AC 2010-1551: EXPLORING THE IMPACT OF VISUALLY-ORIENTED LEARNING SOFTWARE ON

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Exploring the Impact of Visually-Oriented Software on Student Understanding in Chemical Engineering Education

Most engineering curricula have a "gateway" class; a class early in the curriculum that results in a large number of students either withdrawing or failing. In chemical engineering this gateway class is the material and energy balance class. Statistics over the past 24 years at Washington State University show that 35% of the students who enroll in the 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. The students who fail to successfully complete the material/energy balance class show a wide variety of academic abilities, as measured by SAT scores or high school GPA. However, the academic abilities of those students who fail to successfully complete the material/energy balance class and those who successfully complete the class are virtually identical. For example, in the Fall Semester of 2007 the students that failed to successfully complete the material and energy balance course had a cumulative GPA of 3.06 versus 2.95 for those that did successfully complete the class. The SAT scores for these two groups were 1265 versus 1300, respectively. The standard deviation for the GPA was 0.50 while that for the SAT scores was 70. Why, then, do 35% of students fail to complete the material and energy balance course?

Background Studies

Starting in 2006 we began a study to determine whether changes in the manner in which the material/energy balance class is taught might change the level of learning, and therefore the retention, in chemical engineering. By observing pairs of students working on typical material balance problems two problems were observed: translating the problem statement into a process flow diagram (PFD) and then translating the PFD to a set of mathematical expressions. None of the groups was able to put together a correct process flow diagram. Without a correct process flow diagram, the derivation of the appropriate material balances is impossible. Common errors included omission of critical components, symbolizing material streams as processing units, and adding components beyond those that were described in the problem statement. We viewed students' inability to translate a problem statement into a proper process flow diagram as a critical problem that needed to be addressed in order to allow the students to make satisfactory progress in the class[1].

Based on the learning theory of Vtogsly[2] an approach to overcoming these difficulties is to use a scaffolded approach.[3] In this approach guidance in the form of coaching, task structuring, feedback, and hints are made available in order to assist the learner in mastering the material. To assist in the development of such an approach the Felder and Silverman Inventory of Learning Styles[4] (ILS) survey was used to determine the learning preferences of the students in the material/energy balance class. The ILS instrument evaluates students on four measures: active/reflective, sensing/intuitive, visual/verbal, and sequential/global. On each of these scales the students receive a numerical ranking from – 11 to 11. For example a ranking of -11 on the active/reflective scale would indicated a strong preference for an active learning style while a ranking of

11 would indicate a strong preference for a reflective learning style. Felder and Silverman have found the majority of learners in engineering are visual learners. As shown in Figure 1, the students in our material and energy balance are no different, showing a strong preference for a visual learning style (average score = - 5 on the Felder-Silverman scale).

