121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014

Paper ID #10575

Studio-based Learning in Multiple Material/Energy Balance Classes

Dr. Richard L. Zollars, Washington State University

Richard Zollars has been on the faculty at Washington State University for 36 years. Prior to that he served on the faculty at the University of Colorado and worked with the Union Carbide Corporation.

Studio-based Learning in Multiple Material/Energy Balance Classes

The material/energy balance class in chemical engineering is described by a number of terms. Faculty call it a gateway class; students call it a flunk-out class. By whichever description, the fact remains that the number of students who successfully complete the class is much smaller than either the faculty or students would like. For the past decade we have been using a number of different techniques to determine whether any of them are effective in raising the percentage of students who will successfully complete this class. The most recent efforts have been focused on using a studio-based approach in the material/energy balance class.

For more than a century, studio-based learning techniques have been used in variety of disciplines, most often in architecture and fine arts. In a studio-based learning experience, students learn not just by doing, but also by receiving critiques on their work from both students and experts, as well as providing critiques to other students. Engineering students often do this in informal settings (e.g., study groups) but rarely do so in a formal classroom setting. The critiquing activity is the strength of the studio-based learning process, as it requires students to evaluate and explain (teach) the material to others, thus strengthening their own understanding of the concepts.

To implement this approach, a team from the chemical engineering program and the computer science program have been working on developing two software packages to aid students in developing their skills in the material and energy balance course in the chemical engineering curriculum. The first of these (Chemical Process Visualizer – ChemProV) is a software package developed to assist students in converting written descriptions into a graphical format and then into a mathematical representation. It also provides a common format representing solutions to material/energy balance problems. The second software package (Online Studio-Based Learning Environment – OSBLE) provides a means whereby ChemProV solutions can be shared and discussed in an asynchronous online environment.

With the development of these two packages, we have implemented a studio-based approach in our material/energy balance class. In addition, we are working with seven other chemical engineering programs in implementing a studio-based approach in their material/energy balance classes. All eight programs have agreed to make comparisons of the knowledge gained, retention, and student attitudes between a typical class approach and a studio-based approach.

Studio-Based Learning

Studio-based learning (SBL) techniques have been used in a variety of disciplines, most notably in architectural education.[1] The technique is rooted in a type of constructivist learning theory called sociocultural constructivism.[2] The studio-based approach typically encompasses four key steps (see Figure 1).[3] First, students are given complex and meaningful problems for which they have to *construct* solutions. Second, students *present* their solutions and justifications to the entire class for discussion and feedback. Third, students' peers *critique* their solutions and provide comments. Finally, students are given the opportunity to *respond* to these comments and criticisms, and to modify their solutions appropriately.

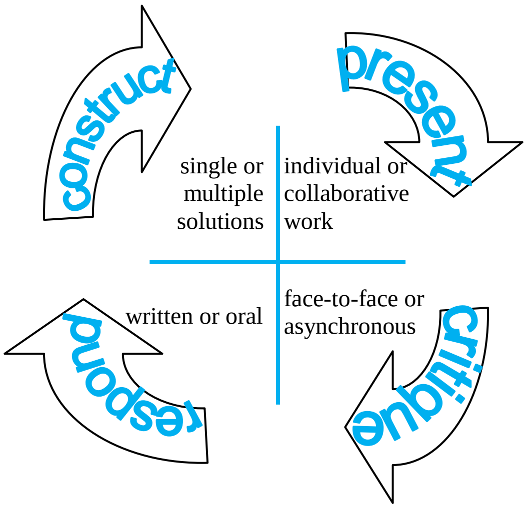

Figure 1. Schematic of SBL Model

Note that SBL, as defined above, differs from a variety of other instructional techniques that also use the terminology "studio". Among the more notable is the Scale-Up[4] program introduced at North Carolina State University. In Scale-Up programs students experience a mixture of presentations, desktop experiments, web-based assignments and collaborative exercises while working in small groups using networked laptops (studio labs). Others have recently reported on a similar approach in chemical engineering where an active learning studio session is integrated with a more traditional lecture portion of a class[5]. These approaches require active participation by the student as well as providing an open-ended problem-solving environment. However, while the critiquing and response aspect of SBL may take place in these approaches, they are not required components of the approach.

