SELECTING COMPUTER-AIDED INSTRUCTIONAL SOFTWARE

Susan Montgomery and H. Scott Fogler

Department of Chemical Engineering

University of Michigan

Ann Arbor, MI 48109

Abstract

Interactive computing can address the needs of a variety of learning styles, and a broad range of educational objectives, while serving a number of pedagogical roles: Presentation, Assessment, Exploration, and Analysis. These three issues are discussed in detail, along with examples from chemical engineering educational software, to help faculty learn how to analyze educational software to ensure that it's meeting the needs of their students.

Keywords

Bloom's Taxonomy, POLYMATH, Learning Styles, Objectives, Pre0sentation, Assessment, Exploration, Analysis, Michigan Modules, Chemical Reactor Design Tool, Purdue Computer Simulation Modules, PICLES, Multimedia, Virtual Reality, Hypertext.

I. Introduction

Students learn best when acting and reflecting, not by watching and listening (1-3). The standard textbook-lecture-homework triad involves little systematic reflection and even less action. Interactive computer software packages that supplement traditional classroom presentations can provide opportunities for both. A well designed package can supplement the presentation of basic course concepts, test their understanding, provide feedback for their efforts, and generally increase both the quantity and the depth of their learning. On the other hand, a poorly designed program can lead to massive expenditures of time by both instructors and students without enhancing learning at all.

Our purpose in this paper is to suggest a framework for determining the potential effectiveness of instructional software in a given class setting. We propose that software be classified in terms of answers to the following three questions:

1.*What are the intended roles of the software?* Possible roles include *presentation* (providing information), *assessment* (interrogating students on presented material and providing feedback on their responses), *exploration* (providing students with opportunities to explore alternative choices and vary system parameters within a constrained system), and *analysis* (providing tools for mathematical and/or logical analysis and problem solving).

2.*What thinking skills is the software designed to challenge?* Possible skills are those defined in the well-known Bloom Taxonomy of Educational Objectives (4): *Knowledge* (rote repetition of memorized information), *comprehension* (repetition with understanding), *application* (use of the information to solve a problem of complete a task), *analysis* (explaining or modeling system behavior), *synthesis* (creative thinking, design), and *evaluation* (critical thinking, specifying criteria and choosing from among alternatives).

3. *What student learning styles does the software accommodate?* Possible styles are those defined by Felder (5): *Sensing* (concrete, real-world oriented, wanting facts and data) and *intuitive* (imaginative, abstract, wanting explanations and interpretations); *visual* (wanting pictures, diagrams, charts) and *verbal* (wanting written and spoken explanations); *inductive* (wanting presentations to proceed from specific phenomena to general principles) and *deductive* (wanting to proceed from general principles to specific phenomena); *active* (wanting to experiment in order to understand) and *reflective* (wanting to understand before experimenting);

sequential (building a big picture understanding in small logically-connected steps) and *global* (needing to see the big picture before filling in the detailed connections).

We begin the paper by expanding on these definitions. Since the software roles will be discussed in terms of the thinking skills and learning styles they address, the latter two issues will be discussed first. By way of illustration, we suggest answers to these three questions for several software packages currently being used in chemical engineering education, as well as some software tools currently under development.

II. Instructional Objectives

One of the key factors to the successful development and use of interactive computing is the identification of activities that cannot be accomplished by other means (e.g. pencil and paper, calculator). By activities, we mean those exercises that are used to learn new material, practice certain skills, or test comprehension of previously learned material. In deciding which activities to include in educational software an instructor can take advantage of Bloom's Taxonomy of Educational Objectives (4), which is composed of the following six skill levels:

1. **Knowledge:** The remembering of previously learned material. Can the problem be solved simply by defining terms and by recalling specific facts, trends, criteria, sequences, or procedures. This is the lowest intellectual skill level. Examples of knowledge level questions include: 1. *Write* the equations for a batch reactor and *list* its characteristics. *Which* reactors operate at steady state? *Other words* used in posing knowledge questions: *Who* . . . , *When* . . . , *Where* . . . , *Identify* . . . , *What formula* . . . .

