AC 2011-1283: BI-MODAL NO MORE SHIFTING THE CURVE IN MATERIAL AND ENERGY BALANCES COURSES

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Suzanne Kresta is a Professor at the University of Alberta who has been teaching process analysis since 1994. During the last 15 years, her class sizes have doubled but the student performance on mastery of the material has improved.

Inci Ayranci is currently developing new active learning materials for the course through a Fraser and Shirley Russell Teaching Fellowship.

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Bi-modal No More:  
*Shifting the Curve in Material and Energy Balances Courses*

In the early 1990’s, common wisdom stated that a bi-modal distribution in process analysis is “normal”, with a significant number of students needing to take the course twice before they “get” the material. As class sizes in second year chemical engineering at the University of Alberta grew to over 100 students, we took a hard look at the root causes of this distribution. The goal was to consciously uncover and remove barriers to student learning which result in the “bi-modal distribution”. To determine whether this had a quantitative effect on student learning, the class marks on the final exam for three successive years were combined from the beginning of the work (1995-1998), the middle years (2003-2006) and the last three years (2008-2010) with the distributions shown in Figure 1. The instructor was the same for all classes and the averaging over three successive classes removes any significant differences between student groups. While the course content was changed after the first set of data (1995-1998), it was constant from the second set of data to the third set of data. Statistical details are given in Table 1. The results show a clear quantitative shift in the distribution of performance on the final exam. This correlates well with more detailed classroom assessment results, and with observations of changes in the affective domains of student learning (learner confidence, depth of questioning) and student comments on mid-term course evaluations.

![Figure 1: Shift in final exam performance as the teaching methods were changed. The bottom peak is evident in the early course offerings (1995-1998), with a fairly normal distribution in the middle sample (2003-2006) and a skew towards mastery in the last three offerings (2008-2010).](image-url)
Table 1: Statistical data for the distributions in Figure 1.

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<tbody>
<tr>
<td>Average class size</td>
<td>56</td>
<td>74</td>
<td>98</td>
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<tr>
<td>Average on final</td>
<td>52</td>
<td>57</td>
<td>65</td>
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<tr>
<td>Passing grade on final</td>
<td>40</td>
<td>50</td>
<td></td>
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<tr>
<td>Total students in histogram</td>
<td>169</td>
<td>221</td>
<td>295</td>
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Methodology

The methodology of course development began with establishing the student learning styles in our student body. First, the Felder and Silverman learning styles inventory\(^1\) was administered for 4 years until a dominant pattern emerged. The students have a preference for verbal, sequential thinking, which is typical of engineering students. Second, the Woods\(^2\) approach of direct observation of student problem solving was used. Where Woods was trying to understand problem solving approaches, my goal was to apply the problem solving model to determine where students were getting stuck in mastery of the material. Armed with information about the largest student need, new teaching tools were designed, and then assessed against two criteria: student acceptance and change in student performance based on targeted questions using the third assessment tool, classroom assessment techniques based on the work by Angelo and Cross\(^6\). The problems and solutions presented were explored and applied starting at the beginning of the course and moving through to the energy balances portion of the material. This reflects the reality of being able to collect one data point a year as each class moves through the material and each successive obstacle to learning is removed. Once a class has lost the train of understanding, the dynamic of learning the remaining material is lost until a new solution is applied and the course progresses.

Problems Identified and Solutions Implemented

In this section a very brief description of the problems and solutions implemented is given, along with a short summary of the student responses. Several failures are also reported as they illustrate some important principles. The problems are given in the order they were tackled: some of them are in rough chronological order following the course content, others came up as teaching conditions changed at the University of Alberta. Since this is a transformative learning course with a large jump in problem solving skill, both the affective domain results (student confidence and engagement) and the cognitive domain results (test performance) are extremely important.