SBL is clearly an "active" learning technique. As has been cited by many authors, and summarized by Prince,[6] active learning provides a much fuller educational experience. In addition to the several advantages of being an active learning technique, SBL also addresses all six cognitive levels of Bloom's taxonomy.[7] Of particular importance is the critique phase of SBL wherein the *Evaluation (Evaluate)* level of the taxonomy is clearly invoked. This aspect of learning is not incorporated in many active learning procedures but clearly is an essential part of SBL.

A drawback to the implementation of SBL in a traditional class is that it is time-intensive. As the title suggests, this technique has most frequently been used in studio-based classes. The class time allotted for studio sessions is more typical of that for a laboratory class in engineering—two to three hours. So while the SBL approach might work in a class for which an extended recitation section is part of the class, the time constraints inherent in a typical one-hour class would seem to be a large impediment to using SBL. With the advent of asynchronous communication media, this no longer need be a barrier.

Prior Work

The desire to seek improvements in teaching strategies in material/energy balance classes started with the observation that approximately 35% of the students enrolling in such classes either dropped out of the class, failed the class or received a grade lower than a "C" (a necessity to continue taking classes in chemical engineering at this university). This statistic seemed to be constant no matter who taught the course and also appeared to be the situation at other universities.

In 2006 a diagnostic activity was performed in which pairs of students from the material/energy balance course were observed solving problems typical of the class. During these observations it was noted that students struggled with two major problems— translating the written problem descriptions into an appropriate graphical representation (process flow diagram) then translating the information from the diagram into mathematical expressions.[8] The difficulty in obtaining important information from a verbal description is in line with the observation by Felder and Silverman that the majority of engineering students have a preference for a visual rather than a verbal learning style.[9]

This observation led to the development of a software tool designed to provide a scaffolded environment to help the students through these two translations. In creating ChemProV, we wanted to aid the students in building their own skills in transforming written information into visual form, without giving them so much aid that the software becomes a crutch. Grounded in the learning theory of Vtogsky,[10] this approach is in line with a rich legacy of software scaffolding approaches[11,12] in which learners are initially aided by modifications to problems that make them initially more doable; the modifications are then gradually removed as learners gain more skills. The tool would, in addition, give students an opportunity for early success in the material/energy balance class, leading to enhanced learning according to self-efficacy theory.[13]

In 2008 and 2009, we conducted a laboratory experiment to assess the effectiveness of ChemProV. To conduct this experiment, we divided the material/energy balance class into four groups. Two different material balance problems, of equal difficulty, were developed. Each group was asked to solve the two problems: one problem to be solved using a full version of ChemProV and the other problem using a version of ChemProV with the feedback messaging system turned off. It is through the feedback messaging system that the scaffolding is provided for the students. The version of ChemProV used and the order of the problems solved were fully mixed.

As shown in the figure below, the use of ChemProV did result in improved problem solving.[14] The group that solved their first problem using the full version of ChemProV (labeled "Feedback First") had a statistically significant improvement in solution accuracy when compared with the group using ChemProV without the feedback messages (labeled "No Feedback First"). When the group that did not have the full version of ChemProV now solved the second problem, using the full version of ChemProV, the accuracy of their solutions also showed a statistically significant improvement in accuracy. Most importantly, the group that used the full version of ChemProV first then used the version of ChemProV without the feedback messages for their second problem (the Feedback First results shown for Task 2) showed improved accuracy when solving the second problem (without the feedback messages), while continuing to outperform the other group of students at a statistically significant level. These results demonstrated that ChemProV was satisfying its desired goals. It provided a learning environment in which students could learn the skills needed to successfully solve material/energy balance problems. In addition, these skills remained with the students in situations where no feedback was being provided. Although not shown above, a second observation was that using the full version of ChemProV resulted in significantly more time on task when compared with time on task for the no feedback version of ChemProV.

