Session 3213

Effective Teaching and Active Learning of Engineering Courses with Workbook Strategy

Yaşar Demirel
Department of Chemical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

Abstract

Often mismatches between learning and teaching styles arise because students are in majority visual and sensing learners, and most instructors are intuitive and reflective learners. Beside that, textbooks also have their own styles, and their contents, depth of coverage of materials, and organization may affect the teaching and learning environment. Instructor, as the primary selector of the textbook, has the responsibility in providing students with effective teaching strategy. Here, we present a new strategy called the 'workbook strategy," which integrates these four elements: (i) classroom analysis, (ii) use of workbook beside textbook, (iii) group work, and (iv) use of 'blackboard' as information technology. The workbook strategy provides verbal and visual elements of the course material in an organized way, and relates fundamentals to applications. Such strategy may reduce the mismatches between learning and teaching styles, and hence improves active learning, critical thinking, and problem solving skills. Most of the students who are exposed to the workbook strategy have found it very effective in their learning.

1. Introduction

All educational institutions emphasize that teaching is important, and give high priority to developing effective learning and teaching strategies.[1-6] Effective teaching may include high level of creativity in analyzing, synthesizing, and presenting knowledge in new and effective ways. It should instill in the students the ability to be analytical, intellectually curious, culturally aware, employable, and capable of leadership.

Student's native ability, background, and the match between the learning and teaching styles determine the level of learning. To maximize students learning, we should improve the effectiveness of our teaching by incorporating a multi-style approach to engineering education, since the strength and dimension of students learning styles vary.[7-10] This study presents a multi-style teaching/learning approach called the workbook strategy implemented in the Department of Chemical Engineering at Virginia Polytechnic Institute and State University. We plan to share the elements and outcome of this strategy with other engineering departments across the Nation.

2.. Basis for Development of Workbook Strategy

Among others, the following issues are widely observed and acknowledged in engineering education. (i) There are often mismatches between the learning and teaching styles; most instructors are intuitive learners, and yet students are in majority visual and sensing learners;[7,10-12] textbooks also have their own styles in providing the theory and applications, which may affect the teaching and learning styles. (ii) Students often learn problem solving using cook-book procedures instead of learning how to solve problems by understanding the concepts.[12-14] (iii) Students mainly lack the skill of transferring and synthesizing knowledge in higher order within a course or across courses.[15,16] (iv) Instructors should improve the effectiveness of their teaching, since student's native ability, background, and the match between the learning and teaching styles determine the level of learning.[7-10]

2.1. Learning and Teaching Styles

Learning styles involve verbal or visual input modality, sensing or intuitive perception, active or reflective processing, and sequential or global understanding of a course material. On the other hand teaching styles involve instructor's emphasis on factual or theoretical information, visual or verbal presentation mode, active or reflective student participation, and sequential or global perspective.[9,10] However, the dimensions of learning and teaching styles are neither unique nor comprehensive.[10-13,17,18] Preferences in various learning styles may vary among students depending on the field or background. For example, a student may have balanced preferences in verbal and visual learning, or one of these may be mildly or strongly preferable. There is a mismatch between learning and teaching styles since most students are visual and sensing learners, and yet 90-95% of content for most courses is verbal, and most instructors are intuitive and reflective learners.[7-11] Therefore, a multi-style approach is an essential part of a strategy for an effective, and collaborative student-centered learning environment.[7-9,19-26] However, teaching in engineering education mainly is instructor-centered and traditionally deductive.[2,7,12]

2.2. Effective Teaching and Active Learning

Engineering students are encouraged to work with real-process applications, charts, diagrams, hands-on practices, and demonstrations beside theory, equations, and words.[15,22-26] An effective teaching technique should engage students actively, stimulate sense of enquiry, and facilitate collaborative learning, through, for example, group work.[22-32] In group-work activity, two or three students can apply a newly learned concept in a short application, such as problem solving, which promotes problem-based learning.[22,25,29,30] Group-design projects, in-class presentations, computer simulations, experiments, would be part of the active learning and deep learning.[28-33] This would enhance the skill of transferring knowledge in higher order within a course or across courses.[15,16] Some current educational systems teach students to solve problems using cook-book procedures rather than teaching students how to solve problems in engineering analysis, and a survey[14] shows that in some institutions, both instructors and students believe that there is no urgent need for changing the present educational practices, mainly because of misleading assessment practices.