2. **Comprehension:** This is the first level of understanding. Given a familiar piece of information, such as a scientific principle, can the problem be solved by recalling the appropriate information and using it in conjunction with manipulation, translation, interpretation, or can one manipulate the design equation formulas to fond the effluent concentration or extrapolate the results to find out the reactor volume in the flow rate were doubled? *Compare* and *contrast* the advantages and uses of a CSTR and a PFR. *Construct*

a plot of N_A as a function of *t*. *Other comprehension words:* . . . *Relate* . . . , *Show* . . . , *Distinguish* . . . , *Reconstruct* . . . , *Extrapolate* . . . , *This is skill level 2.*

3. **Application:** The next higher level of understanding is recognizing *which set* of principles ideas, rules, equations, or methods should be applied, given all the pertinent data. Once the principle is identified, the necessary knowledge is recalled and the problem solved as if it were a comprehension problem (skill level 2). An application level question might be: *Make use* of the mole balance to solve for the concentration exiting a PFR. *Other words:* . . . *Apply* . . . , *Demonstrate* . . . , *Determine* . . .

4. **Analysis:** This is the process of breaking the problem into parts such that a hierarchy of sub problems or ideas is made clear and the relationships between these ideas is made explicit. In analysis, one identifies missing, redundant, *and* contradictory information. Once the analysis of a problem is completed, the various sub problems are then reduced to problems requiring the use of skill level 3 (application). An example of an analysis question is: What conclusions did you come to after reviewing the experimental data. *Other words:* . . . *Organize* . . . , *What are the causes* . . . , *What are the components* . . .

5. **Synthesis:** This is the putting together of parts to form a new whole. A synthesis problem would be one requiring the type, size, and arrangement of equipment necessary to make styrene from ethyl benzene. Given a fuzzy situation, synthesis is the ability to formulate (synthesize) a problem statement and/or the ability to propose a method of testing hypotheses. Once the various parts are synthesized, each part (problem) now uses the intellectual skill described in level 4 (analysis) to continue toward the complete solution. Examples of synthesis level questions are: *Find a way* to explain the unexpected results of you experiment. *Propose* a research program that will elucidate the reaction mechanism. *Other words:* . . . *Speculate* . . . , *Design* . . . , *Develop* . . . , *What alternative* . . . , *Suppose* . . . , *Create* . . . , *What would it be like* . . . , *Imagine* . . .

6. **Evaluation:** Once the solution to the problem has been synthesized, the solution must be evaluated.

Qualitative and quantitative judgments about the extent to which the materials and methods satisfy the external and internal criteria should be made. An example of an evaluation question is: *Is the author justified* in concluding that the reaction rate is the slowest step in the mechanism. *Other words: . . . Was it wrong . . . , Will it work . . . , Does it solve the* ***real*** *problem . . . , Argue both sides . . . , Which do you like best . . . , Judge . . . , Rate . . . .*

A typical undergraduate course focuses on the first three levels only. Computer-based materials are one way to allow students to exercise their higher level thinking skills.

III. Learning Styles

Once the skills have been identified, the instructor or software developer needs to determine how to reach the student most effectively to ensure that these skills are indeed exercised. A number of learning style models are currently being used in engineering education, including the Kolb/McCarthy model (6,7) and the Myers-Briggs Type Inventory (8). We have found the model suggested by Felder (5) to be most useful in helping students understand their learning needs and preferences. Table 2 summarizes the five learning style dimensions in Felder's model.

Soloman's Inventory of Learning Styles (9), can be used to assess four of the five learning style preferences in Felder's classification scheme.

In combination, Bloom's taxonomy of educational objectives and Felder's learning style classification scheme provide a means of determining both the skills being exercised by the software and the mode of interaction with the student, as shown in Figure 1. Keeping these two considerations in mind, we now address the pedagogical role of interactive computing, and how different types of interactions satisfy different skills and learning styles.

IV. Roles of Software Packages

In order to identify appropriate software to satisfy a specific pedagogical objective, it is useful to utilize a classification scheme. The scheme categorizes software by its role in addressing specific educational objectives and learning styles. We suggest that interactive software for engineering instruction can best be divided into the following four categories: *Presentation*, *assessment*, *exploration*, and *analysis*.

A. Presentation

In the *presentation* phase the emphasis is on the knowledge, comprehension, and application levels of Bloom's Taxonomy. Software within this category focuses on the delivery of technical material, which can occur in a number of ways. The following list is representative of these ways and the corresponding learning style dimension.

1. Display of text material. (Verbal)
2. Access to expanded explanation of text material through hot keys. (Active, sequential)
3. Visual and graphical representation of material. (Visual, sensing, global)
4. Use of animation to display Phenomena (Global), or manipulate Equations (Active)
5. Display of video clips to display industrial situations. (Global, visual, sensing)

For example, dynamic on-screen manipulation of equations, with the appropriate use of animation and color, is much more effective than a long blackboard derivation, particularly for Felder's visual and sequential learners.