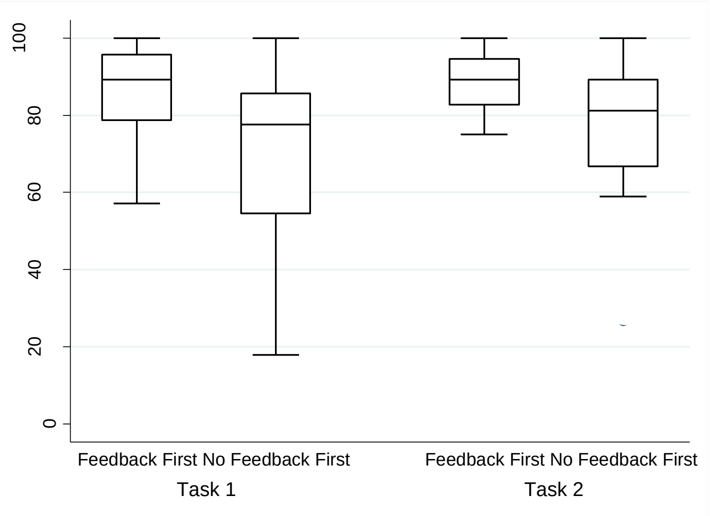

Figure 2: Box plot of solution accuracy by condition and task

Incorporating SBL into Material/Energy Balance Classes

While the results described above were encouraging, the development of ChemProV also opened the opportunity for overcoming the difficulties in using SBL in a material/energy balance class. In 2011 we conducted an empirical study in which a group of students from an introductory chemical engineering class used ChemProV to solve a typical material balance problem, and to present their solutions to the class for feedback and discussion. ChemProV plays an important role in implementing the SBL approach by providing a common tool and format for solving material and energy balance problems, and for presenting solutions for feedback and discussion. This made it easier for the groups to understand what the presenting group was trying to accomplish and thus easier to offer suggestions about how to solve the problem if the presenting group was stuck, correct any errors in the solution that was presented, or suggest alternatives to the solution offered. No attempt was made to assess the effectiveness of the SBL approach during this trial, but attitudinal surveys indicated that the students liked the format and felt they had learned from the experience.

An interesting observation arose when comparing the results between the two alternative versions of ChemProV used in this study. In the first study session, the groups used a full version of ChemProV when solving their problems. In the second session, a different set of groups used a version of ChemProV without the feedback messaging. During the critiquing portion of the evening, when the full version of ChemProV had been used, the discussions among the groups were rather limited. Often this resulted from the fact that ChemProV had provided enough guidance that the solutions presented were full and correct. The solutions presented during the second study session were not as complete and contained more areas where either the groups could not find a solution or had an error in their solution. The resulting discussions were much richer and involved more of the students.

In order to make it possible to implement SBL *asynchronously and online,* we have integrated ChemProV with OSBLE, an online learning management environment developed in prior research.[15] OSBLE supports three user interfaces: (a) student; (b) instructor; and (c) moderator. Students can submit problem solutions (using ChemProV) to be reviewed through the system. Once they have done so, their solutions become "locked": they may no longer modify them, but they now have access to the solutions of other students. Following their submission of a solution, a period of on-line review can begin. Students view the solutions of others, identify issues with those solutions, and comment on those issues.

To test the impact of SBL implemented using the ChemProV/OSBLE combination, seven other universities have agreed to participate in a multi-year quasi-experimental study. At these seven schools the participating faculty agreed to teach their material/energy balance class in their normal fashion during the 2012-2013 academic year. This would be followed by using a SBL approach, implementing ChemProV/OSBLE, during the 2013 – 2014 academic year. At this university (the lead institution on this project), however, the material/energy balance class was taught in its normal fashion during the 2011 – 2012 academic year and using a SBL approach in both the 2012 – 2013 and 2013 - 2014 academic years.

The implementation of the SBL approach in the material/energy balance class was performed in the following fashion. At the sixth week of the semester, just after the students had begun to be exposed to solving material balance problems with no chemical reactions or recycle streams, we conducted an SBL training activity in class. In this training activity, students were given a solution to the following problem.

> *An air stream, containing 10.0 wt% acetone and 90.0 wt% air, enters a scrubber at a total flow rate of 1.00×10^3 lb_m/min. In the scrubber this stream is mixed with a water stream. The water stream entering the scrubbing unit consists of a fresh water feed and a recycled water stream coming from another unit (to be described later). Two streams leave this scrubbing unit; a liquid stream containing only water and acetone and a gas stream containing air, water and acetone. The gas stream leaving the scrubbing unit is discharged to the air. This gas stream contains 1.60 wt% water. The liquid stream leaving the scrubbing unit is sent to a second unit where it is heated to produce a gas stream and a liquid stream. The gas stream leaving the heater contains only acetone. It also contains 99.0% of the acetone that enters the system. The liquid stream from the heater is recycled and is mixed with the fresh water to form the water feed entering the scrubber.*
>
> *Find the unknown values for all streams?*

The solution contained a number of intentional errors. Attached to the solution was a small packet of Post-it®'s in one of four different colors. The students were given ten minutes to examine the solution, find areas where they disagreed with the solution, write on a Post-it® where they disagreed with solution, what the disagreement was, and how to change the solution to resolve the disagreement. Each place where they found a disagreement was to be noted on a separate Post-it®.

