AC 2007-1550: VISUAL LEARNING IN A MATERIAL/ENERGY BALANCE CLASS

Richard Zollars, Washington State University

Dr. Zollars is a professor in, and director of, the 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 28 years. His interests are colloidal/interfacial phenomena, reactor design and engineering education.

Christopher Hundhausen, Washington State University

Dr. Hundhausen is an assistant professor of computer science in the School of Electrical Engineering and Computer Science at Washington State University. Director of the Visualization and End User Programming Lab (http://eecs.wsu.edu/~veupl), Dr. Hundhausen pursues research on computer-based visualization, simulation, and programming environments for science and engineering education.

Melissa Stefik, Washington State University

Melissa Stefik is a graduate student in computer science in the School of Electrical Engineering and Computer Science at Washington State University.

Visual Learning in a Material/Energy Balance Class

The material and energy balance class is frequently the "gateway" class in chemical engineering. Our experience is no different. Statistics over the past 22 years show that 35% of the students who enroll in our material/energy balance class either fail, withdraw, or receive a grade lower than a "C". A large majority of these (66%) never complete their chemical engineering degree. Indeed most of these students fail to complete any type of engineering degree. The students that fail to successfully complete the material/energy balance class show a wide variety of academic abilities, as judged by SAT scores or high school GPA. In fact the incoming academic abilities between those students failing to successfully complete the material/energy balance class and those who successfully complete the class are virtually identical.

Why then are 35% of the students not being successful in completing their plans to major in chemical engineering because of the material and energy balance course? A number of suggestions have been made and we have implemented a number of these. Included in these efforts are freshman level introductory classes, freshman housing specifically coordinated for science, mathematics and engineering students, and mathematics and science classes where students are clustered by major. None of these changes has altered the observations from above.

Defining a Solution

While we had a number of ideas as to why the material and energy balance course might be such a stumbling block we sought some other way to identify possible causes. We approached this in the following manner. Within the School of Electrical Engineering and Computer Science an experimental learning laboratory exists. Contained in this laboratory are two rooms separated by a two way mirror. In one of the two rooms there is a Smartboard system. This works like a whiteboard but also records everything that students in the room write on its surface (in addition to many other options). From the second room observers may watch the students in the first room as well as record all of their actions (both audio and visual), comment of these actions, and communicate with the students when necessary.

To probe for possible reasons why students might struggle with the work in the material and energy balance course we asked for four volunteer two-person teams from the material and energy balance class. This class is taught in the first semester of the sophomore year and is the first core class in the chemical engineering curriculum. This first aspect of our investigation was started in the first week of the semester, but after each of the teams had had a chance to work together in the material and energy balance class. They were given a simple material balance problem to solve and given an hour to come to a solution. The problem they were given is shown below.

> *Liquid extraction is an operation used to separate the components of a liquid mixture of two or more species. In the simplest case, the mixture contains two components: a solute (A) and a liquid solvent (B). The*

mixture is contacted in an agitated vessel with a second liquid solvent (C) that has two key properties: A dissolves in it, and B is immiscible or nearly immiscible with it. (For example, B may be water, C a hydrocarbon oil, and A a species that dissolves in both water and oil.) Some of the A transfers from B to C and then the B-rich phase (raffinate) and the C-rich phase (the extract) separate from each other in a settling tank. If the raffinate is then contacted with fresh C in another stage, more A will be transferred from it. This process can be repeated until essentially all of the A has been extracted from the B.

Draw a process flow diagram in which acetic acid (A) is extracted from a mixture of acetic acid and water (B) into 1-hexanol (C), a liquid immiscible with water in a single stage. Label each stream with enough values to fully characterize that stream (flow rate, composition, etc.). Provide a numerical value if possible or a symbol for an unknown value (e.g., $\dot{m}$ for a flow rate).

The following facts are given:

1) The acetic acid/water solution enters at a rate of 400 gm/min. The acetic acid compromises 11.5 % of the solution by weight.
2) The extract phase leaving the process contains 9.6 % acetic acid by weight.
3) The raffinate phase leaving the process contains 0.5% acetic acid by weight.

(Problem 4.7a, Elementary Principles of Chemical Processes, 3rd Edition, R. M. Felder and R. W. Rousseau, John Wiley and Sons, Inc., 2005)

At this point in the semester they had not yet been given a similar problem in the material and energy balance class. They were asked solve the problem above, using the Smartboard for any written material. They were also told that what we were interested in was how they approached the solution to the problem rather than the solution itself. They were encouraged to discuss their approach so that we could follow their logic as the solution was developed. The students were allowed to work for 45 minutes before a 15 minute debriefing period.

Observations

After this first round of trials it was clear that there was one area where all of the groups had difficulties – translating what the problem statement said into mathematical expressions (which all of the groups were able to solve easily). Some of the groups attempted to start writing equations but most tried to sketch a diagram of the system. None of the groups was able to put together a correct process flow diagram. Common errors included omission of critical components, symbolizing material streams as processing units, and adding components beyond what are described in the problem statement.