3. **Workbook Strategy**

The workbook strategy aims to enhance effective teaching and active learning in engineering education by integrating the following four elements: (1) analysis of classroom, (2) use of workbook in teaching, (3) group work, and (4) 'blackboard' as information technology aided tool. The workbook strategy may enhance the effectiveness of instructor and textbook by making the course material more visible and easily extractable, relevant with applications, and hence reducing the mismatches between the learning and teaching styles. The elements and implementations of them are described in the following sections.

3.1. Analysis of Classroom

Most college classrooms in the United States consist of students with diverse educational and cultural backgrounds. Classroom analysis takes this into account, and reveals the following attributes of the students: (i) learning preferences, (ii) course loads, (iii) programming and computer skills, (iv) native background, and (v) specific concerns, such as employment responsibilities, or learning disabilities, or student athletes. Development of a standard classroom analysis procedure is in progress. This analysis can help instructor to communicate with the classroom more effectively, and establish groups consisting students with different learning preferences, so that they may teach each other in their group work.

The Felder-Soloman's Index of Learning Styles (ILS)[(11)] is a statistically acceptable tool for assessing the learning preferences of engineering students.[(13,17,18)] The ISL is used to assess the learning preferences of 36 students taking the separation course. The index shows that 85 % of the students have a mild to strong preference for visual learning, and half of the students are active learners.

3.2. Preparing and Using Workbooks

The workbook starts with a detailed course syllabus containing the break of topics to be covered from the textbook. It presents these topics with all the essential verbal and visual elements taken from the textbook in a systematic and organized way to teach students with various learning preferences and diverse backgrounds. The visual elements are most of the related simulation or experimental presentations, graphs, diagrams, algorithms, flow charts, tables, pictures, figures, and data. The verbal elements include theory and analysis, definitions, and equations. Visual and verbal elements support each other in a categorized way, and hence (i) stimulate easy understanding, (ii) relate fundamentals to applications, and (iii) reduce mismatches between learning and teaching preferences. This is important because, students and instructors have to connect the pieces in classroom by searching equations, data, and concepts, which sometimes may be spread out on several pages within the textbook. If this vital connection, when needed the most, fails or incomplete then effectiveness of teaching and learning decreases at best, or may fail completely. Within the workbook an engineering analysis and a related flow chart showing the use of analysis in solving a problem appears as a package on the same or on the next page.

However, some of the verbal and visual elements are deliberately left incomplete or missing, so that instructor and students have to complete them jointly during lecturing to create effective course notes. The workbook identifies example and homework problems and allocates spaces for them. Students and instructor discuss these problems to relate fundamentals to applications. The best format of a workbook mainly depends on the experience of the instructor, organization of textbook, level of course, and feedback from the department and students.

Procedurally, at the start of the semester, the workbooks are distributed. Instructor delivers lectures from the transparencies of the workbook with an overhead projector, and completes the missing verbal and visual elements jointly with the students. The note taking becomes systematic and organized, and the time is reduced considerably, since the crucial diagrams, figures, and some fundamentals are already provided. Teaching with all the crucial visual elements available to instructor and students leads effective teaching and learning. The time saved for having a figure or a chart in the right time and location can be channeled to critical thinking, asking questions, and in-class group work.

Some of the anticipated and observed benefits of learning and teaching environment with the workbooks are:

(i) The workbook provides the students with objectives, visual elements, analysis, and applications in categorized way. Hence, it may reduce the mismatches between the learning and teaching styles, and help the students with diverse backgrounds.

(ii) Instructor and students collaborate actively during the lecturing as they complete the missing or incomplete visual and verbal elements, and discuss applications.

(iii) The workbook provides students with organized course notes, hence more time in their critical thinking and interactions with the instructor. This enhances deep learning of the course material, and the skill of transferring knowledge within or across courses.

(iv) The workbook provides easy access to definitions, analyses, applications, synthesis, graphs, diagrams, figures, tables, data, examples, and homework problems, leading to effective review of the course material.

(v) The workbook provides example and homework problems, and relates them to fundamentals.