During this time large Post-it®'s, containing the same solution that had been distributed to the students, were posted around the classroom. Students then were instructed to assemble in groups of four in front of these large Post-it® solutions where each student in the group had to have a different color small Post-it®. They then stuck their individual comments on the large solution at the appropriate place. With all of the students' comments on the large Post-it® it was now easy to see where there was agreement amongst the students about problems with the solution as well as places where the students disagreed. As shown in Figure 3, there were areas where there was almost unanimous agreement between the students as well as other areas where only one student identified a problem with the solution. This was followed by a 15 minute period during which the students were to discuss amongst themselves places where they were in agreement about a problem with the posted solution as well as places where there was not agreement. The consensus of these discussions was noted by one of the students in the group (a scribe selected on the basis of the color of the Post-it® they had used). These consensus statements were recorded on a white Post-it® and attached to the large solution at the appropriate place.

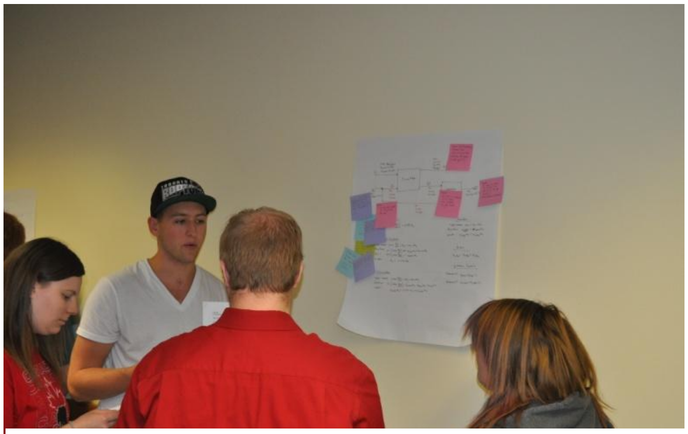

Figure 3: Students Involved in Studio-Based Learning Training Activity

This classroom session mirrored the online activities that were to follow in the class. Students were assigned a typical problem to solve using ChemProV. Their solutions were submitted using OSBLE. After the due date for submission one-third of the solutions were randomly selected for review by groups of three students. The students used the electronic Post-it® functionality in ChemProV to make their comments just as they had with the actual Post-it® during the class. Once a student had submitted their electronic Post-it® comments, they could then see the comments of others within their review group. Using the online discussion facilities of OSBLE, each member of the review group then could comment on areas of agreement and disagreement among the comments submitted by all review group members. Unlike the classroom activity, students were free to add to the discussion at any time rather than being confined to the class period. After one week, however, the students were instructed to come to a consensus and the review discussion was closed.

There were three ChemProV/OSBLE assignments during the semester. The first of these involved a material balance problem with no recycle and no energy balance. The second involved a material balance problem with recycle but no energy balance. The final problem involved both material and energy balances for a system involving a recycle stream. Each time one-third of the initial student submissions were randomly selected for review, making sure that no student had more than one of their problem solutions reviewed. The identity of the student submitting the solution, as well as all members of each review group, was kept anonymous. The members of the review groups were also randomized so that the same groups were not commenting on all three solutions.

In order to encourage a full discussion the TA's in the class were assigned the role of a moderator. As moderators the TA's were encouraged to review the student's comments and encourage pursuit of relevant topic strings without providing evaluative comments. To be effective as moderators, the TA's were provided a short training exercise prior to their participation.

