AC 2012-3180: USING STUDIOS AS A STRATEGY TO RESPOND TO INCREASING ENROLLMENT

Dr. Milo Koretsky, Oregon State University

Milo Koretsky is a professor of chemical engineering at Oregon State University. He currently has research activity in areas related to thin film materials processing and engineering education. He is interested in integrating technology into effective educational practices and in promoting the use of higher level cognitive skills in engineering problem solving. Koretsky is a six-time Intel Faculty Fellow and has won awards for his work in engineering education at the university and national levels.

Dr. Kenneth J. Williamson, Oregon State University
Dr. Jeffrey A. Nason, Oregon State University

Jeff Nason is an Assistant Professor of environmental engineering at Oregon State University. His research interests are in the area of physical/chemical treatment of water, with a focus on particle removal processes. He is also interested in developing effective techniques for implementing active learning activities in high-enrollment engineering courses.

Prof. Goran Jovanovic Ph.D.
Dr. Chih-hung Chang, Oregon State University

Chih-hung (Alex) Chang is a professor of chemical engineering at Oregon State University. He is a SHARP Labs of America Scholar, and a recipient of Intel Faculty Fellowship, AVS Graduate Research award, National Science Foundation’s CAREER Award, and awardee of W.M. Keck Foundation. His group has studied solution-based thin film deposition processes, ink jet printing, microreaction technology, and x-ray absorption fine structure.

Adam Z. Higgins, Oregon State University
Mr. Craig M. Gates, Oregon State University
Dr. Richard Mark Roehner, Oregon State University

©American Society for Engineering Education, 2012
Using Studios as a Strategy to Respond to Increasing Enrollment

Introduction
Recently chemical engineering programs nationwide have shown significant growth, probably driven by student interest in addressing critical societal needs such as alternative energy production and sustainability. With the increasing student populations, many programs have struggled with serving more students while maintaining effective learning environments. Traditional management approaches are to establish enrollment limits in the programs or to deliver the required classes in multiple sections. This paper reports an alternative approach in which larger lecture classes are punctuated by smaller studios. In the studios, students are afforded the opportunity to actively engage the content presented in the large lectures. This paper presents a description of the first part of a comprehensive implementation of the studio approach that comprises the incorporation of studios in nine classes during the 2011-2012 academic year at Oregon State University. We will provide a description of the studio approach, and analysis of student perception of the first quarter of the widespread studio implementation in three classes: material balances, thermodynamics and fluid mechanics. We will also comment on the administrative support and department culture needed for this type of curricular innovation.

The foundation of the studio architecture is based on the demonstrated effectiveness of active learning pedagogies from the physics education research community. These methods seek to promote a substantially higher level of engagement from students during in-class times. In a recent study, Deslauriers et al.1 studied the effectiveness of active learning reform pedagogies using a split design amongst 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 active learning. 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.” (page 862). Moreover, these activities were imbedded 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 significantly higher in the experimental group.

Other, more comprehensive studies similarly find increased learning in classes that use active learning pedagogies.2,3 Using pre/post-test data of over 6,000 physics students from a valid and reliable concept inventory, Hake4 found that courses that used active learning had normalized learning gains that were twice as large as the gains for classes that used only traditional lectures. Similarly, over a span of thirteen years, Poulis et al.5 studied over 5,000 students in chemical engineering, electrical engineering, industrial engineering, chemistry, and physics classes. They found the pass rate in the classes where active learning pedagogies were used increased by 25% over those classes that used a traditional lecture format. While a few learning scientists have
critiqued these reform methods based on a theoretical foundation,\textsuperscript{6} resistance is far more common from faculty who have not considered the data.\textsuperscript{7}

Curricular reform of “Introductory Physics” classes has successfully incorporated active learning methods for two decades. In some cases, the entire class time is based on an active learning design, such as with the Rensselaer Studio Model\textsuperscript{8} and Workshop Physics.\textsuperscript{9} Recently, these efforts have been expanded to include design of technology-enhanced classroom architectures to support learning, such as with the SCALE-UP project at North Carolina State University\textsuperscript{10,11} and the Technology Enabled Active Learning (TEAL) project at the Massachusetts Institute of Technology.\textsuperscript{12} 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\textsuperscript{13,14} and Collaborative Group Problem Solving.\textsuperscript{15} The implementation of studios reported in this paper is based on the latter model and is described next.