The workbook strategy has been implemented in three engineering courses in the Chemical Engineering Department at Virginia Tech.[(33,34)] The first workbook is 108 pages, prepared for the textbook "Introduction to Chemical Engineering Thermodynamics" by Smith et al.,[35] and used in *CHE 2164 Chemical Engineering Thermodynamics*. The second is 97 pages, prepared for the textbook "Numerical Methods for Engineers" by Chapra and Canale,[36] and used in *CHE 2124 Simulations.* The last one has 118 pages, prepared for *Equilibrium Staged Separation* by Wankat,[37] and used in *CHE 3134 Separation Processes*. The sample workbook formats for the courses are elaborated in the following sections.

Figures 1 to 2 show typical incomplete workbook pages in the thermodynamic course. In Figure 1, an experimental isobaric vapor liquid equilibrium data for ethanol-water system in table form is analyzed. Degrees of freedom are explained, and the azeotropic point was underlined. Underneath the table, *T-x-y* and *x-y* equilibrium diagrams are supplied. A feed mixture located in the subcooled liquid region on the *T-x-y* diagram is heated, and the phase behavior of the mixture has been explored by obtaining the compositions and phase amounts of the system at various temperatures. Following this, a group work is assigned to obtain the boiling and dew point temperatures of a mixture; all the groups worked on their packages containing *T-x-y* phase diagrams.

Figure 2 starts with background information on vapor-liquid equilibrium calculations. In the following box, the type of calculations, the variables specified and to be calculated for bubble point calculations using the gamma-phi method are explained and discussed. The related flow diagram is also supplied, and explains how to start, proceed and finish the calculations by using the appropriate equations. The flow diagram and equations provide the necessary connections between the concept and the block diagram. Therefore students will not be distracted to search for these equations in learning the block diagram.

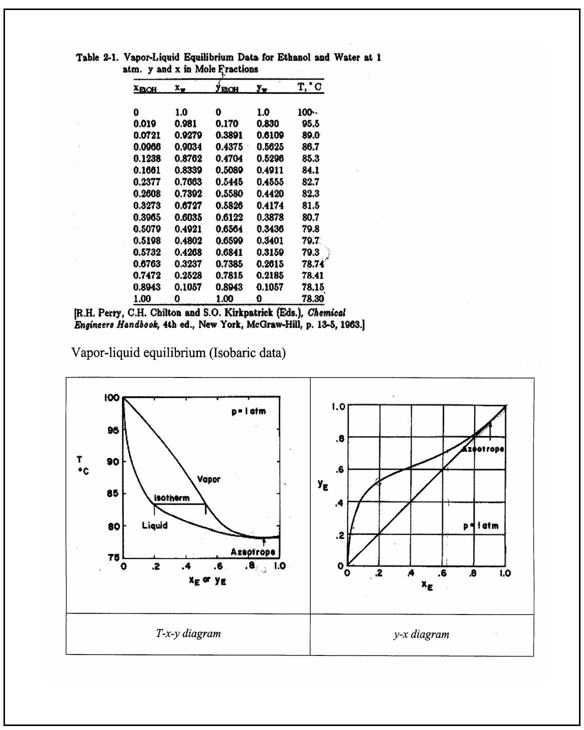


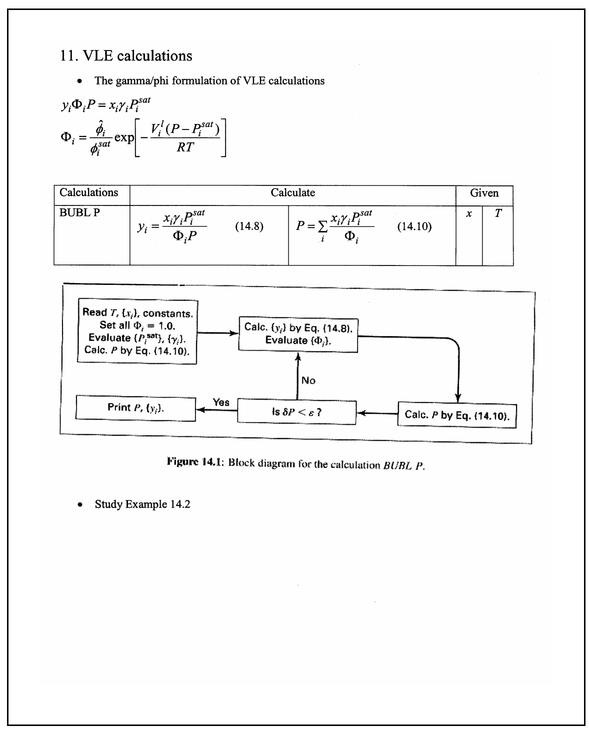
Table 2-1. Vapor-Liquid Equilibrium Data for Ethanol and Water at 1 atm. y and x in Mole Fractions