Evaluation Procedure

Evaluation of the impact of SBL on instruction in the material/energy balance class is proceeding as follows. At the start of the semester, the participating faculty will give both a problem in a standard format and a critiquing problem (similar to that shown above) to the students in the class. The level of the problems will be selected from among three levels, to be commensurate with the expectations of what the students should know by the end of that class (e.g., material balances only or material and energy balances). At the end of the semester the students are given the same two problems again. Scoring rubrics have been developed for all problems so that the pre- and post-class problem results can be compared to determine how much the students have learned. The amount of change from the first academic year of the study (normal teaching strategy) can then be compared with the change from the second academic year (OSBLE/ChemProV).

In addition to these results students are also asked to complete attitudinal surveys at both the start and the end of the class. To measure attitudinal changes, we used modified forms of the Motivated Strategies for Learning Questionnaire (MSLQ)[16] coupled with the Classroom Community Scale (CCS)[17]. The results of these surveys can be combined with the comparison of pre- and post-class problem results described above as well as data from the class (average grade, percent retention, etc.) to assess the impact of the SBL approach. This data will be collected from the eight participating programs. Should significant differences in the results appear between programs the results can be analyzed on a program by program basis rather than being pooled.

Representatives from the eight schools involved in this study have now attended three workshops, each held just prior to the annual ASEE meetings. The first of these, held on June 25 – 26, 2011 in Vancouver served to introduce the participants to ChemProV, the IRB requirements for the study, and the intended plans for the study. The second workshop, held on June 9 – 10, 2012 in San Antonio, was used to introduce the participants to the SBL approach, work on assessement activities, and receive feedback about the prior year. The third workshop, held on June 22 – 23, 2013 in Atlanta, GA, provided the opportunity to review the implementation of the SBL at the lead university for the project as well as to finalize the materials to be used during the 2013 – 2014 academic year.

As a result of these workshops the following plan was implemented. During the 2011 – 2012 academic year the lead univeriesty conducted their material/energy balance class in their normal fashion. During the 2012 – 2013 and the 2013 – 2014 academic years the SBL approach was implemented. For the other participating universities the material/energy balance classes were conducted in their normal fashion for both the 2011 – 2012 and the 2012 – 2013 academic years with the SBL appraoch implemented during the 2013 – 2014 aademic year. In all cases the students in the classes completed both the pre- and post-class problems (both the normally formatted problem and the critiquing problem) as well as the pre- and post-class surveys.

Another activity at the 2012 workshop was a calibration of the scoring rubric to be used when assessing the quality of the student solutions for both the normally formatted and the critiquing problems. The scoring rubric for the regularly formatted problems breaks the scoring into three areas – construction of the process flow diagram, specification of stream components and quantities, and development of the balance equations. Scoring of the critiquing problems is a yes (they did identify the error included in the problem) or no (they did not) decision with the score being the number of yes's. The calibration was accomplished by giving the participants sample solutions to pre- and post-class problems, along with the scoring rubric, and having them score the results. This was followed by a comparison of the scores and a discussion of why each participant scored the problem in the manner that they did. This was followed up by a second round of scoring, performed after the conclusion of the workshop. Using the discussion conducted at the workshop as a basis, the scores given by the participants now show a much closer agreement.

Results to Date

To date only the survey results from students enrolled in the material/energy balance class at Washington State University have been analyzed. This includes 47 students in 2011, 71 students in 2012, and 85 students in 2013.

Attitudinal Data

Survey questions were drawn from several questionnaires to assess students' perceptions at the beginning and ending of each semester. The Motivated Strategies for Learning Questionnaire (MSLQ)[16] was used to assess students' beliefs about *Task Value* (e.g., I think I will be able to use what I learn in this course in other courses), *Self-Efficacy* (e.g., I'm confident I can understand the basic concepts taught in this course), *Critical Thinking* (e.g., I treat the course material as a starting point and try to develop my own ideas about it), *Peer Learning* (e.g., When studying for this course, I often try to explain the material to a classmate or friend), and *Intrinsic Goal Orientation* (e.g., In a class like this, I prefer course material that really challenges me so I can learn new things). Students responded to these questions using a 7-point Likert scale.

Students' task goals for *Mastery Goal Orientation* (e.g., I like school work that I'll learn from even if I make a lot of mistakes) were assessed using questions from the Patterns of Adaptive Learning Scales[18] (PALS;). The PALS questions required students to respond to the questions using a 5-point Likert scale.

