APPLYING NEW TECHNOLOGIES TO THE CLASSROOM – WHAT HAVE WE LEARNED FROM PAST EXPERIENCE

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Introduction

Application of new technologies in the classroom in the modern era has probably started with the introduction of the concept of Computer-Based Instruction in the nineteen seventies (see, for example, Shacham and Cutlip, 1981), where interactive computer terminals with touch sensitive screens were used to enhance the learning process. Since those early days considerable amount of experience has been accumulated in successful and less successful applications of new technologies in the classroom.

A well knows success story is the Process Control laboratory where "virtual" experiments have replaced some of the hands-on experiments. The use of virtual (simulated) experiments can reduce considerably the cost of a laboratory course, increase the number of experiments included and enable carrying out experiments that otherwise would require working with dangerous materials and/or working in dangerous conditions. In the nineteen eighties the Advanced Control System (ACS) of IBM was used in several Universities for carrying out simulated laboratory experiments (Corripio, 1987). In the nineteen nineties PC based simulation programs have replaced the main frame based ACS program (Cooper, 1993). Nowadays, the virtual laboratory experiments are widely used in the process control laboratory and there are attempts to introduce them into additional laboratories, such as the Unit Operations laboratory (Wiesner and Lan, 2003).

There are also indications of success of the application of new technologies to enhance "distance learning". Distance learning is directed mainly toward a target audience of employed professionals. The use of distance education in Bachelor engineering studies has been very limited so far, however there are several successful distance learning based Masters' programs (Bourne et al. 2005). Distance learning has been also successfully utilized for delivering various courses to practicing engineers in programs called "Continuing Education" and "Lifelong Learning."

In courses that teach technical skills, such as the use of various computer-based tools for problem solving, preparation of documentations and presentations, and even computer programming, there is considerable amount of evidence to show that in such courses classroom instruction can be successfully replaced by e-learning even in on-campus study environments. The textbook by Seider et al. (2004), for example, contains a CD-ROM that provides multi-media instructional materials to teach the usage of the process simulation programs ASPEN PLUS and HYSYS. These software packages are studied only in a self-paced manner, without any classroom instruction.

In contrast to these success stories there is also evidence of failures in the use of instructional technology. Felder and Brent (2005), for example, caution in their article "Death by PowerPoint" against the excessive use of pre-prepared PowerPoint visuals for teaching. The undesired effects of such extensive use may include the following: 1) the attendance in the class session may drop as students have access to copies of the presentation in the course web site; 2) the class may become mind-numbing for students who have studied the material, and the pace may be too fast for students who did not; 3) the students may not appreciate the knowledge of the instructor as he/she only "repeats what is already written on the slides".

Roskowski et al. (2002) report on student resistance to use an instructional and computational software package that had no particular assignment attached to it. To overcome the initial resistance, the package was introduced into homework problems and tests. After the students learned to use the new package they found it beneficial to continue using it in assignments where the use was not requested explicitly. Thus, students may often disregard instructional material if it does not seem to affect the final grade.

Incorporating new technologies into a course may require tremendous amount of effort while taking the risk of failure to reach the desired goals. However, successful incorporation of new technologies is often an evolutionary process. The initial development of the instructional material should be followed by application-feedback-revision cycles, until the results are satisfactory. In the following sections our experience in fifteen years of evolutional refinement and use of Computer Based Exams (CBE) in the Chemical Engineering Department of the Ben-Gurion University of the Negev are briefly described.

Use of CBE in a Self Paced, Mastery Oriented Framework

The development of the early versions of CBEs was motivated by the introduction of the "Keller Plan" of Personalized System of Instruction (PSI, Keller, 1968). The key concepts of the PSI are the following:

1. *Individually Paced*, divided into 15 to 20 units and detailed study guides are provided
2. *Mastery Oriented*
3. *No Punishment for Failure*
4. *Proctors Deliver Course*: repeated testing and immediate scoring
5. *Stress upon Written Materials*: lectures are optional

CBE can be a preferable choice for self paced learning with requirement for repeated testing and immediate scoring. Indeed CBE has been widely used in disciplines such as social sciences and medical studies. The exams given in those disciplines are fairly simple; contain multiple choice and true/false type questions. Such type of questions can be used in exams where the students are tested for knowledge, recollection and understanding of the course material. In engineering the student is requested to do more than that. He must also demonstrate ability to use the knowledge for problem solving. Thus the CBE in engineering must include problem solving.