x_{EtOH}	x_W	y_{EtOH}	y_W	T, °C
0	1.0	0	1.0	100
0.019	0.981	0.170	0.830	95.5
0.0721	0.9279	0.3891	0.6109	89.0
0.0966	0.9034	0.4375	0.5625	86.7
0.1238	0.8762	0.4704	0.5296	85.3
0.1661	0.8339	0.5089	0.4911	84.1
0.2377	0.7663	0.5445	0.4555	82.7
0.2608	0.7392	0.5580	0.4420	82.3
0.3273	0.6727	0.5826	0.4174	81.5
0.3965	0.6035	0.6122	0.3878	80.7
0.5079	0.4921	0.6564	0.3436	79.8
0.5198	0.4802	0.6599	0.3401	79.7
0.5732	0.4268	0.6841	0.3159	79.3
0.6763	0.3237	0.7385	0.2615	78.74
0.7472	0.2528	0.7815	0.2185	78.41
0.8943	0.1057	0.8943	0.1057	78.15
1.00	0	1.00	0	78.30

[R.H. Perry, C.H. Chilton and S.O. Kirkpatrick (Eds.), *Chemical Engineers Handbook*, 4th ed., New York, McGraw-Hill, p. 13-5, 1963.]

Vapor-liquid equilibrium (Isobaric data)

Figure 1. A typical workbook page from for the isobaric vapor-liquid equilibrium data in the form of table, *T-x-y* and *y-x* diagrams with group work



11. VLE calculations

- The gamma/phi formulation of VLE calculations

$$y_i \Phi_i P = x_i \gamma_i P_i^{sat}$$

$$\Phi_i = \frac{\hat{\phi}_i}{\phi_i^{sat}} \exp\left[-\frac{V_i^l (P - P_i^{sat})}{RT}\right]$$

Calculations	Calculate		Given	
BUBL P	$y_i = \frac{x_i \gamma_i P_i^{sat}}{\Phi_i P}$ (14.8)	$P = \sum_i \frac{x_i \gamma_i P_i^{sat}}{\Phi_i}$ (14.10)	x	T

Figure 14.1: Block diagram for the calculation *BUBL P*.

- Study Example 14.2

Figure 2. A typical workbook page for the bubble and dew point iterative temperature calculations with group work for a ternary mixture.

Figures 3 and 4 show some typical incomplete pages from the workbook prepared for the simulation course. In Figure 3, the secant method and the modified secant method are introduced. The Secant method is explained with a figure. After that example 6.6 is solved and discussed, and a short group work is assigned to apply the secant method to estimate the root of an equation. After the group work, the secant method has been compared with the False-position method on the series of graphs.

Figure 4 demonstrates the introduction of optimization. Here, firstly the concept of extremum is related to minimum and maximums of a continuous function with some visual elements of figures immediately following. Later the golden-section search is explained with many examples for optimization problems. A short group work has followed this analysis. This analysis and applications are further associated with the dimensions from an old Greek temple.

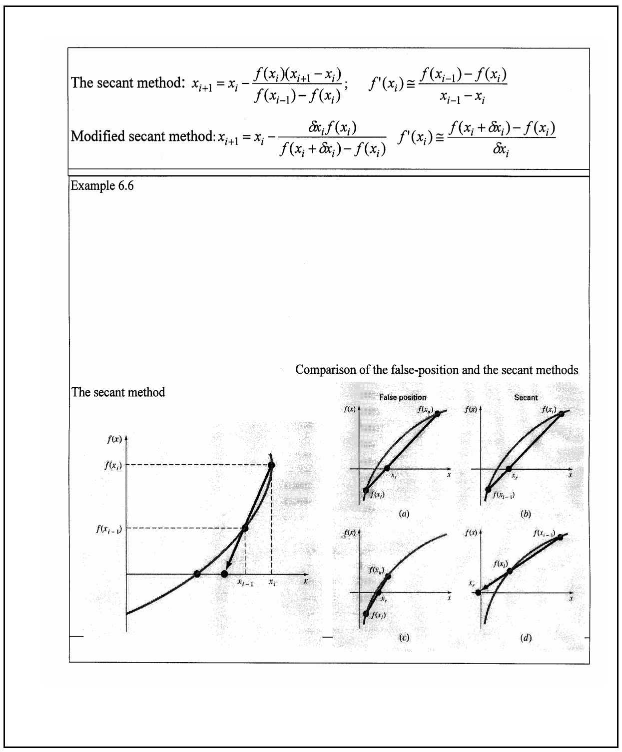


Figure 3. A typical incomplete workbook page on the matrix operations and set of linear algebraic equations from the workbook for the course on simulation.