Students' perceptions of the classroom environment, including *Classroom Connectedness* (e.g., I feel connected to others in this course) and *Classroom Learning* (e.g., I feel that I am encouraged to ask questions), were assessed using the Classroom Community Scale (CCS)[17]. The CCS questions are based on a 5-point Likert.

Finally, students were asked to respond to the following question "After taking this course, how likely are you to continue pursuing a degree in Chemical Engineering?" using a 5-point Likert scale. Their responses to this question were used as an indicator of their *Persistence* in the major.

Within Year Analysis

For each academic term (2011-2012, 2012-2013, 2013-2014), a within year analysis was conducted to determine whether students' opinions changed across time and if there were any main effects based upon other factors (Gender, Race, and Major). Two things should be noted. First, the 2011-2012 data does not include data gathered regarding the students' major, thus these are not reported. Secondly, the material/energy balance class under review has students majoring in both Chemical Engineering and Bioengineering.

In 2011, analyses of students' *Peer Learning* scores revealed a significant Gender interaction, reflecting the tendency for women's scores to decrease and men's scores to increase from pre-test to post-test. Students' *Classroom Connectedness* scores increased significantly from pre-test to post test. Accounting for Gender and Race *Classroom Connectedness* increased for Caucasian males and females and Asian males.

In 2012, the results were mixed with interactions based upon the specific demographic variables (Gender, Race, or Major). For instance, *Task Value* scores decreased significantly. *Intrinsic Goal Orientation* scale scores also decreased. *Peer Learning* reflected the tendency for women's scores to decrease and men's scores to increase. *Classroom Connectedness* was driven by the fact that Caucasian students showed declines in scores if they were Chemical Engineering students but increases if they were Bioengineering students.

In 2013, the attitudinal scores were again mixed. For example, *Task Value* scores were found to decrease significantly. *Critical Thinking* results were mixed, with women's *Critical Thinking* scores decreasing whereas men's scores increased.

The differences between Chemical Engineering and Bioengineering students were obvious throughout many of the scales. For example both female and male Chemical Engineering students' *Critical Thinking* scores increased while both female and male Bioengineering students' scores decreased. Yet another example is found with *Classroom Connectedness*. Connectedness scores decreased if students were female Chemical Engineering majors, but increased if they were a female Bioengineering major. In contrast, males' *Classroom Connectedness* scores increased regardless of whether they were a Chemical Engineering major or a Bioengineering major.

Between Year Analysis

Given the differences that were observed for each scale in the within year analyses, we examined whether these effects would also be observed if all three years were examined simultaneously. Again, the results were mixed and often contingent upon the demographic variable and its interactions with the assessments. Collapsing across all three years of data, it was found that *Task Value* scores decreased significantly. The *Self-Efficacy* scores were found to differ as a function of both Race and Major. For instance, Asian and Hispanic students both showed increases if they were Chemical Engineering majors, but a decrease if they were a

Bioengineering major. Analyses of students' *Critical Thinking* scores yielded a significant interaction with Gender. Women's *Critical Thinking* scores decreased whereas men's scores increased. Similar results are found with *Peer Learning* where females' scores decreased whereas males' scores increased.

Summary

Although both the within year and between year analyses indicate that a number of scales show changes, only for half of the scales was the Pre-Post factor found to interact with Year and so, therefore, with exposure to SBL (*Task Value*, *Mastery Goal Orientation*, *Classroom Connectedness*, *Classroom Learning*, as well as *Persistence*). This suggests that for the other scales (i.e., *Self-Efficacy*, *Critical Thinking*, *Peer Learning*, and *Intrinsic Goal Orientation*) the patterns remain relatively stable across years. Again, the stability across years indicates that there are no changes resulting from the use of SBL.

The between year analyses revealed only one main effect (*Task Value*), but the within year analyses revealed main effects in several instances (e.g., *Classroom Connectedness* in 2011, *Task Value* and *Intrinsic Goal Orientation* in 2012, and *Task Value* in 2013). This suggests that the most stable impact of the studio-based learning environment is the impact it has on students' views of *Task Value*. Unfortunately, the stable impact of the new instructional technique was to yield a decrease in students' perceptions of the class' *Task Value*. However, even *Task Value* scores were found to vary as a function of Major, Race, and Gender. This suggests that these *Task Value* scores, as well as those from other scales, must be evaluated in light of the demographic characteristics of the students who provide those scores. Only by considering how these factors might affect students' perceptions of the new instructional technique can we begin to gain a better understanding of when this method can be expected to help or hinder students' learning. From a preliminary standpoint, the data is incredibly mixed and needs to be correlated to other assessments from the class including overall course grade. This analysis may shed light upon the unique differences between specific sub-groups within the class.

