AC 2009-1529: ENHANCING STUDENT LEARNING VIA THE USE OF VISUALLY ORIENTED SOFTWARE MODULES

Richard Zollars, Washington State University

Dr. 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 30 years. His interests are colloidal/interfacial phenomena, reactor design and engineering education.

Christopher Hundhausen, Washington State University

Dr. Hundhausen is an associate 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.

Pawan Agrawal, Washington State University

Pawan Agrawal is a graduate student in the School of Electrical Engineering and Computer Science at Washington State University.

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Enhancing Student Learning via the Use of Visually Oriented Software Modules

The material and energy balance class is frequently the "gateway" class in chemical engineering. Statistics over the past 23 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 our students fail to complete the material and energy balance course?

Defining an Approach

To explore why the material and energy balance course might be such a stumbling block, we studied the problem solving activities of introductory chemical engineering students. To do this, we ran an exploratory study in the Fall of 2006 using four pairs of students and a SmartBoard™ electronic whiteboard to (a) draw chemical process diagrams of a given material and energy balance problem, (b) develop accompanying systems of equations, and (c) solve for the unknowns. Students were told that we were interested in 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.

Our review of the recordings made it clear that there was one area in which all of the groups had difficulties: 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.

Based on our 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. 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. Using the Felder and Silverman Inventory of Learning Styles[1] (ILS) survey the students in our introductory chemical engineering course were evaluated 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). 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.

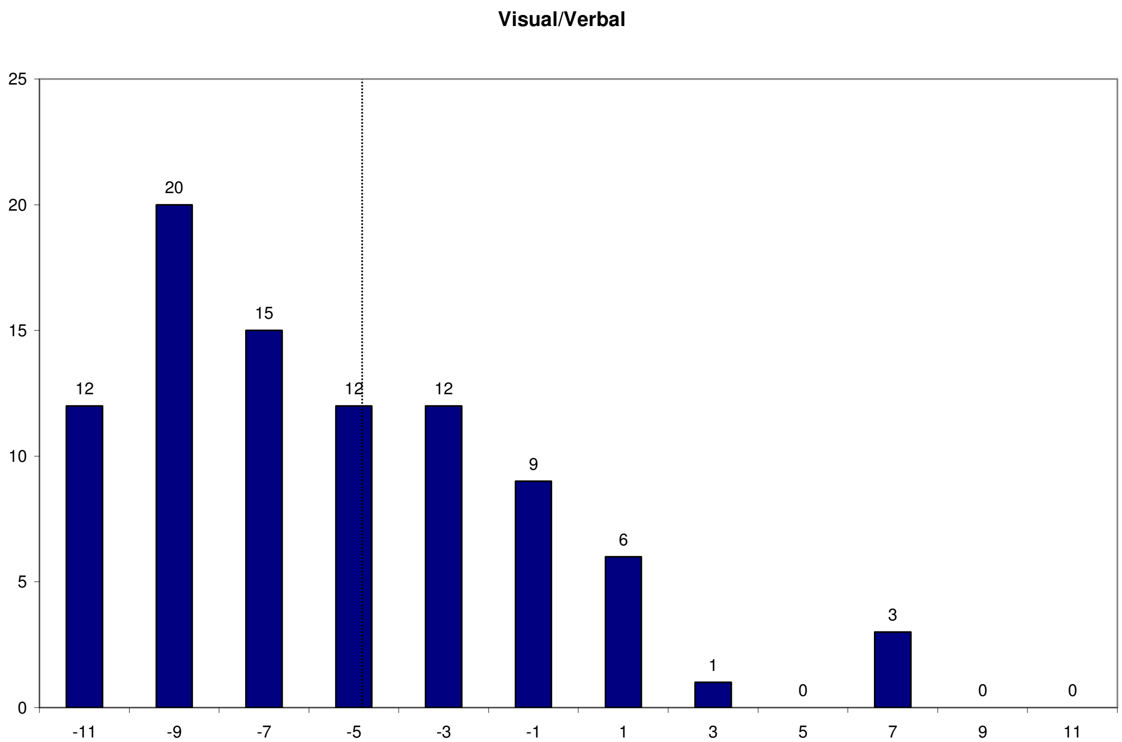

Figure 1. Scoring on Felder/Silverman Inventory of Learning Styles (Visual/Verbal)