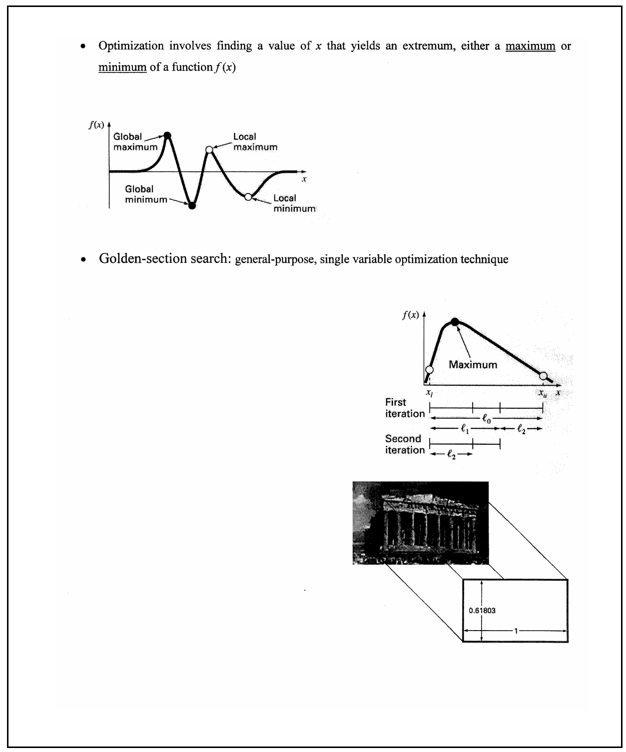
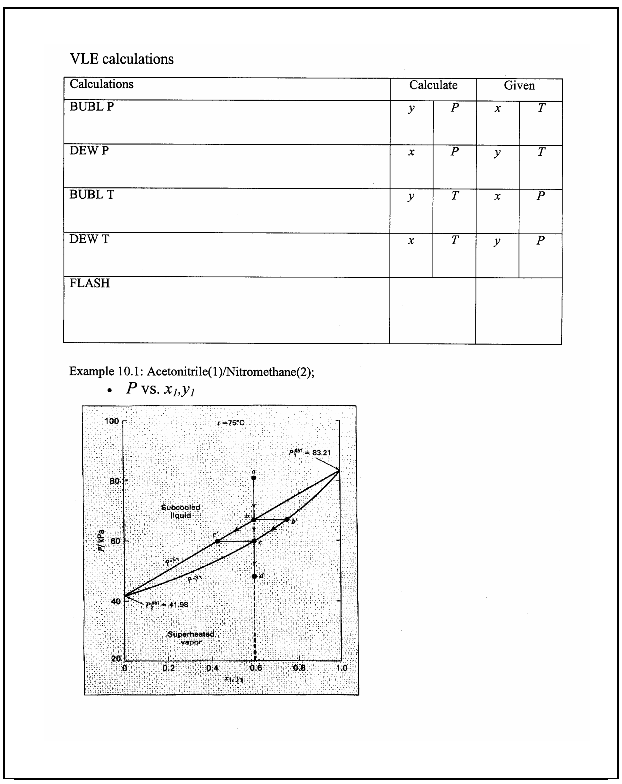


Figure 4. A typical workbook page for optimization concept and 'golden search method' in the workbook for the course of simulation

Figures 5 and 6 show some trial-page formats from the workbook prepared for separation processes course. Figure 5 starts with analysis of vapor-liquid equilibrium calculations of bubble point, dew point, and flash. For each type calculations the variables specified and those to be calculated are identified; objective functions to satisfy are discussed. The analysis has been related to graphical determination of bubble and dew point pressure calculations on a *P-x-y* phase equilibrium diagram. Following this a group work is assigned to calculate the dew point pressure.

