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# Use of Studio-based Learning in a Material/Energy Balance Class

**Dr. Richard L. Zollars, Washington State University**

Dr. Richard Zollars is a professor in and associate director of the Gene and Linda Voiland School of Chemical Engineering and Bioengineering at Washington State University. He received his Ph.D. from the University of Colorado. He has been teaching engineering for 35 years. His interests are learning styles, colloidal/interfacial phenomena and reactor design.

**Dr. Christopher Hundhausen, Washington State University**

Dr. Chris Hundhausen received the B.A. degree in Math/Computer Science from Lawrence University in Appleton, Wis. in 1991, and the M.S. and Ph.D. degrees in computer and information science from the University of Oregon in 1993 and 1999. Recipient of a National Science Foundation CAREER Award, Dr. Hundhausen is founder and director of the Human-centered Environments for Learning and Programming (HELP) Lab at Washington State University, where he's an associate professor in the School of Electrical Engineering and Computer Science. His research focuses on the general area of human-computer interaction with specific interests in computer-based visualization, end-user computing, educational technology, and computer science education. Dr. Hundhausen has established himself as an international leader in the field of algorithm visualization, which explores technology and pedagogical approaches that enhance human understanding of computer algorithms. He is also one of the leaders of a national effort, funded by the National Science Foundation CPATH and CCLI programs, to adapt studio-based instructional methods for undergraduate computing education and chemical engineering education.

**Mr. Adam Scott Carter, Washington State University**

# Use of Studio-based Learning in a 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 other students 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 learning activities in studio-based learning as it requires students to be active as well as encouraging students to evaluate and explain (teach) the material to others, thus strengthening their own understanding of the concepts.

Over the past few years 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 single format for the communication of the solutions to material/energy balance problems between students . The second software package (On-Line Studio-Based Learning Environment – OSBLE) provides a means whereby the ChemProV solutions can be shared between students in an asynchronous online environment.

## 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 comments and criticisms, and to modify their solutions appropriately.

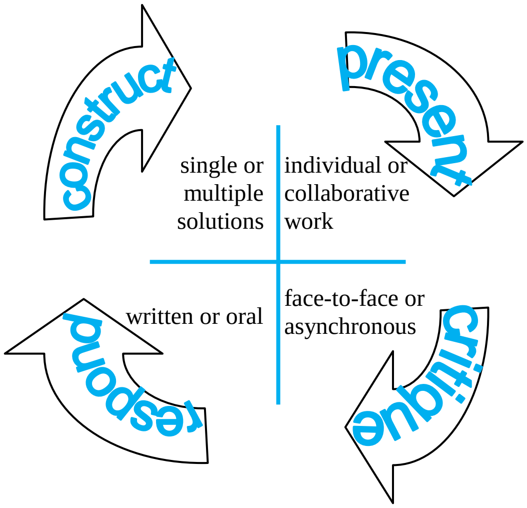

**Figure 1.** Schematic of SBL Model

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 do 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* 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. Thus 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". 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 (Chemical Process Visualizer), 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]

Unlike typical process simulation packages (HYSYS, ASPEN, PRO/II), in ChemProV the development of the process flow diagram and the needed balance equations were left entirely to the students and no numerical solution programming was provided. A number of other educational software programs for material/energy balance classes have recently appeared, for example the offerings of Sapling Learning. These tend to be overly prescriptive in the problem solving procedure employed, thus reducing the educational experience for the student. The goal of ChemProV was to provide a scaffold for learning but leave the problem solving strategy flexible enough to accommodate multiple learning styles and approaches. The intent was that by the end of a typical material/energy balance class, the students would have developed their skills to the point where the use of ChemProV was no longer necessary.

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 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 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) but, more importantly, continued 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 into 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.

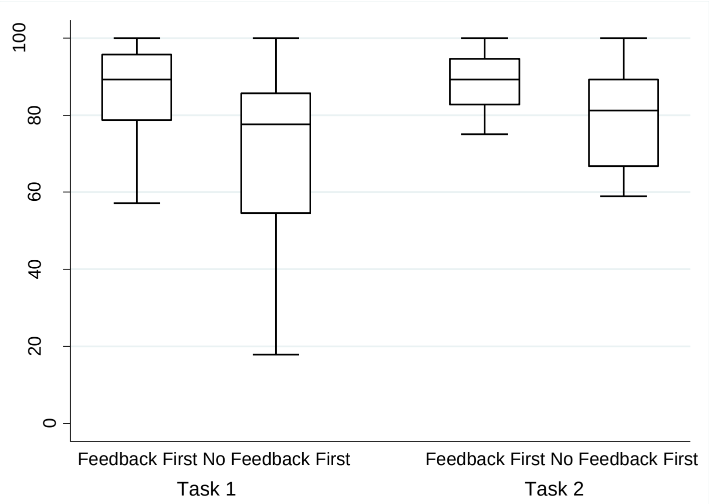

Figure 2: Box plot of solution accuracy by condition and task

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 evening 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 many more of the students.

The sessions described above took place during a 2 – 3 hour time block. As noted above, SBL is typically implemented during extended class periods such as these. The difficulty in implementing SBL is that the technique does not fit well within a typical one-hour per session class structure.

In order to make it possible to implement SBL *asynchronously and online,* we have integrated ChemProV with OSBLE (Online Studio-Based Learning Environment), 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 are encouraged to view the solutions of others, to identify issues with those solutions, and to 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 the 2012 – 2013 academic year.

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* $1.00 \times 10^3$ $lb_m$*/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 student's 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.

