out to express my admiration, and in the years that followed we became good friends.

I first came to South Africa in 1994, right after the end of apartheid. At that time engineering education in South Africa was faced with the hardest challenge faced by any system of higher education in any country in the world. Roughly 10% of their incoming student population—the English and Afrikaner students—were as good as the best students anywhere. Most of the other 90%—the black and colored students—hardly had what would be recognized as a secondary school education, and many of them had English as a second or even a third language and could barely speak or understand it.

I subsequently returned to South Africa several times to give teaching workshops, at which participants would always ask "How can we teach two groups of students with such dramatically different backgrounds and learning needs?" Initially I would say "I don't know—no one has ever done it. When you figure it out, let me know." Within about three years, my answer changed to "Ask Duncan Fraser. Duncan and his colleagues at UCT have developed strategies to take students with every conceivable background and turn them into chemical engineers in not much more time than traditional curricula around the world with much better prepared students take to do it."

There are two important messages to be derived from the life work of Duncan McKenzie Fraser. To those of us on faculties, I propose that if Duncan could overcome the extraordinary obstacles engineering education faces in South Africa, no matter what obstacles to meeting the needs of our students we might confront, we can overcome them. And to our students struggling with the intense intellectual demands and heavy workloads of the chemical engineering curriculum, I suggest that if Duncan's students could overcome their serious background deficiencies and succeed in chemical engineering in South Africa, *you* can do it wherever you are. ❑