Figure 6 shows an application of theory introduced previously by solving the example problem 11.2 on the multistage batch distillation. Since McCabe-Thiele diagram is provided, the procedure is explained step by step in order to construct the plot of $(1/(x_D - x_W))$ versus x_W by using the changing values of x_D on the *y-x* equilibrium diagram. The area underneath the curve is calculated using Simpson's rule to find the final amount of liquid W_F, the total distillate D, and the average distillate composition $x_{D,av}$. The solution is provided on the same page with all the related analysis and diagrams, whereas analysis and application may be spread out in various pages in some textbooks.



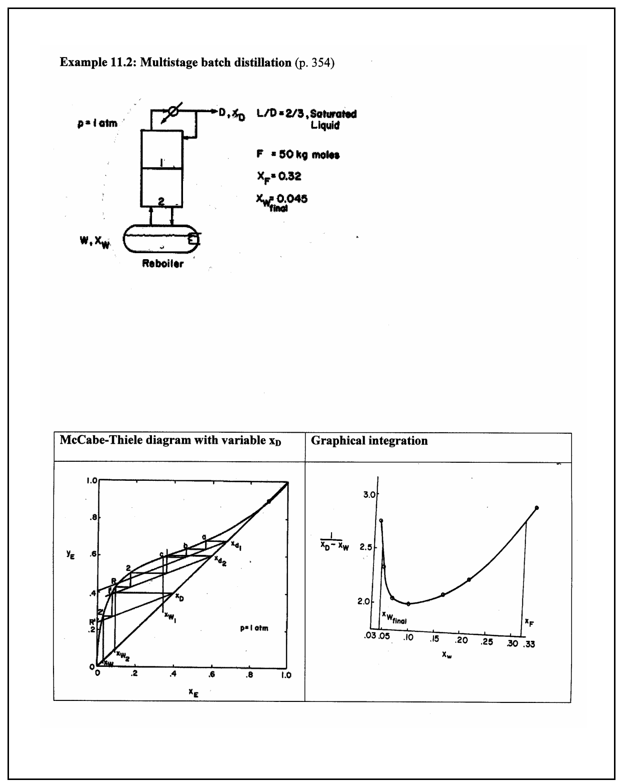
VLE calculations

Calculations	Calculate		Given	
BUBL P	*y*	*P*	*x*	*T*
DEW P	*x*	*P*	*y*	*T*
BUBL T	*y*	*T*	*x*	*P*
DEW T	*x*	*T*	*y*	*P*
FLASH				

Example 10.1: Acetonitrile(1)/Nitromethane(2);

- *P* vs. x_1, y_1

Figure 5. A typical workbook-page from the separation processes for multicomponent flash calculations using Newtonian method, the Rachford-Rice equation. An application problem is continued on the next page.



Example 11.2: Multistage batch distillation (p. 354)

Figure 6. A typical workbook-page for separation processes course for the multistage batch distillation using the equilibrium graph and the curve for graphical and numerical integration.

3.3. Group Work

Groups consist of two or three students with different learning preferences. Group work activity splits into two: (i) in-class group work, and (ii) out-class group work. For in-class group work, instructor prepares and distributes group packages containing some of the graphs, diagrams, and data that are to be used to record all the group activities all through the semester. Practically in every lecture, groups solve a short problem related to freshly introduced fundamentals and analysis. They, usually, work about 10 to15 minutes in their collaborative learning, and submit the packages at the end of each lecture. Instructor checks and returns the group work within the next lecture. Besides that, in 'two-minute breaks', students talk with each other, think on what they are doing, and ask questions. Sometimes they answer questions, such as 'what are the three important keywords within the last chapter?'

Out-class group projects on engineering analysis and computation are assigned for each group. Groups prepare the projects in two or three weeks, and often present them using power point presentation in front of other groups.

3.4. 'Blackboard" Information Technology

"Blackboard" information technology is a secure, Web-based teaching, learning and communication platform. Instructor can use 'blackboard' for providing students with course syllabus, course information, supplemental course material, Web sites, assignments, group projects, assignment, quiz or test solutions, test objectives, announcements, and communications with email. Other features of 'blackboard,' such as instructional design and course assessments can also be utilized. Student information systems, such as Datatel Colleague, People Soft SIS are available in the 'blackboard learning systems.'