B. Assessment

In the *assessment* category the student is tested on mastery of the material, such as through the use of multiple choice questions. These questions are often closed-ended and focus on the first four levels of Bloom's Taxonomy (Knowledge, Comprehension, Application, and Analysis), although the upper two levels (Synthesis and Evaluation) can also be reached. Other examples include short answer questions, where the program can search for key words in the students' answers. The correct solutions to the questions are displayed immediately after the student's solution is entered. Alternatively, one could ask students to generate brainstorming lists, come up with possible explanations for system performance, choose among alternative designs and justify their choices, etc. These types of assessments are particularly suited to Felder's active (they get to interact), sequential (orderly) and sensing (if it deals with real situations) learners.

C. Exploration

The third category, *exploration*, allow users to better understand the role of various parameters on the performance of a given process through exploration of the process. These are exploratory simulations within a confined parameter space. Software can also provide for the planning of experiments by allowing the students to choose experimental systems, to take simulated "real" data, to modify experiments to obtain data in different parameter ranges, to manipulate data so as to discriminate among mechanisms, and to design a piece of equipment or a process. These interactive computer modules can provide a students with a variety of problem definition alternatives and solution pathways to follow, thereby exercising their divergent-thinking skills. Active learners appreciate the chance to manipulate parameters, visual learners benefit from graphical representations of phenomena, deductive learners can practice drawing their own conclusions, and sensors and global learners get to experience a real process, or at least a simulation of it. Software within this category focuses on levels 3 and 4 of Bloom's Taxonomy (Application and Analysis).

D. Analysis

The *analysis* category includes those software packages that allow students to enter the equations and parameter values for any system. These packages include spreadsheets, and equation solvers such as Maple, Mathematica and MathCAD. These tools allow users to create and solve new models and the corresponding sets of equations very easily. As a result, one can give students greater practice on developing their synthesis skills to better understand the role of various parameters on the performance of a given process. Software within this category gives students, particularly active, deductive and visual students, practice of the higher levels of Bloom's Taxonomy (Synthesis and Evaluation).

V. Illustrative Examples

In this section we provide examples of the categories described above, taken primarily from chemical engineering educational software. While these examples might be of particular interest to chemical engineers, they serve to illustrate the categories for all engineering educators.

A. Presentation

Examples of the first three classifications can be found in the twenty-four interactive computer modules developed at the University of Michigan (12). The review sections make extensive use of animation in the derivation of equations, as in the very visual derivation of the energy balance equation in HEATFX2, shown in Figure 2.

Hypertext allows students to explore a given topic through a variety of paths. Pohjola and Myllyla (13) discuss an object-oriented hypertext approach to organizing educational chemical engineering information, setting the groundwork for future efforts, and highlighting the use of animation and other techniques to assist students in creating mind pictures of the steps occurring at the molecular level in chemical engineering processes. Multimedia also allows students to interact with information in a variety of ways. Qasem and Mohamadian (14) found that multimedia allows the student to take an active role in the educational process by freeing the student from being a passive recipient of information. Coburn et al. (15) include video images, animation, sound and full-motion video in their modules for introductory thermodynamics.

One of the authors (SMM) has developed multimedia materials for use in the material and energy balances course as well as in the chemical engineering undergraduate laboratory. These computer-based instructional materials integrate graphics, animation, video images and video clips into multimedia packages that allow students to learn the basic concepts in chemical engineering through exploration of actual situations ranging in scope from simple bench-scale experiments and day to day experiences to industrial chemical plants. They are aimed primarily at visual, active, sensing and global learners. For example, for an open ended problem on mass balances, a multimedia module (Figure 3) allows students to tour the phosphate coating system of Ford Motor Company's Wixom Assembly Plant. The module includes a description of each stage in the system, chemical usage, tank size and dump schedule information, and a short video clip of each stage. The real situation appeals to sensing learners. In a module on multiphase systems (Figure 4), students can apply their expertise using T-xy diagrams to actual industrial equipment, a valuable experience for active, sensing, and global learners.

The next avenue currently being explored by software developers in the presentation category is the World Wide Web, which allows for a very visual presentation of material, albeit with little interaction so far. As connection speeds increase we can expect that more interactive educational software will be available on "the Web."

B. Assessment

The assessment category includes those packages that allow students to test their knowledge of the material. This testing could take place through a problem solving session that might include a scenario that captures the student's interest. For example, in the Michigan SHOOT module (12), the objective is to master simplification of the equations of fluid motion. The student must determine which terms in the equation would be dropped for a given situation. As seen in Figure 5, these decisions are made in an amusement park setting, to make the learning more interesting.