Development of a Software Tool

Designing a software tool that scaffolds the transition from written to visual material 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 a software tool to address the fundamental problem of mapping a written problem description into a visual representation of that problem, we employed a user-centered design process.[2] 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. Both of these should have ports on them that would serve as clues to the user that a material stream can be docked to them. In addition, we wanted to make it easy for students to build equations based on the chemical flow diagrams that they created. To that end, we decided to include an equations editor in the software, and to allow users to drag-and-drop elements of chemical flow diagrams into the equation editor.

Our software environment, called ChemProV (Chemical Process Visualizer), is now close to being fully developed. Figure 2 shows the computer screen that a student would see immediately after starting ChemProV. Notice that the palette contains just a few basic tools: two process units, a separator and a mixer, a chemical stream tool, and tools for splitting/joining a stream and identifying a subprocess. As currently constructed, the separator tool allows only one inlet while the mixer allows only one outlet. These software constraints help prevent students from building invalid diagrams. While this selection of tools and limitations may be too severe for experienced students, we have found them to be appropriate for novices. Indeed, using these operations, one can construct the flow diagrams for many elementary material balance problems commonly encountered in a first semester chemical engineering course.

Once a flow diagram has been constructed, the user can expand the "stream tag" associated with each chemical stream to specify the details of the stream (see Figure 3). In a separate equation editor (see top right-hand corner of Figure 2), the user can build equations by dragging-and-dropping elements in the stream tags. This drag-and-drop functionality not only constrains the elements that can appear in equations; it also reinforces the relationships between the chemical flow diagram and the equations. The result of one participant's use of ChemProV to solve a problem is shown in Figure 4.