The objectives of the studio implementation include:

1. Provide an environment where a large number of students are engaged in active learning.
2. Design a learning environment that allows strategic and tactical implementation of active learning pedagogies and which allows relatively easy scaling to meet changing enrollments.
3. Provide a scaffolded support structure for GTAs which promotes their integration in class organization and achievement of learning objectives and that allows them to develop their teaching skills, knowledge of how students learn, and increases the value they place in teaching.

\textbf{Studio Architecture and Implementation Design}

In the studio-based curriculum design, classes are divided with studios interspersed between lectures. Figure 1 shows a weekly schedule for a typical 3-credit class with a capacity for 150 students. 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

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{studio_schedule.png}
\caption{Weekly class structure for a typical studio course.}
\end{figure}
to reinforce content from the lecture that was delivered the day before. A few of the activities involve “virtual laboratories” where students collect data on their computers. 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 graduate teaching assistant (GTA) or instructor can circulate around the room, interact with students and teams, 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 recitations, 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 active minority who ask. Students seldom witness or encounter what to do if 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 class time in action to answer conceptual questions, solve problems, explain phenomena from in class demonstrations, work on virtual laboratories, etc. The GTAs or instructors interact with students in a facilitative mode where they ask probing questions designed to enable the students to reflect on appropriate procedures and concepts so that the students themselves can identify what to do next. The emphasis is shifted from having students obtain the “correct” answer to developing their thinking processes 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.

A two phase GTA training program was implemented to help the graduate students understand and be prepared for their role of facilitating learning in the studios. First, all new GTAs were required to attend a university-level GTA orientation. The orientation lasted one full day for all students and was preceded by an additional day for international students. It was designed to be broad to serve the many disciplines in the university and addressed the following topics: instructional policies and procedures, diverse student populations, preparing for the first class sessions, and essential communication skills for the classroom. The day ended with a networking session and a resource fair. Second, an engineering specific half-day orientation followed one week later. This session included GTAs from chemical engineering, bioengineering, environmental engineering, civil engineering, and construction engineering management. The goal of this session was to have GTAs value their role in instruction and understand how their responsibilities fit into the educational approach to facilitate student learning. The group of approximately 40 GTAs was divided into four subgroups that rotated around interactive sessions led by faculty with assistance from senior GTAs. Topics included: the role of the GTA and connections to learning, feedback, academic integrity and classroom management, and microteaching. Appendix A shows the assessment results of the perceived effectiveness of the orientation.

The implementation of the studios is executed by a coordinated team effort. Table 1 shows the members of the team for Fall 2011. Each class has a professor, an instructor who serves as studio developer and manager, and graduate student teaching assistants. Moreover, coordination
between classes and general management of implementation was allocated to two Studio Coordinators. In addition to the pre-term training program for GTAs, there are regular biweekly meetings between the entire instruction team and weekly meetings between personnel in a given class. These meetings contain a broad array of topics, including studio design and delivery; effectiveness and assessment; and uniform delivery, formatting, and grading. One intention is to align the design and delivery amongst classes and between classes. In this way, 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 learning community amongst the instructional personnel. We found that GTAs are eager to participate in such workshops and crave to learn how to be a successful teacher.