As another example, consider a program that helps students prepare for an undergraduate laboratory experiment on pumps. Some short questions (Figure 6) gives students a chance to practice their lab skills. In another section students also get practice setting up the pumping equipment to achieve certain goals. Sensing and active learners benefit from this type of interaction, as do reflective learners, in that it allows them to gain confidence before tackling the actual equipment. This type of activity also reaches into the upper levels of Bloom's taxonomy.

C. Exploration

One of the great opportunities afforded by the use of computers is the chance to simulate a real-time interaction with process equipment. PICLES™ (Process Identification and Control Laboratory Experiment Simulator), (16), for example, is an IBM-PC based training simulator that provides hands-on experience with process dynamics and control. Students using PICLES™ get experience in real-time use of various process control techniques. One example is the control of the distillate and bottom composition in a distillation column (Figure 5). This type of interaction is ideal for visual, active, sensing and global learners, and if used correctly, can exercise their application, analysis, synthesis and evaluation skills.

An additional example of an outstanding set of exploration tools is the Chemical Reactor Design Tool developed at the University of Washington (17), which allows students to vary parameters and observe trends in complex chemical reaction engineering problems, such as flow reactors with axial and radial dispersion. The exploration of parameters allows users to very easily make their own deductions about the importance of physical phenomena, as well as make design decisions that may revolve around conflicting constraints. The interface provides the user with 3D perspective views, 2D contour plots, and solutions variables, making it easy for the user to make comparison studies. This is ideal for active, visual, and global learners.

The Purdue-Industry Chemical Engineering Computer Simulation Modules are examples of the educational exploratory benefits that can result from collaborations with industry (18,19). Their materials combine videotaped tours of portions of chemical engineering plants with computer simulations of the systems, which allow students to perform "real world" design experiments to solve open ended problems (sensing, global, visual). These simulations, meant to supplement traditional laboratory experiments, have seen extensive use both in undergraduate laboratories, as well as in reactor design and process control courses. The key to the success of these modules is two fold: Students can see the actual plant through the videotape, and use of the computer simulation allows students to study the effects of changes of system parameters on the operation of the system. These two features make these modules ideal for visual, global, sensing, and active learners.

Another exciting area on the horizon is virtual reality (VR). One module currently under development at the University of Michigan by John Bell and Scott Fogler is the prototype of a chemical plant that uses a straight through transport reactor with a coking catalyst. The student can explore the reactor room where he/she can change the operating parameters and see their effect on the reaction variables such as degree of coking and conversion. Students can also enter the catalyst pellet to view the pore space inside the pellet along with the reactions occurring on the surface, as seen in Figure 8. This visualization of the process and reaction mechanisms will greatly enhance the students' understanding and appreciation of this reaction engineering process. In general, the advent of virtual reality tools opens a wide door to the types of exploration possible.

D. Analysis

One of the earliest analysis applications available to chemical engineers was POLYMATH (20,21). Using POLYMATH, students are able to easily set up a system of equations to obtain an intuitive feeling of the problem being studied. This feeling and understanding is obtained because the student is able to use a significant amount of time to explore complex problems by varying the systems parameters and operating conditions rather than spending tedious time programming the system of equations used to model the physical system as well as the numerical techniques needed to solve these equations. For example, in analyzing two parameter models of residence time distribution in a reactor, students can create different models to apply to a given RTD function. The emphasis can be on the analysis, rather than on the programming. As a result, the student not only learns through discovery from the results of his/her parameter variation, he/she has the opportunity to be creative in the solution to the problem and practice his/her creative and synthesis skills. It has become evident in the last few years that it is important that our students get a chance to practice their qualitative problem solving skills as well. A computer module for problem analysis, one of a set developed to supplement Fogler and LeBlanc's problem solving textbook (22), allows users to analyze a given situation to determine the source of a problem, as shown in Figure 9.

VI. Summary

Much educational software is currently being developed. When evaluating software for possible class use, it is important to focus on the pedagogical roles, educational objectives, and learning styles addressed by the software. In this paper we have provided some guidelines that potential software users can use to determine if a certain software package meets the needs of his/her students.

VII. Acknowledgements

The authors gratefully acknowledge Dr. Richard Felder's advice and suggestions on this article. Financial support from the National Science Foundation made possible the development of the PC-based Interactive Computer Modules for Chemical Engineering Instruction (USE-8953534) and the Problem Solving Modules (USE-9254354).