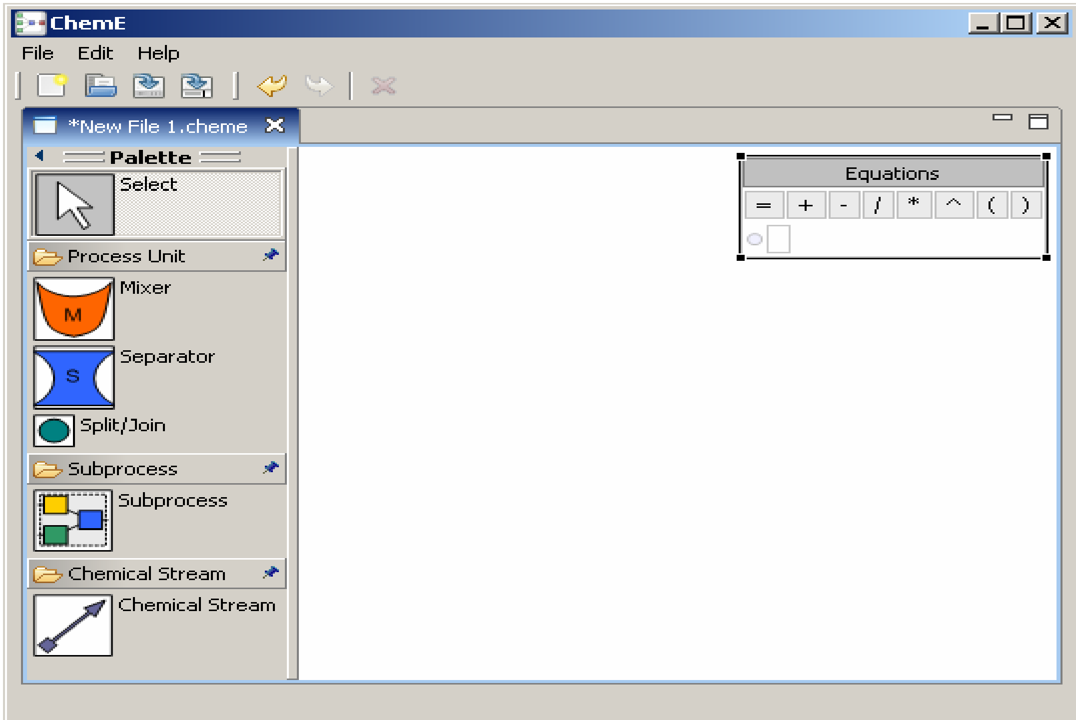

Figure 2. Screenshot of the ChemProV Software

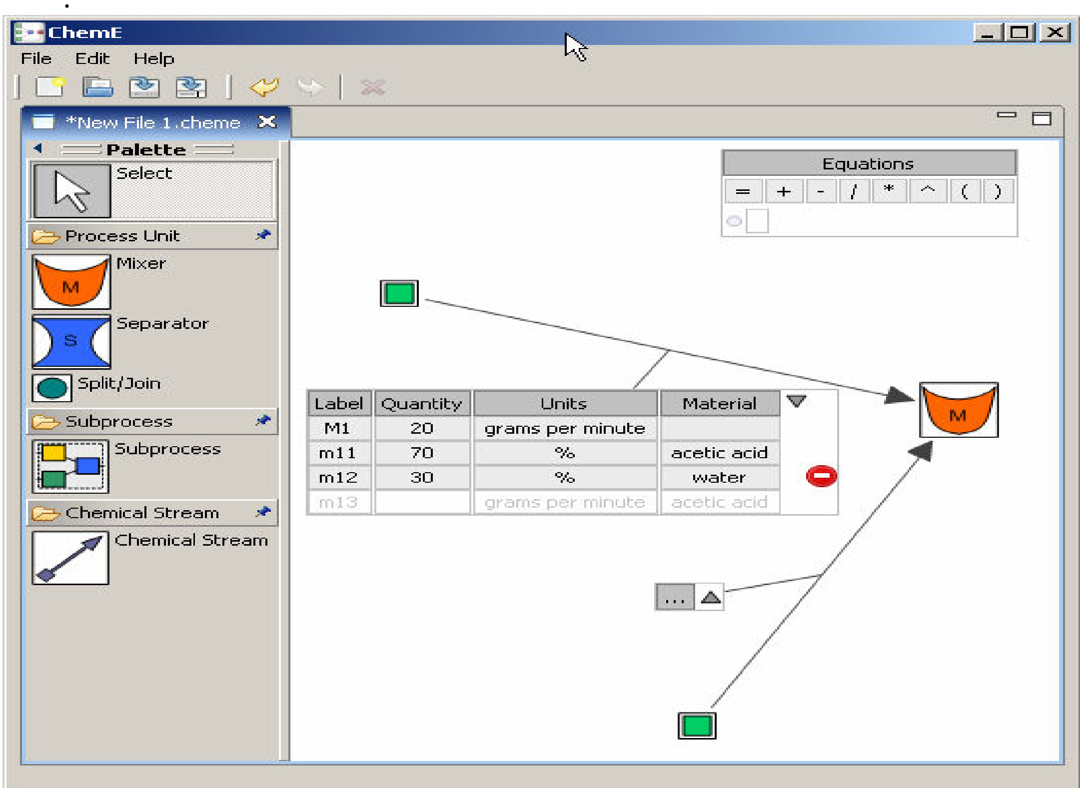

Figure 3. Use of 'Stream Tag" to specify details of chemical stream

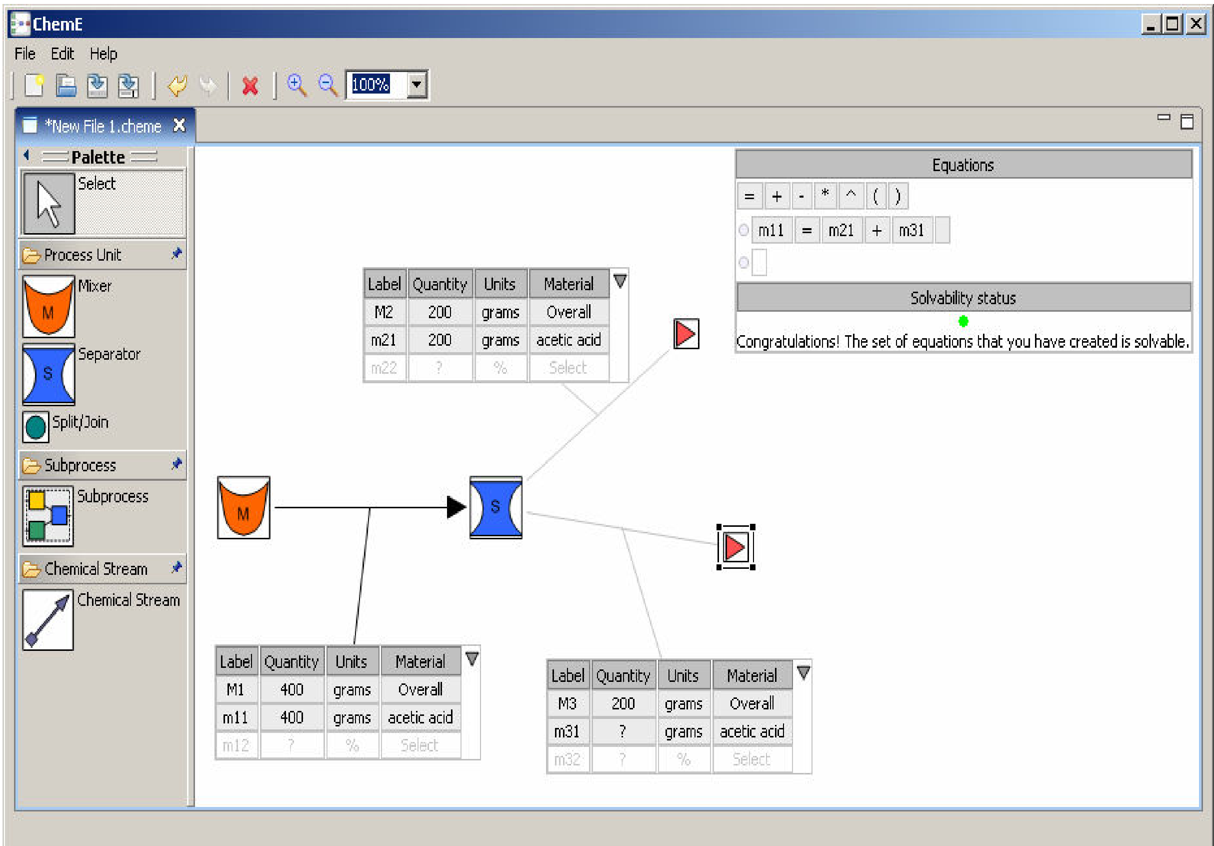

Figure 4. Using ChemProV to Solve the Sample Problem: One Participant's Solution

In sum, there is a major difference between the software we have developed and commercially available simulation packages. In the commercially available packages, the development of the needed balances is done in the background, with no input from the user. In contrast, our ChemProV software provides a set of scaffolds to ease the process of transferring written material into mathematical expressions; however, it leaves the actual development of the balances and solving of the equations totally up to the student, thereby requiring students to practice those important skills.

Testing for Efficacy

The current version of ChemProV supports the construction of chemical flow diagrams and systems of equations, as illustrated in Figure 4. We now wish to test our hypothesis that the ChemProV software can aid in the development of the skill of transforming written descriptions of material balance problems into graphical representations and ultimately into an appropriate mathematical representation. To that end, we are conducting a formal experimental study that compares the ChemProV tool to simple paper-and-pencil—the current "gold standard" medium for solving chemical balance problems. In our study, a group of students from an introductory chemical engineering course will be asked to solve two chemical balance problems that are isomorphic with respect to difficulty: one using the ChemProV tool, and the other using pencil-and-paper. Task and treatment order will be fully counterbalanced in order to guard against order effects.

The two problems to be solved by the students are given below.

Problem – A

Using the ChemProV software that has been launched on your computer, please complete the following problem. Remember to read it aloud before you start.

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 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.

Create a process flow diagram in which acetic acid is extracted from a mixture of acetic acid (A) and water (B) into n-hexane (C), a liquid immiscible with water.

The following facts are given:

1) *The acetic acid/water solution enters at a rate of 400 gm/min. The acetic acid composes 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.*

Calculate the flow rate of the n-hexane, the extract and the raffinate streams.