<table>
<thead>
<tr>
<th>Class/Role</th>
<th>Lead Instructor</th>
<th>Studio Developers</th>
<th>Studio GTAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Balances</td>
<td>Prof. 1</td>
<td>Instructor 1</td>
<td>GTA 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GTA 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GTA 3</td>
</tr>
<tr>
<td>Thermodynamics</td>
<td>Prof. 2</td>
<td>Instructor 1</td>
<td>GTA 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GTA 5</td>
</tr>
<tr>
<td>Fluid Mechanics</td>
<td>Prof. 3</td>
<td>Instructor 2</td>
<td>GTA 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GTA 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GTA 8</td>
</tr>
<tr>
<td>Studio Coordinators</td>
<td>Coord. 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The heart of the studio learning process centers around the directed student activities, which are done individually or in teams. The activities are focused by the use of studio worksheets (an example in Appendix B). 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 prediction 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 the worksheet. The worksheet development process also can vary, but is ideally completed as follows. The faculty member comes up with a seed idea for the worksheet. The worksheet then is developed in detail by the instructor, based on the pedagogical considerations cited above. It then is completed by the GTAs who will be facilitating the studios. The group of instructors and GTAs then meets to revise the worksheet before delivery in the studio. The studio developer kept a running log of each studio, documenting what went well and what could be improved which serves as feedback to future worksheet development.

**Student Perception of Studio Implementation**

**Method**

As discussed above, the studio structure was implemented in three courses in Fall 2011, a sophomore-level material balances class (labeled mat bal), and junior level thermodynamics 1
(thermo) and transport phenomena 1 (fluids). At the midpoint of fall quarter, students were asked to complete a brief survey to provide their perceptions of the studio experience. Two weeks later they were asked to provide input about the effectiveness of the GTA in their section.

The two surveys consisted of five Likert-scale questions and four free response questions. The five-point Likert-scale questions asked the students if they strongly disagreed, disagreed, were neutral, or agreed, or strongly agreed to the following statements:

1. Studios help me to learn the class material.
2. For the same amount of total time in-class, I would rather have part Studio and part Lecture than all Lecture.
3. The Studio worksheets are too long to complete in 50 min.
4. The TA is a good resource for me to complete the Studio Worksheets.
5. The TA is able to spend enough time with me during the Studio to help with my questions on the Worksheets.

The results for the Likert-scale problems are presented where the positive (agree and strongly agree) and negative (disagree and strongly disagree) responses are aggregated.

The four free-response questions asked the students to:

1. Write down one thing about Studios that helps you to learn.
2. Write down one thing that could improve the Studio.
3. Write down one thing the TA is doing well.
4. Write down one thing that the TA could improve in Studio.

Only the first two of the free response questions are analyzed in this paper. An open-coding approach was taken to identify emergent categories in the data. The instructors identified important themes by examining responses for the two questions from each of the classes. The categories showed general similarity, but had different labels. Both instructors and one of the studio coordinators then met and reached consensus on code categories and definitions for each category. The responses were then recoded with this common rubric. The coordinator then reviewed coding from all classes to ensure consistency.

**Likert-Survey Results**

Figure 2 shows the survey results for the first two Likert-scale questions that inquire about the students' perceptions of the effectiveness of the studios. The response rate for thermodynamics was considerably lower than material balances and fluid mechanics. Both questions show generally consistent results between questions, with positive responses greater than negative responses. Moreover, since the survey was administered at the beginning of the studio project, it is expected that start-up adjustments and normalization of student attitudes would lower the overall perception of the students. The perceptions for the junior-level courses and the distributions between the two classes are very similar despite being implemented by entirely different personnel. Such a result is a positive indicator of the benefits of the systematic implementation plan described above. While the majority of student responses for all three classes are positive, a lower fraction of sophomores perceive value. 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 active 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.

Figure 2. Student perceptions of studios after 4 weeks of instruction.

Figure 3 shows the perceived effectiveness of the GTAs. In general, students agree that the

Figure 3. Student perceptions of GTA effectiveness after 4 weeks of instruction.
GTAs are a good resource (70 – 84%) and about 70% of students agree that the GTA is able to spend enough time with them during the studio. In order to further increase the effectiveness, a survey/probe/guide/confirm model for feedback was discussed at a team meeting.\textsuperscript{15} and GTAs were encouraged to spend less time per interaction, but instead go through many (about 30-40) iterations of facilitative feedback during a single studio.