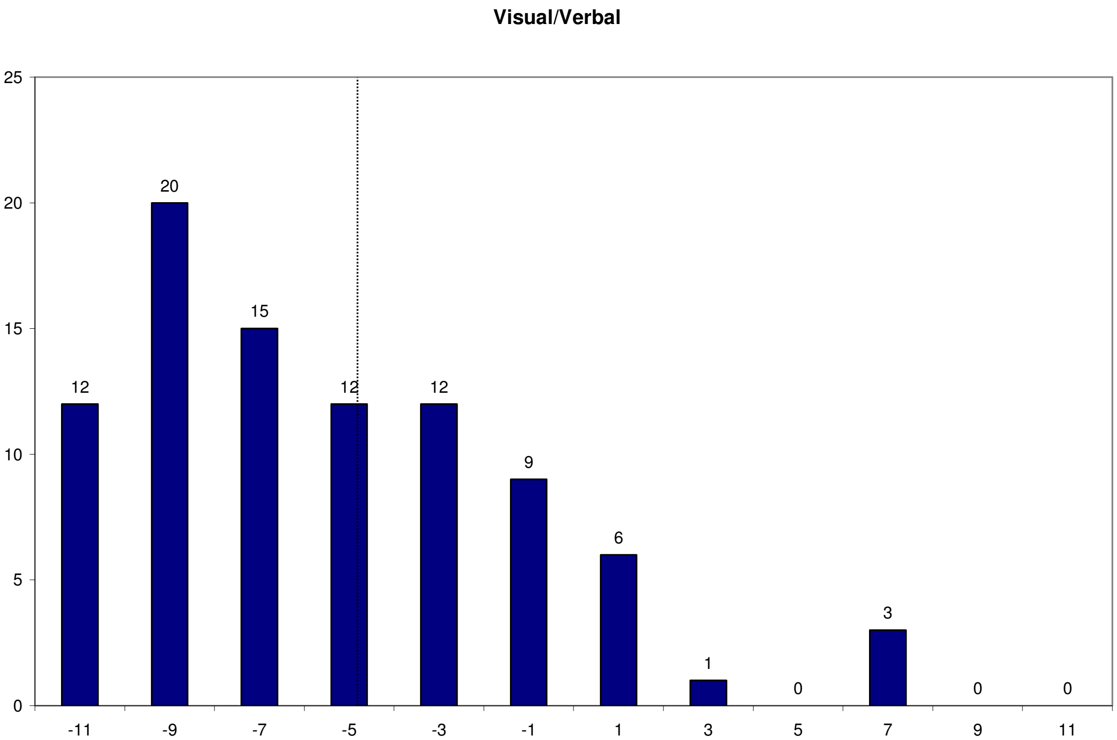

Figure 1. Scoring on Felder/Silverman Inventory of Learning Styles (Visual/Verbal)

Based on these observations, we felt that we needed to develop some type of tool or procedure to help students make the transition from written material to visual material to mathematical representation. Aside from being an important skill in its own right, the ability to map a written problem to a visual diagram allows students to continue learning using their preferred learning style. By creating a tool to aid in transforming written information into visual images, we believed that we could help students develop an essential skill that they will need not only in the material and energy balance class, but throughout their careers as engineers.

Development of a Software Tool

To provide this scaffolding we wished to design a software tool that would aid in the transition from written to visual to mathematical representations. Such a task faces a fundamental challenge: how to provide students with enough guidance that they can master the skill, without giving them so much guidance that they cannot perform the transition without the use of the tool? A tool similar to what we were aiming for comes with virtually all process simulation software (ASPEN, HYSYS, PRO/II). In these software packages, the user is presented with a palette of unit operations. These can be dragged and dropped into a worksheet, and then connected with material and/or energy streams to construct a process flow diagram.

For a student attempting to learn the basics of chemical engineering, these software packages fail for a number of reasons. First, and foremost, the skills that we seek to build—the ability to develop material and energy balances—are done in the background in these packages. Thus a student using these software packages never develops the necessary problem solving skills. In addition, these packages are intended for use by professionals, and thus contain far more details than can be managed by a student at the time of their first introduction to the discipline.

To build the software tool we employed a user-centered design process.[5] Our design process started with the observation that to learn the basics of material and energy balances, one needs to understand only a few generic unit operations. We started with only two: a mixer and a separator. To make it easy for students to build equations based on the chemical flow diagrams that they created we included an equations editor in the software allowing users to drag-and-drop elements of chemical flow diagrams into the equation editor.

This software environment, called ChemProV (Chemical Process Visualizer), was developed and tested in the material and energy balance course (ChE 201 – Chemical Process Principles and Calculations) in the Fall Semester of 2008 as well as an introductory chemical engineering course (ChE 110 – Introduction to Chemical Engineering) in the Spring Semester of 2009. To evaluate the effectiveness of the software, two material balance problems of equal difficulty were developed. These problems would be solved by students using either ChemProV or the traditional technique – paper and pen. Table 1 illustrates of how we assigned these problems and tasks to students within this study. As the table illustrates, we will fully counterbalance both task and treatment order, in order to guard against potential order effects.

	First Task	Second Task
Cohort A	Paper & Pen Problem A	ChemProV Problem B
Cohort B	Paper & Pen Problem B	ChemProV Problem A
Cohort C	ChemProV Problem A	Paper & Pen Problem B
Cohort D	ChemProV Problem B	Paper & Pen Problem A

Table 1. Assignment of Participant Cohorts to Problems and Treatments

In this study, we recorded students' problem solving activities. Their solutions were evaluated with respect to three dependent measures: a) accuracy of the process flow diagram, b) accuracy of the specifications given in the problem statement, and c) accuracy of the equations constructed. To analyze our quantitative results, we constructed a scoring sheet to assess the correctness of the student's solution in each of the three areas described above. This scoring sheet and procedure was used by two faculty members to test its reproducibility. An inter-rater reliability test produced an agreement of greater than 95% between two faculty when 20% of the problems were scored. Because of this agreement, only a single faculty member scored the rest of the student's solutions. We conducted repeated measures ANOVA's in order to test for significant differences between treatments with respect to each of our measures. In addition, in a follow-up qualitative analysis, we reviewed the video recordings of students' activities in order to identify any differences in the problem-solving processes of the students on a treatment-by-treatment basis.

After testing to assure a normal distribution of our results the statistical analysis was conducted to assess whether a) the use of ChemProV impacted learning, b) there is a transfer of training effect (the use of ChemProV allowed students to continue to learn without the use of the software), and c) the use of the software altered the time on task for the students. No statistically significant differences were observed between any of the four groups in any of the areas mentioned above.