Problem – B

Using the ChemProV software that has been launched on your computer, please complete the following problem. Remember to read it aloud before you start.

Fractional distillation is an operation used to separate the components of a liquid mixture of two or more species by their boiling points. In the simplest case, the mixture contains two components. The mixture is heated until it boils. The vapor phase, having a higher concentration of the more volatile component, is removed from the distillation tower and condensed to give a liquid that is rich in the more volatile component (the overhead product). The liquid that is not vaporized in the tower is also removed and forms a second liquid stream that is rich in the less volatile component (the bottoms product).

Create a process flow diagram in which a stream containing benzene (B), cyclohexane (C) and toluene (T) is fed to a distillation tower. The bottoms product from this first tower is recovered as a product stream. The overhead stream from this distillation tower is fed to a second distillation tower. The overhead and bottoms streams from the second tower are both recovered as product streams.

The following facts are given:

1) *The benzene/cyclohexane/toluene mixture is fed to the first distillation tower at a rate of 1000 kg/hr. The composition of this stream is 25 % benzene (B), 60 % cyclohexane (C) and 15 % toluene (T) by weight.*
2) *The overhead stream from the second tower flows at a rate of 300 kg/hr. It has a composition of 66.7 % benzene (B) and 33.3 % cyclohexane (C).*
3) *The bottoms stream from the second tower contains 12.5 % benzene (B) and 87.5 % cyclohexane (C).*
4) *The bottoms stream from the first distillation tower contains only cyclohexane (C) and toluene (T).*

Calculate the flow rate of the bottoms streams from both distillation towers and the composition of the bottoms stream from the first distillation tower.

These two problems were judged to be isomorphic with respect to difficulty for the following reasons:

1) In both cases the PFD will consist of two processing units.
2) The results requested cannot be obtained by starting with the information given about the feed stream and calculating the remaining unknown quantities following the path taken by the flow of material (i.e., you must take information about the exiting streams as well as the entering streams to arrive at a solution).
3) Three material balances must be performed to obtain the requested solution.
4) Each of the problems requires that a total flow rate for one of the streams be determined by knowing the flow rate of one component and its concentration in that stream.
5) All of the equations derived can be solved individually; no solutions to simultaneous equations are required.

The procedure for solving each of the problems will be the same. Whether the students are solving the problem using paper and pencil or ChemProV they will first be given a tutorial on how to use the technique. For paper and pencil this will consist of a set of instructions on the manner in which a PFD should be drawn (lines for streams, boxes for processing units) and how the properties of any streams should be identified. For ChemProV the instructions will be essentially identical except that they will now be directed as to how to make the software perform these tasks.

The experimental study will adopt a within-subjects design. Students from the introductory chemical engineering course (ChE 110) will be recruited. This class is offered during the freshman year, thus insuring that the students will not have had any prior exposure to typical material balance problems. The students will be split into four cohorts. Each cohort will be asked to solve one of the problems above using an electronic ink application on a tablet PC (equivalent to a pencil and paper solution), and the second using the ChemProV software.

Table 1 provides an illustration of how we will assign 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. In this study, we will record students' problem solving activities. Their solutions will be evaluated with respect to three dependent measures: a) accuracy of the process flow diagram, b) accuracy of the equations constructed, and c) the distribution of the time that they spend solving the problem (fraction spent constructing the PFD, fraction spent deriving equations, and fraction spent constructing equations). To analyze our quantitative results, we will conduct 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 will review 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.

	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

The testing described above is currently under way. Groups of students who are currently enrolled in the material and energy balance course (and who presumably have started to develop the desired problem solving skills) are testing the usability of the software. By following this procedure we will insure that the students in the actual testing will not be hampered by software problems but can focus on problem solving skills.

We hope that our results will shed light on the impact that the use of the software has on the skill development in the students, ultimately providing an empirical foundation for an improved introductory chemical engineering curriculum that increases retention by addressing a problem that we have found to be troublesome for introductory students: that of translating a written problem description into visual form.

Bibliography

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[2] D. Norman and S. Draper, User-centered system design, Lawrence Erlbaum Assoc., Mahwah, NJ, (1986).