Qualitative Data

As part of the overall research for this project, all participants were asked to complete a series of 50 qualitative questions. The questions were either "yes/no" questions or open-ended questions related to specific aspects of the course. The qualitative questions can be sub-divided into the following areas:

- Expectations
- Impact on learning through specific experiences
- Interest in chemical engineering
- Social interaction
- Confidence and comfort in receiving and providing feedback

For the qualitative aspects of the research, all data was collated based upon the question groupings. For "yes/no" questions, the answers were quantified using basic descriptive statistics. For all open-ended responses, the responses were reviewed using "constant-comparison" methods, a systematic process of breaking down discrete "incidents" or "units" and coding them into categories.[19] Through constant comparative analysis, the units are refined until "themes" are exposed from the data. Thus, the open-ended data was processed through multiple iterations in search of exposing noticeable themes for each year.

Out of the five "themes" listed above, only two showed qualitatively focused themes related to the research of this project.

Social Interaction. Across all three years, the students seemed to grow in the social interaction domain. There were many students who referred to themselves as "extroverts" and stated that the course had little impact on their social interactions. However, there were some notable statements from students who considered themselves to be "introverts". They admitted that the course forced them to become more social. What is interesting is that this happened in all three years, including the traditional year. For 2011, it was noted that the social interaction was based upon an interdependence developed through study groups. For 2012 and 2013, while the study groups did continue, many of the students noted that they were forced to communicate with other classmates more often due to the studio-based approach to instruction. However, the 2013 cohort mentioned that it preferred "face-to-face" opportunities to the online interactions. Yet, many of the students understood and appreciated the online interactions.

Confidence and comfort in receiving and providing feedback. The most notable differences in responses were found in this domain. For 2011, the students expressed that they had limited opportunities to provide and receive feedback from their peers. Thus, they often did not understand the questions and felt that the course did not really build their confidence or comfort in doing so outside of the typically "getting to know people better" construct. During 2012 and 2013, the student’s attitudes changed drastically. Due to being forced to provide and receive feedback from classmates, the students overwhelmingly stated that their confidence and comfort in receiving and providing feedback increased. While they missed the face-to-face interactions with their classmates on the problems (and the discussions connected to them), they stated that being forced to exchange feedback had many positive aspects. Most notably, a few students noted that it "helped me feel better about myself because I saw that it was challenging to everyone else". Many noted that the online environment was "basically just a study group online". This analogy was discussed as neither negative or positive, just a description of the framework.

Retention

One factor that can be assessed is the impact of the SBL approach on student success/retention in the material/energy balance class at this institution. For approximately 20 years prior an average of 35% of the students initially enrolled in the material/energy balance class either withdrew or received a grade lower than “C” in the class. Receiving a grade of “C” or better is required in order for students to take further classes in the major. In 2012 only 25 of 106 (24%) were unable to continue with classes in chemical engineering as a result of a low grade in the material/energy balance class. In 2013 the percentage dropped further with only 19 of 104 (18%) failing to get a “C” or better.

Conclusion

Studio Based Learning (SBL) offers many advantages for student instruction. In addition to being an active learning technique the construct-present-critique-respond cycle within SBL addresses all six cognitive levels of Bloom's taxonomy. An impediment to the incorporation of SBL in a typical class is the time constraint imposed by the usual one-hour long time block for most classes. We have combined two software programs to overcome this difficulty. ChemProV is a scaffolded learning tool that has demonstrated effectiveness in assisting student learning in material and energy balance classes. OSBLE is an on-line learning management environment that allows the implementation of SBL outside of the classroom. OSBLE provides the potential for SBL outside the usual one-hour class time constraint, while ChemProV provides a structured environment that makes communication of material/energy balance problems easier. Faculty from eight institutions are involved in assessing the impact of SBL on their material/energy balance classes. At the PI's institute baseline data was collected in the 2011 – 2012 academic year. The same evaluations were used again following the implementation of an SBL approach at this institution in 2012 – 2013 and 2013 – 2014. A partial analysis of these data shows mixed results for the impact of SBL on the student's knowledge and attitude in the material/energy balance class. Retention data from this institution indicate that the percentage of students not making satisfactory progress in the material/energy balance class has dropped to half its prior value after implementing the SBL approach.