Two important observations did arise from this testing, however. For the testing in the ChE 110 class when the quantitative results were analyzed taking onto account the student's final grade in the class (upper half of the class versus lower half) a significant difference did appear. ChemProV did show a significant improvement in learning for the students in the lower half of the class while no significant impact of ChemProV on learning was observed for the students in the upper half of the class. This should not have been an entirely unexpected result; students in the upper half of the class may already have the skills to master the textual to visual to mathematical conversions needed to be successful in performing material balances so that the use of ChemProV may not have an impact. For students struggling to make these conversions (typically those in the lower half of the class) ChemProV could provide a benefit.

A second observation was made during the evaluation of the recording made of the students during the time they were working on the problems. As originally configured ChemProV places a warning sign adjacent to any stream or equation in which the student attempts to do something that is not allowed. By mousing over this warning sign the user would receive a message describing the action that is not allowed. This message forms the core of the scaffolding inherent in ChemProV. The message not only alerts the user to an item needing attention but also gives the user some direction in how to address the issue. Unless the user mouses over the warning sign they do not receive the message. Analysis of the records from the sessions using ChemProV shows that only 16% of the warning messages are read by the user. A reason why this percentage might be so low is that the warning sign is sufficient to alert students to items needing attention. However, the fact that so many of the messages are never read means that much of the guidance inherent in the scaffolding is never utilized.

Current Status

With these results in mind ChemProV was extensively reworked over the summer. Our goal was to insure that the warning messages are read by the users since these messages are a vital component of the scaffolded structure of ChemProV. To accomplish this a separate area on the ChemProV was dedicated to display of the warning messages. An example of the current ChemProV screen is given below in Figure 2. The warning sign has been replaced by a number. The number appears not only at the site of the error but also is attached to a warning message that appears in the "Feedback Messages" section in the ChemProV screen. When a student mouses over either the number or the warning message both are highlighted to further emphasize the connections between the two. One further change was made to the warning messages. All of the messages were reformatted so that first, all state what problem is being identified, and second, all messages give some direction to help resolve the problem.