Following this premise CBEs were developed in the Chemical Engineering Department in the early 1990, in several courses (“Introduction to Personal Computers”, “Modelling and Simulation of Chemical Processes”, “Optimization” and “Fluid Mechanics”). Detailed descriptions of some CBEs are provided by Shacham (1998). A brief discussion of the subject is included here.

According to the principles of the mastery learning most of the material learned must be included in the exams. To ensure inclusion of as much material as possible five to six mastery oriented quizzes and an evaluative final exam were given during the semester.

The key components for the CBE were the exam grading programs. These programs were typically Visual Basic programs that checked the credentials of the student, carried out the computations required for the solution of a particular problem, presented questions related to the problem being solved, provided feedback on the answers and, finally, recorded the grade which was obtained based on the fraction of the questions that were answered correctly. The tests were typically delivered in a classroom with networked PC’s. Numerical software packages such as POLYMATH[1], Excel[2], or MATLAB[3] were used to solve the exam questions. All the questions required some numerical data that could be varied so that to yield different solutions. Every student received three different sets of data for his exam. At first he had to solve the problem using the first set of the data. The solution files were saved and some of the numerical results were copied into the exam sheet. Next, the exam's grading program was opened and questions related to the solved problems are presented. For a correct answer the feedback "correct" was provided. For an incorrect answer the student was given one chance to correct his answer. This was done in order to allow him to correct technical mistakes, such as those originating from typing errors, accidental key-press or insufficient significant digits in the answer. If the second answer was also wrong, the correct answer was shown and points were deducted from the grade.

If all the answers were correct, the student had to answer only a few key questions. If not, more questions related to the intermediate stages of the solution are presented. This, together with the presentation of the correct answer, allowed the student to find out where the mistake was made. If there was enough time left, he could correct his mistakes, resolve the problem (using a different set of data) and improve his grade. After finishing the exam the student had to turn in the entire set of Polymath, Excel or MATLAB solution files and the exam form, where his particular data and key results are written. The solution files, that contain a complete documentation of the solution process, could be used to verify that the grade given by the computer represents correctly the student's achievements in the exam, or additional reviews of the solution file were required.

Practical stumbling blocks in the implementation of the PSI

In spite of the proven pedagogical advantages of the "Keller Plan" (Keller 1968), its practical implementation using CBE run into several stumbling blocks. The most serious difficulties were the following.

"Self Pacing" dictates that the students can take quizzes, test or exams whenever they feel ready. What actually happened is that the best students took the tests first and they disclosed the information regarding the questions presented and the correct method of solution to the rest of the students. Thus, most of the students did not have to learn all the course material but only the parts which were actually covered in the quizzes and exams.

Mastery learning requires covering in quizzes or exams as much of the course material as possible, so that many quizzes should be scheduled during the semester. The supervision in the rooms where the exams or quizzes are carried out is expensive; therefore, the University Administration limited the number of quizzes that could be given. Furthermore, mastery learning enables most of the students to obtain grades which are significantly higher than in regular courses. Grades that do not reflect the ranking of the students according to their abilities are unacceptable by the administration, either.

Because of these practical considerations it was decided to abandon self pacing and mastery learning. Unfortunately, when CBEs (of the form that was described in the previous section) are used not in a mastery learning mode, they are not easier to grade than the traditional exams. The grading program will detect the first incorrect numerical answer, but most probably all the rest of the answers down the solution path, from this point on, will be

[1] POLYMATH is copyrighted by M. Shacham, M. B. Cutlip and M. Elly, http://www.polymath-software.com/
[2] Excel is trademark of Microsoft Corporation, http://www.microsoft.com
[3] MATLAB is trademark of The Math Works, Inc., http://www.mathworks.com

judged incorrect. Thus, the program itself cannot detect how many errors were actually made, and manual grading is required. With manual grading the extra effort in preparation of CBEs is not justified and a different approach must be developed.