References

1. Felder, R.M. and L.K. Silverman, "Learning and Teaching Styles,"*Engineering Education*, April, 1988, 674-681.

2. McKeachie, W.J., *Teaching Tips: A Guidebook for the Beginning College Teacher, 8th ed.* D.C. Heath and Company, Lexington, MA, 1986.

3. Wankat, P.C. and F.S. Oreovicz. *Teaching Engineering*, McGraw-Hill, New York, 1993.

4. Bloom, Benjamin S., *Taxonomy of Educational Objectives; the Classification of Educational Goals, Handbook I: Cognitive Domain*. David McKay Co., New York, 1986.

5. Felder, R.M., "Reaching the Second Tier - Learning and Teaching Styles in College Science Education," *J. Coll. Sci. Teach* vol. 23, no. 5, 1993, 286-290.

6. Kolb, D.A., *Experiential Learning: Experience as the Source of Learning and Development,* Prentice-Hall, Englewood Cliffs, N.J., 1984.

7. Harb, J.N., S.O. Durrant, R.E. Terry, "Use of the Kolb Learning Cycle and the 4MAT System in Engineering Education," *J. Eng. Ed.*, vol. 82, no. 2, 1993, pp. 70-77.

8. McCaulley, M.H., E.S. Godleski, C.F. Yokomoto, L. Harrisberger and E.D. Sloan,

"Applications of Psychological Type in Engineering Education," *Engineering Education*, February, 1983, 394-400.

9. Soloman, B.S., Inventory of Learning Styles, North Carolina State University, 1992.

10. Felder, R.M., "Meet your Students. I. Stan and Nathan." *Chemical Engineering Education*, Spring 1989, pp. 68-69.

11. Felder, R.M."Meet your students: V. Edward and Irving." *Chemical Engineering Education*, Winter 1994, pp. 36-37.

12. Fogler, H. S., S.M. Montgomery, and R.P. Zipp, "Interactive computer modules for chemical engineering instruction," *Computer Applications in Engineering Education* vol. 1, no. 1, 1992, 11-24.

13. Pohjola, V.J., and I. Myllyla , "Object-Oriented Hypermedia as a Teaching Aid in Chemical Engineering Education," In TH. Bussemaker and P.D. Iedema (Eds.), *Computer Applications in Chemical Engineering*, Elsevier, Amsterdam, 1990, pp.199-202.

14. Qasem, I. and H. Mohamadian, "Multimedia Technology in Engineering Education," *Proceedings. IEEE Southeastcon '92 (Cat. No. 92CH3094-0)* vol. 1., IEEE, New York, 1992, pp. 46-49.

15. Coburn, W.G. G.C. Lindauer, R.L. Collins, T.E. Mullin, and W.P. Hnat, "Development of Multifaceted Instructional Modules for Introductory Thermodynamics," *1992 Frontiers in Education Conference, IEEE, Proceedings* , 1992, 150-155.

16. Cooper, D.J., "PICLES: The Process Identification and Control Laboratory Experiment Simulator," *CACHE News* vol. 37, 1993, 6-12.

17. Rosendall, B. and B. Finlayson, "The Chemical Reactor Design Tool," *1994 ASEE Annual Conference Proceedings*, ASEE, Washington, DC, 1994, pp. 2219-2222.

18. Jayakumar, S., R.G. Squires, G.V. Reklaitis, P.K. Andersen, K.R. Graziani, B.C. Choi, "The use of computer simulations in engineering capstone courses: A Chemical Engineering Example - The Mobil Catalytic Reforming Process Simulation." *International J. of Engng. Educ.* , vol. 9, no. 3, 1993, pp.243-50.

19. Squires, R.G., P.K. Andersen, G.V. Reklaitis, S. Jayakumar, and D.S. Carmichael, "Multimedia-based applications of computer simulations of chemical engineering processes," *Computer Applications in Engineering Education* vol. 1, no. 1, 1992, pp. 25-30.

20. Shacham, M. and M.B. Cutlip, "Computer-Based Instruction: is There a Future in ChE Education?," *Chemical Engineering Education*, 1981, p. 78.

21. Shacham, M. and M.B. Cutlip , "Chemical Reactor Simulation and Analysis at an Interactive Graphical Terminal," *Modeling and Simulation in Engineering*, 1983, p.27.

22. Fogler, H.S. and S.E. LeBlanc, *Strategies for Creative Problem Solving*, Prentice-Hall, Englewood Cliffs, NJ, 1995

LIST OF TABLE CAPTIONS

LIST OF FIGURE CAPTIONS