This inability to translate a problem statement into a proper process flow diagram was viewed as a fundamental weakness. Without a proper flow diagram it was going to be impossible to derive an appropriate set of equations to solve thus resulting in an inappropriate solution. This leads to further problems. As Felder and Silverman[1] have found, the majority of learners at the college level are visual learners. The problem statements they are given in a material and energy balance class are verbal, however. This disconnect between what they are given and the manner in which they learn the best may be partially responsible for the unacceptably high drop-out rate in material and energy balance classes. Yet this ability to transform verbal information into visual images is an essential skill they will need not only in the material and energy balance class but throughout their careers as chemical engineers.

Solution for the Observed Weakness

Thus, after observing this first group of students, we felt that we needed to develop some type of tool or procedure by which we could help students make the transition from written material to visual material. This is not only a necessary skill but also would allow students to continue learning using their preferred learning style. If students were able to master this skill they would be more successful in the material and energy balance class and thus more likely to succeed in completing their educational goals.

The difficult part of this task is to give the students enough guidance so that they can master the skill of transforming written material to graphical material without giving them so much guidance that they cannot perform this transition without the use of the tool developed for them. In fact a tool similar to what we were envisioning comes with virtually all process simulation software (ASPEN, HYSYS, PRO/II). In these software packages the user is presented a palette of unit operations. These can be dragged and dropped into a worksheet then connected with material and/or energy streams to construct a process flow diagram. After adding material properties and other information the software then constructs and computes all of the necessary material and energy balances.

For a student attempting to learn the basics of chemical engineering these software packages fail for a number of reasons. First, and foremost, is that the skills we sought to build – the ability to develop material and energy balances – is done in the background in these packages. The user is only told whether enough information has been supplied to allow a calculation to occur. Thus a student using these software packages never develops the problem solving skills necessary for them to become a complete engineer. In addition these packages, being intended for use by professionals, contain far more details than can be managed by a student at the time of their first introduction to the discipline.

To build a software package such as we envisioned we started with the concept that to learn the basics of material and energy balances required only a few generic unit operations. We started with only two, a mixer and a separator. Each of these would have ports on them that would serve as clues to the user (student) that a material or energy stream had to be supplied. The students then would be asked to provide these connections.

Once the flow diagram had been constructed details would have to be supplied. By clicking on an incoming material stream (a stream not interconnecting two unit operations) a dropdown menu would appear asking for information such as the components in the stream and flow rates (either total plus fractional composition or individual flow rates).

After the components and flow rates had been entered clicking on a unit operation would give a list of variable names (flow rates, fractional composition, etc.). In a separate equation palette students would be asked to use these variables to construct material and energy balances for the process flow diagram they had constructed. This is a major difference between the software we are seeking to develop and the commercially available simulation packages. In the commercially available packages the development of the needed balances is all done in the background with no input from the user. In order to develop the skill of transferring written material into mathematical expressions this step is left entirely to the student in our software. At any time in this process the students could request that the computer solve the set of equations they had developed. If the student had not supplied enough equations they would receive a statement indicating so. Similarly, if the student had overspecified the problem an appropriate statement would be issued. Only if the student had developed enough independent balances would the computer provide the numerical results.

Tool Development

Before the code for such a program would be written a paper version of the program was developed in cooperation with a faculty member and graduate students for the Computer Science program on this campus. A “Wizard of Oz” approach was used in the initial development stages. This version was constructed as a series of screens that could be manually displayed on the Smartboard. Thus if a student requested a separation unit the observer, from the observation room, would display the appropriate screen on the Smartboard (like the wizard behind the curtain). When students indicated that they had clicked on an outlet stream the observer could command that one of the dropdown menus would appear. By having the observer supply the material we were able to make quick changes to the objects presented to make sure that the use of the software would be intuitive and would also provide the expected information.

To aid in this development teams of students (2 students per team) were again asked to volunteer for a testing session during the eighth week of the semester. As before they were presented with a sample problem then asked to discuss the solution with their partner while working on the Smartboard. As they worked through the problem they were again asked to verbalize what they were doing. This allowed us to both observe difficulties in translating written materials into process flow diagrams as well as areas where the “software” or its implementation was not clear.

To date the paper version of the software has undergone two tests with student volunteer groups. Further developments will be taking place during the spring semester of 2007. The actual code is currently underdevelopment with the hope of having a test version of the software ready for use in the material and energy balance class offered in the fall semester of 2007. During the first implementation the class will be divided into two sections with student development measured in each section to determine any effect that the use of the software may have. Longer term assessments can be based on the rate at which students successfully complete the material and energy balance class since we have a reliable 22 year record of this.

[1] R.M. Felder and L.K. Silverman, "Learning and Teaching Styles in Engineering Education," *Engr. Education, 78*(7), 674-681 (1988).