The evolution of CBE in Chemical Engineering Courses

In light of the difficulties described in the previous section it was essential to modify the requirements in the courses where CBE's were used. All the quizzes were converted to Internet based homework assignments. Details of such assignments (self tests) are available in the publication Shacham (2005) and also on the website: http://echem.bgu.ac.il/staff/Mordechai%20Shacham/introduction.htm. The benefits of the homework assignments are the same as of the CBEs provided that the students complete all the assignments and also that they work them out independently on their own. To ensure that all the assignments are completed their grades are included to the extent of 10 % in the course grade. To ensure that the students solve the problems on their own, they are requested to use a software package that requires programming, (such as MATLAB) to reach the solution. In the midterm and final exams the students are requested to use the same problem solving tool. We have found that a student, who does not solve the homework assignment on his own, does not acquire enough proficiency in the use of the problem solving tool and have no chance to pass the exams. The importance of working out the homework assignments on their own, is explained to the students in the beginning of the course.

A Currently Used CBE in Midterm and Final Exams

The midterm and the final exams of the course are held in a computer laboratory, under supervision, where the students have to present their identity card to take the exam. The duration of the midterm exam is two hours and the final exam is three hours.

A typical midterm exam which was recently given in a "Mathematical Modeling and Numerical Methods" course is presented in Appendix A. The exam questions are based on problem 12.3 in the book of Cutlip and Shacham (2008). There are two questions in the exam. The first one involves the calculation of the Wilson equation coefficients for a binary system which includes ethyl alcohol and a another randomly assigned organic compound. The Wilson equation represents activity coefficients for non-ideal systems and in this question the students should use azeotropic point data to calculate the coefficients. This requires the solution of a system of two nonlinear algebraic equations. The students should specify the mathematical model of the problem, use MATLABs' symbolic manipulation capabilities to derive the partial derivatives of the functions and solve the problem iteratively using the Newton-Raphson method. All the steps of the solution are implemented in MATLAB programs. The second question involves the calculation of the dew point temperature for the same non-ideal binary system that was used in question 1. The method of solution is similar to the solution of question 1, except that in this case there are three simultaneous nonlinear algebraic equations and the partial derivatives are calculated using finite differences.

After finishing the exam the students turn in the exam form, where their individual data are specified and all the MATLAB files that were used for the solution. The MATLAB programs provide clear and precise documentation of all the solution steps. Thus, the programs are the best means to assess the knowledge level of the student and to grade the exam. No self grading is used now in the midterm and final exams.

Conclusions

Using CBE as an example it has been demonstrated that application of new technologies to the classroom is a lengthy, evolutionary process. At first, educational theory can be used to determine the best way of application of the new technologies; however cycles of class test-feedback-revision are often needed in order to reach the most beneficial combination.

In the case of CBE the initial intention was to use it in order to enable self pacing and mastery learning in chemical engineering courses. Class tests have shown that traditional universities (based mainly on classroom learning) are not ready yet to accept these forms of learning. Evolutionary change of the concepts, over a period of about ten years, enabled reaching a satisfactory combination where computer grading and immediate feedback are used to enhance the effectiveness of the homework assignments. The presentation of the solution in a form of a computer program (in the midterm and final exams) ensures complete understanding of the course material.

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Appendix A

Problem Statement for the Midterm Exam of the Course: "Mathematical Modeling and Numerical Methods in Chemical Engineering"[†]

The Wilson[*]1 equations are used to correlate the activity coefficients of strongly non-ideal, but miscible systems. The Wilson equations for activity coefficients in binary system are:

$$\begin{aligned} \ln \gamma_1 &= -\ln(\theta_1) + \frac{x_2(G_{12}\theta_2 - G_{21}\theta_1)}{\theta_1\theta_2} \\ \ln \gamma_2 &= -\ln(\theta_2) - \frac{x_1(G_{12}\theta_2 - G_{21}\theta_1)}{\theta_1\theta_2} \end{aligned} \tag{A-1}$$

where $\theta_1 = x_1 + x_2 G_{12}$ and $\theta_2 = x_2 + x_1 G_{21}$, G_{12} and G_{21} are adjustable parameters which must be determined from experimental data, x_1 and x_2 are mole fractions of components 1 and 2 respectively.