In developing studio assignments, there is a balance towards accommodating students at different ends of the spectrum of prior knowledge, preparation and quickness of thought. Figure 4 plots 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 felt the studios were too long. Attention was paid to reduce the length in the second part of the term.

![Graph showing student perceptions of studios after 4 weeks of instruction.](image)

**Figure 4.** Student perceptions of studios after 4 weeks of instruction.

**Coding of Free Response Questions**

Tables 2 and 3 show the coding categories for the free response questions. Table 2 shows codes developed for statements where students are asked to write down one thing that helps them learn in studios and Table 3 for one thing that could be improved, respectively. The percentage of coded responses associated with these categories for each of the three classes is shown in Figures 5 and 6, respectively.

As Figure 5 shows, the most common benefit identified is with working in small groups. This view is consistent with a social constructivist view that learning is socially mediated and intimately influenced by the culture and activities in which the learning is situated.\textsuperscript{16} Learning environments that foster collaboration replicate the context of professional engineering practice. Through a process of negotiation and appropriation, individuals can construct richer understanding than they would be able to alone, and such a process is particularly effective in
enhancing conceptual change. In addition to small group interactions, the benefits students identify are consistent with the intent of the studio design. Specifically, the studios provide structure that allows for guidance and help from the GTA and serve as a “bridge” between concepts and content provided in lecture and the ability to apply this knowledge and skill on homework. Finally, a few student statements indicated that the studio environment enhances their self efficacy by increasing their confidence that they can be successful engineers. This final factor may be particularly important for students from demographics that are underrepresented. The alignment between the coded responses and the intent of the studio curriculum design is encouraging.

Table 2. Coding categories for the free response question about how the studios help students learn.

<table>
<thead>
<tr>
<th>Code Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Group Interactions</td>
<td>Working in small groups allows me to get help from fellow students and/or exposes me to different perspectives.</td>
</tr>
<tr>
<td>Guidance and Help from TA</td>
<td>I have a TA available to help me when I get stuck and point me in the right direction.</td>
</tr>
<tr>
<td>Practice in Problem Solving</td>
<td>Studios bridge the gap between lecture and homework. They allow me to work example problems and they reinforce the concepts covered during lectures.</td>
</tr>
<tr>
<td>Self Efficacy</td>
<td>Studios reinforce that I have the capability to become an engineer.</td>
</tr>
</tbody>
</table>

Write down one thing about Studios that helps you to learn.

Figure 5. Coding of written results for the free response question about how the studios help students learn.

Figure 6 shows the frequency of responses for what could be improved about studios. The most frequent response is that students would like more time to work on the studio. Several students even suggested extending the length of their time in studio. As discussed above, the length of the
studio worksheets for Material Balances has been reduced based on the results of this survey; however, for the junior-level courses, there is a tradeoff, and designing studios that all students can comfortably complete may not challenge those students at the top of the distribution. The desire to get more help from the GTA is also consistent with the Likert-scale data and has been discussed above. The desire to learn from posted solutions poses an interesting design dilemma. While such a practice can benefit learning, it must also be assumed that industrious students will catalog such solutions and make them available for future classes. Since it is probably impractical to rewrite the entire suite of studios every year, there is a trade-off between what benefits students in the present class and what benefits all students. The desire of students to have the GTAs review class material and homework in the studio reflects their expectations of what class should look like. We suspect that these responses indicate the struggle students have as they are prompted to change from concrete operations to formal operations, which is discussed next.

Table 3. Coding categories for the free response question about things to improve in the studio.

<table>
<thead>
<tr>
<th>Code</th>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Allotted</td>
<td>Allow more time for me to complete the studio worksheet</td>
<td></td>
</tr>
<tr>
<td>Review Class Material</td>
<td>Use the first part of the studio to review the class material that I will need to apply</td>
<td></td>
</tr>
<tr>
<td>More TA Help</td>
<td>The TA is not readily available for me when I am stuck</td>
<td></td>
</tr>
<tr>
<td>Post Solutions</td>
<td>I would like you to post solutions to the studios after I have completed them</td>
<td></td>
</tr>
<tr>
<td>Homework Review</td>
<td>Use the studios to review how to solve the problems assigned for homework</td>
<td></td>
</tr>
</tbody>
</table>

Write down one thing that could improve the Studio.