Literature Cited

[1] E. L. Boyer and L. D. Mitgang, *Building Community: A New Future for Architecture Education and Practice*, Princeton, NJ, The Carnegie Foundation for the Advancement of Teaching, 1996.

[2] J. Lave and E. Wenger, *Situated Learning: Legitimate Peripheral Participation*, New York, Cambridge University Press, 1991.

[3] C.D. Hundhausen, N.H. Narayanan, and M.E. Crosby, "Exploring Studio-Based Instructional Models for Computing Education," *Proc. 2008 ACM Symposium on Computer Science Education*, 392, New York, ACM Press.

[4] M. Oliver-Hoyo and R Beichner, "The SCALE-UP Project," *Teaching and Learning through Inquiry: A Guidebook for Institutions and Instructors*, edited by V. S. Lee, Stylus Publishing, Sterling, VA, 2004.

[5] M. Koretsky, K. J. Williamson, J. A. Nason, G. Jovanovic, C-H. Chang, A. Z. Higgins, C. M. Gates, R. M. Roehner, "Using Studios as a Strategy to Respond to Increasing Enrollment," *Proc. ASEE Annual Conference and Exposition, June 10 – 13, 2012.*

[6] M. Prince, *Journal of Engineering Education*, **93**(3), 223 (2004).

[7] B. S. Bloom, M. D. Engelhart, E. J. Furst, W. H. Hill, and D. R. Krathwohl, *Taxonomy of Educational Objectives: The Classification of Educational Goals; Handbook I: Cognitive Domain*, New York, Longmans, Green, 1956.

[8] R. L. Zollars, C. D. Hundhausen, and M. Stefik, "Visual Learning in a Material/Energy Balance Class," *Proc. ASEE Annual Conference and Exposition, June 24 – 27, 2007.*

[9] R.M. Felder and L.K. Silverman, "Learning and Teaching Styles in Engineering Education", *Engr. Education,* **78**(7), 674 (1988).

[10] L. S. Vygotsky, *Mind in Society*, Harvard University Press, Cambridge, MA (1978).

[11] C. Quintana, B. Reiser, E. Davis, J. Krajcik, E. Fretz, R.G. Duncan, E. Kyza, D. Edelson, and E. Soloway, "A Scaffolding Design Framework for Software to Support Science Inquiry", *Journal of the Learning Sciences*, **13**, 337 (2004).

[12] M. Guzdial, “Software-Realized Scaffolding to Facilitate Programming for Science Learning”, *Interactive Learning Environments*, **4**, 1 (1994).

[13] A. Bandura, “Self-Efficacy: Toward a Unifying Theory of Behavioral Change”, *Psychological Review*, **84**, 191 (1977).

[14] C. D. Hundhausen, P. Agrawal, R. L. Zollars and A. Carter, “The Design and Experimental Evaluation of a Scaffolded Software Environment to Improve Engineering Students' Disciplinary Problem-Solving Skills”, *Journal of Engineering Education*, **100**(3), 574, (2011).

[15] C.D. Hundhausen, A. Agrawal, and K. Ryan, “The Design of an Online Environment to Support Pedagogical Code Reviews”, *Proc. 2010 ACM Symposium on Computer Science Education,* 182, New York, ACM Press.

[16] P. R. Pintrich, D. A. F. Smith, T. Garcia, and W. J. Mckeachie, “Reliability and Predictive Validity of the Motivated Strategies for Learning Questionnaire (Mslq)”, *Educational and Psychological Measurement*, **53**(3), 801 (1993).

[17] A. P. Rovai, “Development of an Instrument to Measure Classroom Community”, *Internet and Higher Education* , **5**(3), 197 (2002).

[18] C. Midgley, M.L. Maehr, L. Z. Hruda, E. Anderman, L. Anderman, K. E. Freemen, et al., (2000) "Manual for the Patterns of Adaptive Learning Scales (PALS), The University of Michigan.

[19] Y. Lincoln and E. Guba (1985). *Naturalistic Inquiry*, Beverly Hills, CA: Sage Publications.