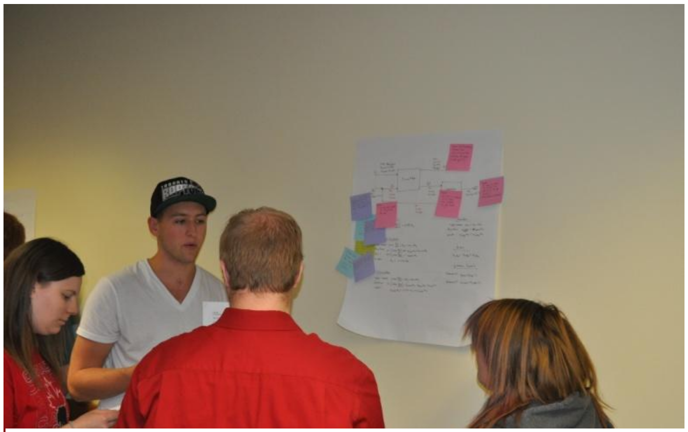

Figure 3: Students Involved in Studio-Based Learning Training Activity

This classroom session mirrored the activities that were to follow in the class. Using ChemProV students were assigned a typical problem to solve. Their solutions were submitted using OSBLE. After the due date for submission of the solution 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.

## Assessment

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 standard format problem and a critiquing problem 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 a number of different programs, many of which conduct their material/energy balance class on different schedules with different approaches. Should significant differences in the results appear between programs the results can be analyzed on a program by program basis rather than being pooled.

## Current Status

Representatives from the eight schools involved in this study have now attended two workshops, each held just prior to the annual ASEE meetings. The first of these, held on June 25 – 26, 2011 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, was used to introduce the participants to the SBL approach, work on assessement activities, and receive feedback about the prior year. During the 2011 – 2012 academic year all of the pacticipants conducted their material/energy balance class in their normal fashion. They did, however, have the students complete 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.

During the 2012 workshop the participating faculty were introduced to the SBL appraoch via the same activity described above. In assessing this activity there was some concern about the readiness of the ChemProV/OSBLE software and the training materials. As a result of this activity, the future plans for the research were changed slightly. The seven other participating institutions would conduct their material/energy balance classes in their normal mode again in 2012 – 2013 as well as collecting another year of baseline data. The PI’s material/energy balance class would be taught using the SBL approach in 2012 – 2013. The pre- and post-class prblems and surveys used in 2011 – 2012 would be administered again. The data from the 2012- 2013 academic year (treatment group) then can be compared with the data from the 2011 – 2012 academic year (control group) to assess the impact of the SBL appraoch.

Another major activity at the 2012 workshop was an assessment of the scoring rubric to be used then assessing the quality of the student solutions for both the normally formatted and the critiquing problems. This was done 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. As shown below the scoring rubric for the regularly

**Pre-Class Calibration Scores**

| Student #1 | | | | | |
|---|---|---|---|---|---|
| | Rater #1 | Rater #2 | Rater #3 | Rater #4 | Rater #5 |
| **Diagram Component Total Score:** | 6 | 6 | 8 | 8 | 6 |
| **Stream Component Total Score:** | 10.5 | 6 | 1 | -3 | 3 |
| **Equation Total Score:** | 0 | 1 | 1 | 0 | 0 |
| **Overall Score:** | 18.9 | 19.5 | 20.2 | 14.0 | 14.0 |
| | | | | | |
| Student #2 | | | | | |
| | Rater #1 | Rater #2 | Rater #3 | Rater #4 | Rater #5 |
| **Diagram Component Total Score:** | 5 | 9 | 7 | 9 | 9 |
| **Stream Component Total Score:** | 10.5 | 13.5 | 9 | 3 | 8 |
| **Equation Total Score:** | 0 | 1 | 0 | 0 | 0 |
| **Overall Score:** | 16.9 | 30.4 | 19.9 | 20.0 | 23.2 |

**Post-Class Calibration Scores**

| | | | | | |
|---|---|---|---|---|---|
| Student #3 | | | | | |
| | Rater #1 | Rater #2 | Rater #3 | Rater #4 | Rater #5 |
| **Diagram Component Total Score:** | 10 | 10 | 10 | 10 | 10 |
| **Stream Component Total Score:** | 35 | 24.5 | 24.5 | 24.5 | 24.5 |
| **Equation Total Score:** | 8 | 7 | 8.25 | 9.5 | 5.5 |
| **Overall Score:** | 71.4 | 61.0 | 65.4 | 69.9 | 55.6 |
| | | | | | |
| Student #4 | | | | | |
| | Rater #1 | Rater #2 | Rater #3 | Rater #4 | Rater #5 |
| **Diagram Component Total Score:** | 9 | 9 | 10 | 10 | 9 |
| **Stream Component Total Score:** | 29 | 30 | 29 | 17 | 12 |
| **Equation Total Score:** | 14 | 11 | 9 | 12 | 8 |
| **Overall Score:** | 86.9 | 76.9 | 71.1 | 73.9 | 54.4 |

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 in a yes (they did identify the error included in the problem) or no (they did not) fashion with the score being the number of yes's. Agreement amongst the scores given by the participants was very good for this activity. With the scoring calibration finalized the particiapnts are now scoring their student's work for the 2012 – 2013 academic year. This will be a second round of baseline data for seven of the institutions and a treatment group data for one institution. Analysis of the the data from this instituion will be completed during the spring of 2013 and be presented at the 2013 workshop for the participants.

## 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 address 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 seven of these institutions baseline data on student learning and attitudes has been collected in the 2011 – 2012 and the 2012 – 2013 academic years. At the PI's institute baseline data was collected in the 2011 – 2012 academic year as well as data collected from the SBL class taught in the 2012 – 2013 academic year. A comparison of these data will give our first indication of the impact of SBL on the student's outcomes in the material/energy balance class.

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