Figure 6. Coding of written results for the free response question about how the studios help students learn.
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 operations and formal operations.\(^{18,19}\) Piaget’s theory has recently been supported by research which has documented the continued physiological development of the brain throughout adolescence.\(^{20}\)

Students who depend upon concrete reasoning can be easily identified in engineering courses because of their inability to deal freely with abstract concepts. From Piaget’s theory, concrete reasoning involves:

- **Seriation and classification.** Students are able to associate and select an abstract characteristic to classify or order objects or phenomena (e.g., how to organize a rock collection). This ability allows students to do “story problems” and to choose appropriate equations and variables to solve problems from written material.
- **Transitivity and reversibility.** Students are able to algebraically manipulate equations and to discern relationships between variables knowing that if A is taller than B, and B is taller than C, then A must be taller than C and that if \( Z = X + Y \) then \( Y = Z - X \).
- **Conservation.** Students can understand that certain characteristics can be conserved even in different forms so that logical relationships can be formulated. The content in classes on material and energy balances rely fundamentally on such conservation principles – although conservation of energy is much more complex for students who use concrete reasoning. Fluid mechanics, where conservation of momentum is applied, is extremely difficult for students who use concrete reasoning.

It is our belief that most students who are enrolled in the studio classes have been academically successful because they are highly proficient at concrete reasoning. As such, many students will revert to concrete reasoning when they are frightened or when their abstract reasoning skills fail them. However, this type of thinking limits their development in chemical engineering.

There are four common classroom behaviors that identify that students are trying to solve problems with concrete reasoning:

1. Students will ask for numbers instead of symbols or will not be able to use different symbols for the same entity in different settings. Numbers and the constant use of symbols are just easier to seriate and classify. \( \).  
2. Students cannot identify what quantity to conserve and to include all forms of that quantity. The classical example of this is when students struggle with redox equations where mass and charge are both conserved.
3. Students don't know “where to start” in solving “story” problems which typically means that they cannot identify the appropriate variables to consider or the appropriate relationships/equations needed to solve the problem.

4. Students seek example problems as a method of understanding. Students often attempt to build a catalog of example problems which they can then classify into problem type; new problems are also classified and the solution approach for a given type of problem will then be applied to the new problem whose type is the same. This tendency leads to learning by rote and causes students to inadequately build an integrated knowledge structure.

Formal (or abstract) operations allow students to think more like practicing scientists and engineers. Formal operations involve:

- **Proportional reasoning.** This is the entire manipulation and interpretation of linear multivariable equations. Almost all of our students are good at proportional reasoning. Proportional reasoning problems are typically solved by picking the right equation, manipulating to get the proper isolation of the independent variable and then putting in the number. Students who cannot do proportional reasoning will often fail to account appropriately for unit conversions or struggle with semi-log or log-log plots and their relationships.

- **Probabilistic reasoning.** This is the application of statistics and the nature of variation within a population and a sample. Almost all lower-division students struggle with probabilistic reasoning and have difficulty solving problems where they cannot consider variables as discrete numbers, but must consider a stochastic distribution. Students are primarily confronted with the need for probabilistic reasoning in upper-division lab courses where they need to make conclusions from measured data which are always probabilistic.

- **Propositional reasoning.** This is the classic application of Aristotelian logical statements and Venn diagrams. This type of reasoning rarely shows up in homework type problems, but often can be found in general conversations about personal choices and ethical issues. The lack of propositional reasoning shows up in students being unable to construct logical discussions or essays to reach a supportable conclusion. However, a lack of propositional reasoning skills can be easily found whenever students have to explain why they chose a particular approach (explaining why A is better than B always involves propositional reasoning).