1. *I don’t even understand the problem statement!* – Experiential vocabulary building first

In early course offerings, much of the three hour lab period for the first few weeks was spent explaining vocabulary. The students, who find new vocabulary difficult to learn, were bombarded with new ideas and new vocabulary all at once. The first assignment was changed to provide a process flowsheet taken from the Kirk-Othmer Encyclopedia of Chemical Technology\(^3\)
and a process description. The students are to identify all the major steps in the process as mixing, reaction, or separation, with a later addition to include changes in temperature or pressure. In deciphering the process in parallel with a picture – the roadmap for chemical engineering – their confidence in deciphering new vocabulary increased dramatically, and their ability to transfer the vocabulary to the next week’s simple material balances was transparent.

2. **Where do I start? – Part 1 – Stream numbers and material balance tables**

The next problem that became apparent is that the students were overwhelmed with the data. Adding it directly to the process diagram was both messy and confusing. The solution came from an industrial guest speaker, who showed us all a process flow diagram with stream numbers and a material balance table. While this may seem trivial to many academics, it revolutionized student learning for a large fraction of the class, and revolutionized grading for the teaching team. The use of standard notation \( (x_{ij} \text{ for mole or mass fractions, where } i \text{ is the component, identified with a letter, and } j \text{ is the stream number; and } F_j \text{ for the stream flow, } f_{ij} \text{ for the component flows}) \) allowed us all to efficiently discuss the problem with many students in quick succession, and when this is combined with the material balance table, communication becomes very simple indeed! Given a way to organize the data, the students quickly gain momentum and confidence in reading the problem statement and deciphering the problem definition.

3. **Where do I start? – Part 2 – Degrees of freedom on single process units and overall**

*I honestly spent 3 hours last night writing equations Dr Kresta, and I got nowhere!*

Only after we enforced the use of degrees of freedom analysis did we see a shift in this problem. The first attempts to use this tool failed, as the students got confused with the complexity of the method. Two changes made the difference: first, focus only on single units, and on the overall process. While this is not a general solution, it allows mastery of the skill to an intermediate level. Second, use a table to structure the degrees of freedom analysis, and apply it repeatedly with every in-class example. The requirement to use degrees of freedom analysis is released once we hit energy balances, but by that point in the course, they seem to have developed enough “intuition” to see where to start without using the formal analysis. In recent offerings of the course a number of problems have been introduced which are either over-specified or under-specified. This stimulates critical thinking and deep learning, and is a key skill for troubleshooting process simulations later in the program. A recent midterm involved an over-specified problem with contradictory data where the students had to uncover and resolve the ambiguity. Two thirds of the students correctly handled both the degrees of freedom analysis and the conflicting data.

4. **Failure number 1 – Project assignment and/or daily problem assignments**

At several points in the first development steps, the solution called “assign more practice problems!” was tried. The first time, 2-3 problems were assigned for each lecture. The second time, one of the Felder and Rousseau case studies was done in its entirety over the course of the term. Mostly, this made the students exhausted, frustrated, and overwhelmed with work. There was some improvement in performance on the final exam, but that group of students also came back years later with vivid memories – not of what they learned – but of how much they suffered in the course. Recent research shows that deep learning requires teaching strategies which reduce the fear of failure and focus student attention and energy on a small number of problems which require more thought.
5. **Antidote number 1 – Freaky Fridays**

Learning from the death spiral of plummeting morale due to experiment number 4, a simple policy of trying to add something lighter and more fun to the Friday lectures was implemented. A collection of relevant videos or slides, in class problem solving activities, and simply wearing jeans and cowboy boots on Fridays lightened the atmosphere significantly, stimulated relaxed interactions, and in hindsight, built many positive memories that our alumni pull out many years later.