4. Preliminary Assessments of Workbooks

Proper assessment is essential for measuring the true effectiveness of the workbook strategy, and developing the best format and procedure for a particular course. Therefore workbook will gain maturity after it is implemented, and assessed properly. It is the author's intention to accomplish a true assessment of the workbook strategy using the support from organizations such as the Center for Excellence in Undergraduate Teaching, and the Center for Survey Research at Virginia Tech. For this purpose a proposal has been submitted to NSF-initiated Engineering Education Programs.

Tables 1 and 2 display the questionnaire used for preliminary assessments of workbooks performed by the author, and the student responses in percentages for the thermodynamics and separation processes courses. A similar survey has also been carried out for the simulation course.[33] This survey was carried out after 12 weeks with the workbook strategy. For the thermodynamics 47, and for the separation courses 36 students responded. The questions are treated with the same weight.

Table 1. A preliminary assessment of the workbook (WB) for the thermodynamics course
(1-disagree; 2- tend to disagree; 3- tend to agree; 4- agree; 5- not applicable)

	Questionnaire	Student Responses %				
		1	**2**	**3**	**4**	**5**
1	You have used WB in previous courses	75	10	2	0	13
2	WB contains a detailed syllabus	0	0	17	81	2
3	WB contains subject schedule from the textbook	0	4	13	77	6
4	WB provides objective, mission, and vision statements	0	0	23	73	4
5	WB provides related chapter & section readings	0	13	36	49	2
6	WB provides subject-related problems	0	2	0	96	2
7	WB provides concepts, definitions, and working equations	0	2	19	79	0
8	WB enhances problem-based learning	0	4	23	71	2
9	WB enhances subject-specific skills & deep understanding	0	4	43	51	2
10	WB enhances problem-solving skills	0	17	36	45	2
11	WB makes it easy to locate definitions, and applications	0	4	30	64	2
12	WB relates a subject to data, tables, diagrams and figures	0	0	13	85	2
13	WB facilitates easy course-note taking	0	2	11	85	2
14	WB facilitates effective review of subjects and problems	0	0	30	68	2
15	WB reduces mismatches between learning and teaching styles	2	4	51	39	4
16	WB reduces mismatches between textbook and instructor styles	0	2	47	49	2
17	WB offers a balanced teaching for various learning styles	0	6	45	45	4
18	WB encourages regular attendance	6	9	36	45	4
19	WB stimulates active learning	4	6	45	43	2
20	WB stimulates group work	0	9	42	49	0
21	WB facilitates higher grades from the tests	0	13	34	49	4
22	WB facilitates higher grades from the assignments	0	0	19	77	4
23	WB does not replace the textbook	4	32	19	45	0
24	WB stimulates effective use of the textbook	4	11	40	43	2
25	With group work and blackboard, WB becomes more effective	2	11	47	36	4
26	Overall, WB is beneficial in effective learning	2	0	26	68	4

The following responses might deserve reviewing:

(i) Around 90% of the students agree and tend to agree that workbook reduces mismatches between learning and teaching styles, and hence offers a multi-style learning environment for the students with various learning preferences.

Table 2. A preliminary assessment of the workbook (WB) for the separation processes course
(1-disagree; 2- tend to disagree; 3- tend to agree; 4- agree; 5- not applicable)

Questionnaire		Student Responses %				
		1	**2**	**3**	**4**	**5**
1	You have used WB in previous courses.	14	3	0	83	0
2	WB contains a detailed syllabus.	0	0	3	97	0
3	WB contains subject schedule from the textbook.	0	0	11	89	0
4	WB provides objective, mission, and vision statements.	0	0	17	83	0
5	WB provides related chapter & section readings.	3	8	28	61	0
6	WB provides subject-related examples and homework problems.	0	0	20	80	0
7	WB provides concepts, definitions, and working equations.	0	0	14	86	0
8	WB enhances problem-based learning.	0	3	14	83	0
9	WB enhances subject-specific skills & deep understanding.	3	0	34	63	0
10	WB enhances problem-solving skills.	3	0	31	66	0
11	WB makes it easy to locate subjects, definitions, and applications.	0	0	17	83	0
12	WB relates a subject to data, tables, diagrams and figures.	0	0	11	89	0
13	WB shortens the time for note taking.	0	3	17	80	0
14	WB facilitates effective review of subjects and related problems.	0	0	14	86	0
15	WB reduces mismatches between learning and teaching styles.	3	0	33	61	3
16	WB reduces mismatches between textbook and instructor styles.	3	3	28	66	0
17	WB offers a balanced teaching for various learning styles.	0	3	28	69	0
18	WB encourages regular attendance.	6	8	25	61	0
19	WB stimulates active learning.	3	0	25	72	0
20	WB stimulates group work, and hence collaborative learning.	3	8	28	61	0
21	WB facilitates higher grades from tests & assignments.	6	8	33	53	0
22	WB stimulates the effective use of the textbook.	9	9	42	40	0
23	WB contains enough visual material (figures graphs, data, picture).	0	6	20	74	0
24	WB contains enough verbal material (definitions, analysis).	6	11	22	61	0
25	WB presents visual and verbal elements in an organized way.	3	3	36	58	0
26	WB provides equal access to learning material for each student.	0	0	31	69	0
27	WB is an effective teaching tool for the instructor.	3	0	11	86	0
28	Overall, WB is beneficial in effective learning.	3	0	14	83	0