- **Combinatorial reasoning.** This type of reasoning allows students to abstractly consider all the possible combinations that could lead to the solutions. Students who lack this skill often skip necessary experimental runs that “cover all the bases.” They are simply unable to logically determine what all the possible solutions to be considered are. All the possible solutions just do not get on their “radar screens.”

- **Separation of variables.** This form of reasoning is absolutely essential for research and for manipulation of abstract relationships. A lack of this skill is identified when students fail to conduct control experiments or collect data from experiments where multiple variable are changing at the same time. Students who cannot do separation of variables often select the wrong answer in conceptual problems like those used with clickers.
Formal reasoning is more than this or that specific behavior, but is an orientation towards approaching and attempting to solve problems. A person may be able to effectively operate with one of these skills, but struggle with others (it is not unusual to see beginning graduate students forget to separate variables as they begin research). However, formal reasoning is open ended and self-correcting in that it leads through failure and frustration to cognitive growth and development. In the lower division classes, one sees a full range of concrete reasoning and formal operations with concrete (object/number oriented) problems being easier to solve than abstract problems. In general, 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, or 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. However, this transition can be uncomfortable for students. 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 being from students who are comfortable with concrete operations 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 develop formal operations.

**Studios as an Opportunity to Address Threshold Concepts**

Meyer and Land\(^{21}\) have recently introduced *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 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 a more naïve perspective that she/he previously had. 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. \(\Delta u\), 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
hypothesis paths between states allows for efficient collection and organization of experimental data. Once the student’s 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. 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 9 courses need to be identified, and then effective pedagogies need to be developed that effectively promote student learning of this content.

**Discussion and Conclusions**

We report in this paper about the initial stage of a coordinated effort to implement active reform-based pedagogies in nine core classes in the chemical engineering curriculum through the studio initiative. 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 classes but also the GTAs working with the students in the studios as well as other faculty in the school. 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 operations 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 classes.

While there is overwhelming evidence in the literature that this type of reform method is critical, we have reported here only student perception. There seems to be evidence from the student perceptions that is consistent with our intent. For example, 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” is 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 itself. A goal of the studio project is to influence the perspective of problem solving. Ultimately, we would like 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 class in isolation, and implementing them in concert amongst the nine classes 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 each faculty who taught in the fall retained their rich and individual interpretations of what it means to know the subject that they are teaching, they all worked with the team to accommodate a uniform curricular architecture of the studio model. One faculty member who will teach in the winter quarter was also involved in the team meetings. Similarly, many of the school faculty who were not involved stopped one of the team for hallway conversations asking about the use of studios and their success.

At the administrative level, there has been full commitment to provide appropriate staffing for the start-up of this initiative. Additionally, time was allocated at the school retreat and at the industrial advisory board meeting so that there could be an understanding amongst the broad community about the studio initiative. We have also received support from the university administration with studio scheduling. At an early team meeting, it became clear that the variety of classroom architectures created a disparity in how well the studios could be implemented. Classrooms with desks that move or larger tables that 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 class type (cooperative studio), and have our choice of which subset of university classrooms are appropriate. While ultimately it would be nice to systematically design a dedicated studio space, the new class type greatly reduces the disparity in execution.

As implemented, the studio curricular design and support structure provided a rich educational experience for the GTAs involved in the initiative. Not only were GTAs tasked with an authentic teaching experience, but the bi-weekly meetings of the studio personnel provided 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 design. 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 in the studio initiative are not typical of the experiences of GTAs in more traditional assignments and represent a significant positive outcome.

Finally, while indicators appear positive for the studio initiative, 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 impact on student learning. Identification of a set of threshold concepts and capabilities that are critical for each of the 9 classes would help target that work. 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 towards performance creates a high stakes environment that is detrimental to 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.