6. **It all falls apart after the first midterm! – Content Tyranny**

This was a difficult step to sort out. The students were now very comfortable with material balances, but could not continue the momentum through the section on phase properties and equilibria. Finally, we sat down as a department and reviewed the curriculum. We discovered significant overlap between the mass and energy balances course and the first and second thermodynamics courses. In addition to this, the instructors of the second thermo course were frustrated because the students arrived confused about large parts of the material. Conversely, the fourth year design instructors were very concerned about the lack of understanding of energy balances. After some careful discussion, most of the thermodynamic properties and phase equilibrium information was removed from the course. This resulted in a substantial improvement in student understanding in the second thermo course. The change in understanding was measured from a targeted question on the interpretation of Raoult’s law, the central part of the thermodynamics section of the course. The second thermo instructor comments that the students did not have to unlearn the confusion and lack of understanding from covering the material too fast in the mass and energy balances course and this made the next course easier to teach. Recognizing content tyranny and making deliberate changes to eliminate it led to positive change for student learning in both courses.

7. **Doubling of the class size**

With the massive boom in Alberta, demand for engineers was intense and our class sizes doubled. With this came some difficult changes in teaching. A single instructor could no longer reach all of the students, even with two lab sections instead of the traditional one. A single grader could not reasonably mark all of the assignments. We now run the course with an instructor, two TA’s and two half-grading assignments. The instructor trains the TA’s, who make up the solution to the assignment before the lab (thus learning the problems). In the lab, the TA’s and the instructor all interact with the students. After the assignments are handed in, the lead TA grades twenty assignments to calibrate the marking scheme, and then discusses the solution with their grader. The students must hand in their work in groups of two or three. One of the assignments is randomly selected for grading, and the group gets the resulting mark. The students are responsible for checking eachother’s work – thus getting immediate feedback and higher marks on the assignments. The graders can spend twice as much time on each assignment, and thus give more detailed information back to the students. In the end, all of the people in the course are getting a better learning experience. The students consistently comment on the course evaluations that they place a high value on being able to interact directly with the instructor in the problem solving labs.
8. **Failure number 2 – using visual illustrations to teach energy balances**

Given the pressure to do a better job with energy balances, we received funding to apply visual learning tools to the energy balances part of the course. We spent three years developing and perfecting lovely graphical representations of enthalpy calculations. It was a complete failure. The students completely rejected our efforts. We took the problem to a workshop on visualization, where it was chosen as the most difficult image, and came back with an improved version – worked on by someone with credentials from Pixar – no less! The students hated it. The mistake, in hindsight, was simple. The pictures had nothing to do with the calculations and the work the students did. They had no way to transfer the images to their problems. The work had to be discarded.

9. **Energy balances? Why are they hard?**

Energy balances are hard for students because they have to coordinate the reference state, the data tables, and the appropriate form of the energy balance equation all at once, at the very beginning of the problem. Showing them this explicitly, providing decision trees and calculation charts and throwing out the confusing pictures, made a big difference in the most recent performance and acceptance of the material. It also helped significantly to share a recent article from Chemical Engineering Progress which gave the reference state as one of the most common errors made by recent graduates! Work on this section of the course is ongoing.

**Conclusions**

The solutions discussed above include visual learning, experiential learning, industrial best practices and structured problem solving techniques which are now embedded in the course. The modified teaching approach progresses in three stages: first, vocabulary building through research on a specific process, through flowsheet construction, and problem statement deconstruction; second, structured visual problem solving tools which are also the back bone of industrial best practice; third, active learning exercises throughout the course to pull out questions and ensure that students are well prepared to tackle problems independently before they get stuck; fourth, problem solving groups which hand in their solutions together.

While there is still a tail in our distributions, the lower hump in the curve has disappeared, and has recently been replaced with a skew towards high performance. This is a clear indication that we are reaching and helping students who previously were lost and bewildered, as well as improving the learning experience for all of the students in the class. These teaching methods take relatively little effort to implement in the classroom, and create a dynamic learning environment based on interaction and critical thinking - which is more fun to teach than the stress laden environment associated with bimodal performance.

Interested readers are invited to attend the workshop associated with this work, or to contact the authors for copies of the teaching materials and lectures.
Bibliography