The vapor liquid equilibrium ratios can be calculated assuming that the modified Raoult's law apply, thus $k_i = \gamma_i P_i / P$, where γ_i is the activity coefficient of component *i* in the liquid phase, P_i is the vapor pressure of component *i*, and *P* is the total pressure.
Vapor pressures at various temperatures can be obtained from the Antoine equation

$$\log P_i = A_i - \frac{B_i}{C_i + T} \tag{A-2}$$

where *T* is the temperature in ºC , P_i is the vapor pressure of component *i* in mmHg and A_i, B_i and C_i are the Antoine equation constants given in Table A-1.

Azeotropes represent a condition where vapor and liquid phases have identical composition, meaning that all the vapor liquid equilibrium coefficients: $k_i = \gamma_i P_i / P = 1$, at the temperature, pressure and composition of the azeotrope. Thus at the temperature of the azeotrope $\gamma_i = P / P_i$. This allows the coefficients of the Wilson equations to be calculated from one set of azeotropic data.

1. For the binary system ethyl alcohol (No.1) and ___________ (No. 2) calculate the Wilson equation coefficients using the binary azeotrope data in Table A-2. For the solution rewrite equations (A-1) in the form of: $f_1(G_{12}, G_{21}) = 0;\ f_2(G_{12}, G_{21}) = 0$. Derive the expressions for the partial derivatives of the functions and solve this system of equations using the Newton-Raphson method. Start from the initial guess: G_{21}=G_{12}=0.1. Stop the iterations when $\|f\|<10^{-5}$ or the number of iterations ≥20. Solve with MATLAB.
2. For the same binary system of Question 1, calculate the dew point temperature (T_d) and liquid composition at the dew point (x_1, x_2) for the case where the ethyl alcohol mole fraction in the vapor phase is y_1 = 0.4. For calculation of activity coefficients use the Wilson equations with the coefficients calculated in question 1. Solve by the Newton-Raphson method using finite difference approximations for the partial derivatives. Start from the initial

[†]Based on Problem 12.3 in Cutlip and Shacham (2008)
[*]Wilson, G. M. J. Amer. Chem. Soc. 1964, 86, 127-130.

guess: T_D = 70 ℃, x_1 = 0.5. Stop the iterations when $\|f\| < 10^{-5}$ or the number of iterations ≥20. Solve with MATLAB.

Table A-1 Antoine Equation Constants for Vapor Pressure of Various Substances‡

Name	Formula	*A*	*B*	*C*
Ethyl Alcohol	C_2H_6O	8.04494	1554.3	222.65
Methyl acetate	$C_3H_6O_2$	7.20211	1232.83	228.0
Methyl propionate	$C_4H_8O_2$	7.12841	1257.14	216.4
Ethyl propionate	$C_5H_{10}O_2$	7.07293	1298.30	210.7
n-Propyl formate	$C_4H_8O_2$	7.04006	1235.00	216.1
n-Propyl acetate	$C_5H_{10}O_2$	7.06665	1304.10	210.0
Benzene	C_6H_6	6.90565	1211.033	220.79
Toluene	C_7H_8	6.95464	1344.80	219.482
n-Pentane	C_5H_{12}	6.85221	1064.63	232.00
n-Hexane	C_6H_{14}	6.87776	1171.530	224.366
n-Heptane	C_7H_{16}	6.90240	1268.115	216.900
n-Octane	C_8H_{18}	6.92374	1355.126	209.517
Carbon Teterachloride	CCl_4	6.9339	1242.43	230.0

Table A-2 Binary Azeotropes Containing Ethyl Alcohol‡

Ethyl Alcohol (B.P. 78.3 °C)	B.P. @ 760 mm (ºC)		% by weight	
	Other component	Azeotrope	Alcohol	Other component
Methyl acetate	57.0	56.9	3	97
Methyl propionate	79.7	72.0	33	67
Ethyl propionate	99.2	78	75	25
n-Propyl formate	80.8	71.8	38	62
n-Propyl acetate	101.6	78.2	85	15
Benzene	80.2	68.2	32.4	67.6
Toluene	110.8	76.7	68	32
n-Pentane	36.2	34.3	5	95
n-Hexane	68.9	58.7	21	79
n-Heptane	98.5	70.9	49	51
n-Octane	125.6	77.0	78	22
Carbon teterachloride	76.8	65.1	15.8	84.2

‡Dean. A. (Ed.), *Lange's Handbook of Chemistry*, McGraw Hill: New York, 1973