References
Appendix A: GTA Perception of GTA Training

A description of the four interactive sessions is provided in Table A1. Each session had a group of approximately 10 GTAs. After rotating through the four sessions, the GTAs were given a survey to assess their perceptions of the orientation sessions. A set of questions using a 5-point Likert scale addressed each of the sessions. The GTAs were asked, “Please rate each of today’s sessions by how much you agree with the following statement: This session helped me prepare for and understand my GTA appointment.” 20 GTAs responded to the survey. Figure A1 presents the results where the positive (agree and strongly agree) and negative (disagree and strongly disagree) results are aggregated. In general the response by the GTAs who completed the survey was positive.

Table A1. Description of the domain-specific TA training sessions

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Topic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROLE</td>
<td>Role of the TA / How Activities Connect to Learning</td>
<td>Discussion of the various roles of the TA / how the TA’s role helps facilitate student learning. Faculty expectations of GTAs in various environments and roles</td>
</tr>
<tr>
<td>FEEDBACK</td>
<td>Feedback</td>
<td>Purpose of feedback, grading, use of rubrics, informal feedback, office hours</td>
</tr>
<tr>
<td>CM&amp;AI</td>
<td>Classroom Management and Academic Integrity</td>
<td>Methods of classroom management, code of student conduct, dealing with conflict and academic dishonesty</td>
</tr>
<tr>
<td>MICRO</td>
<td>Microteaching</td>
<td>Students prepare a short (5 min) presentation on topic of choice, present to faculty and other students, receive feedback. Opportunity to practice and receive constructive feedback.</td>
</tr>
</tbody>
</table>

Figure A1. Participant feedback of GTA training sessions
Appendix B: Sample Studio from Material Balances

Name:____________________________________

I. Qualitative Reasoning

Answer the following questions individually

A. Imagine you are on a row boat in the middle of a small lake. In the boat is a large rock. The specific gravity of the rock is 2.7. If you throw the rock out of the boat will it

_____ Sink

_____ Float

_____ Can’t say without more information

Explain your reasoning using appropriate concepts and terminology.

B. After you throw the rock out of the boat, will the water level in the pond

_____ Increase

_____ Stay the same

_____ Decrease

_____ Can’t say without more information

Explain your reasoning using appropriate concepts and terminology.

C. Get together in a group of 2 or 3 students. Compare your answers and reasoning. Write below any changes to your answer or your reasoning.
II. Simulation

A. Staying in your group, go to the following website
   http://phet.colorado.edu/en/simulation/buoyancy and click the “Run Now” button.
   Spend a few minutes familiarizing yourself with the simulation in the “intro” tab.

B. Go to the “Buoyancy Playground” tab. Create a single block of aluminum with a volume
   of 1.00 L and set the fluid density to be that of water (1.00 kg/L).

   What is the specific gravity of the aluminum block? __________

C. Drop the aluminum block into the water.
   What happened?

   Does this agree with your answer to question IA? If not, explain why.

D. In the Buoyancy Playground, create a second block made of wood with a volume of
   10.00 L. Leave the fluid density to be that of water. Use the wood block to simulate the
   rowboat. Drop the wood block into the water and load the aluminum block on top.

   What is the water level in the pond? __________ L

   What are the magnitudes and directions of the forces acting on the “boat”? Be sure to
   appropriately label and report units for the forces.
Drop the aluminum block into the water. What is the resulting water level in the pond?

__________ L

Does this agree with your answer to question IB? If not explain why.

III. Generalization/Practice

Work on the following problems individually. You can discuss with your neighbor if you get stuck, but try to do as much as you can by yourself.

A. Draw and label a picture depicting the system described in problem 3.9 from F&R (before and after the object has been removed from the boat).

B. Draw and label an appropriate force diagram on the boat before and after the object has been jettisoned.

C. Using appropriate symbols, write out the force balance for the boat with and without the object as described in part B.
D. Reflect on what additional equations/relationships you need to answer part a of Problem 3.9. Summarize your thoughts and the results of any conversations you had with your neighbors below.
E. Complete problem 3.9a as part of homework for this week. In addition, answer the following questions and turn in with your homework

How would your answers to questions IA and IB be different if instead of a rock you had a large piece of wood with a specific gravity of 0.40 in the boat? Explain.

Use the Buoyancy simulator to check your answer.