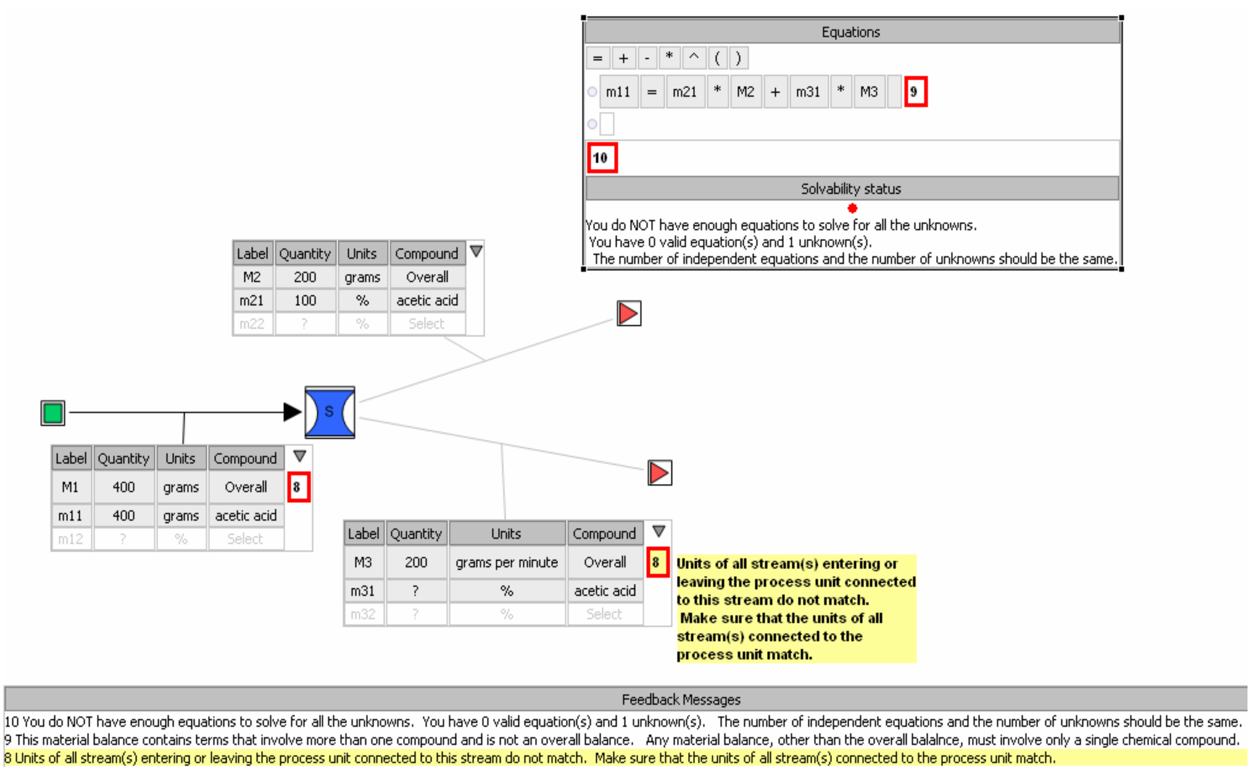

Figure 2. Screenshot of the ChemProV Software

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Testing for Efficacy

The newest version of ChemProV was tested in the material and energy balance class this past fall semester. Our goal in conducting this testing was to test the efficacy of the warning message system since it forms the core of the scaffolded approach. To do this the paper and pen technique was not used. Instead the two techniques used were a full version of ChemProV and a version of ChemProV in which the messaging system had been deactivated. The students in the class were still put into one of four groups, as shown in the table below, with the paper and pen technique replaced by the restricted version of ChemProV. Another change made was in the tutorials provided to the students prior to their use of ChemProV. For the full version of ChemProV the tutorial contained a section in which the students were directed to do something incorrectly then mouse over the warning message and make the necessary corrections to eliminate the warning message. The two problems in use were also examined to insure they were of equal difficulty, both now containing an equal number of unknown quantities.

	First Task	Second Task
Cohort A	ChemProV (restricted) Problem A	ChemProV (full) Problem B
Cohort B	ChemProV (restricted) Problem B	ChemProV (full) Problem A
Cohort C	ChemProV (full) Problem A	ChemProV (restricted) Problem B
Cohort D	ChemProV (full) Problem B	ChemProV (restricted) Problem A

Table 2. Assignment of Participant Cohorts to Problems and Treatments for Current Testing

Results

As with the prior testing student's solutions to the two problems were evaluated with respect to the same three dependent measures: a) accuracy of the process flow diagram, b) accuracy of the specifications given in the problem statement, and, c) accuracy of the equations constructed. A total of 32 students participated in the testing; 21 male, 11 female with an average age of 20.5 years.

After testing to insure that our results were normally distributed a one-sided *t*-test was conducted to assess whether the use of the full version of ChemProV resulted in increased accuracy when compared to the no-feedback version of ChemProV. The analysis demonstrated that the solutions generated using the full version of ChemProV were more accurate (17% more accurate) than those obtained using the restricted version ($p = 0.008$). This result arose whether the student used the full version first or second. What was of particular interest is that the group of students who used the full version of ChemProV first continued to produce more accurate solutions on the second problem, even though they were using the version of ChemProV without the messaging system ($p = 0.021$). As we had hoped, these results showed a strong transfer of learning effect, with the use of the full ChemProV software resulting in greater accuracy in material balances even when the messaging system (scaffold) is not available.

Analysis of the time-on-task showed another interesting effect. The time-on-task for the group of students using the full ChemProV version for their first problem was greater than the time-on-task for first problem by the restricted ChemProV version group ($p = 0.024$). For the second problem the group that used the full version of ChemProV first (now using the restricted ChemProV version) had a shorter time-on-task than did the group now using the full version of ChemProV ($p = 0.024$). The significantly greater time-on-task demonstrated by the group using the full version of ChemProV can be attributed to the presence of the warning messages that are displayed in this version of the software requiring student actions. Greater time-on-task is known to have a positive influence on learning contributing to the greater learning observed when students used the full version of ChemProV.

When the number of warning messages read (as determined by counting when student's moused over any indicator of an error) was evaluated we found that only 18% were now apparently being read compared to 16% in our prior trail. This result would seem to indicate that the changes we made to place greater emphasis on the messaging system had produced no significant change in student behavior. However, unlike the previous version of ChemProV this current version displayed the error messages whether the student moused over the error or not. Thus the students may have been reading the error messages without being counted in this evaluation since mousing over the errors was not longer necessary in order to see the message's content. To fully assess whether the students are actually reading the error messages in the full version of ChemProV could be done using a questionnaire following the test session or use eye tracking equipment to determine if they are reading the messages that are displayed.

Thus our testing has shown a statistically significant impact of using ChemProV with the messaging system. Further the use of the messaging system showed great time-on-task. Most importantly using ChemProV with the messaging system showed a strong transfer of learning effect indicating that this version of the software would accomplish its intent – providing a scaffolding mechanism by which novice learners could learn the basics of material balances but ultimately be able to perform material balances without the use of the software.

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