(ii) Around 92% of them agree and tend to agree that workbook enhances problem-based learning, subject-specific skills, and stimulates active learning.

(iii) Around 90% of the students agree and tend to agree that the workbook stimulates group work and collaborative learning.

(iv) Around 90% of the students agree and tend to agree that overall, the workbook is an effective teaching tool, and beneficial in effective learning.

The following are some examples of the written comments that were made on the assessment questionnaire:

"*I do not have suggestions because I highly approve of the use of workbook. It gives the students time to reflect on what is going on in the class instead of just blindly copying down notes. I encourage all teachers to adopt the workbook which causes positive interactions between student and teacher*."

"*I really like the workbook. It makes the information a lot more clear and cuts out all the messy derivations and extraneous information, so we can understand the concepts then go back to look at it."*

"*The workbook is amazing! It condenses textbook into more meaningful and useful notes; makes more difficult concepts easier to understand. You can tell instructor cares about the student learning and appreciation of the subject matter. Needs no improvements, love the workbook*!"

"*I really like the workbook. It helped me greatly in the course and I wish more teachers would use it. I understand more and have learned a lot*."

"*Workbook helps keep me organized, and allows me to pay attention in class and actively interact with what is going on. It motivates learning, reviewing and comprehension. I wish workbook would be used in all of my classes*."

Table 3 shows a preliminary assessment of the in-class group work after 12 weeks with the workbook strategy for the separation processes course. The author prepared the trial questions, and 36 students responded. Around 90% of the students agree or tend to agree that they have learned from each other most of the time; group work has helped to solve homework problems, and has been an active-learning tool.

Table 3. Preliminary assessment of the in-class group work in the separation processes course (1-disagree; 2- tend to disagree; 3- tend to agree; 4- agree; 5- not applicable)

	Questionnaire	Student Responses %				
		1	**2**	**3**	**4**	**5**
1	You understood the group assignment fully most of the time.	6	11	61	22	0
2	You participated actively most of the time.	0	11	6	83	0
3	You learned from each other most of the time	3	3	40	51	3
4	You contributed ideas and information most of the time.	0	6	16	78	0
5	You listened closely to each other most of the time.	0	8	29	60	3
6	You completed the group work most of the time.	3	19	36	42	0
7	Group work helped to solve homework problems.	0	3	23	74	0
8	You had useful feed back from the instructor on your group work.	8	17	25	50	0
9	The workbook helped you to solve group work.	0	0	39	68	3
10	The group work has been an active-learning tool.	0	6	20	71	3

5. Conclusions

Preparation, implementation, and the preliminary assessments of the workbook strategy for various chemical engineering courses are presented. The workbook strategy incorporates the following in teaching: (i) classroom analysis, (ii) workbook beside the textbook, (iii) group work, and (iv) 'blackboard' as information technology aided platform in education and communication. The preliminary assessments show that the strategy may reduce the mismatches between teachings and learning styles, facilitate greater interactions between students and instructors, and stimulate critical thinking, problem solving, and active learning. Most of the engineering students who have taken the courses have found the workbook strategy is beneficial in their learning. However, a proper assessment is essential to measure the true effectiveness of the strategy in engineering education. This needs a concerted effort from engineering departments, faculty, students, and educational centers.

6. Acknowledgements

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YAŞAR DEMIREL
Dr. Demirel is a visiting professor in the Department of Chemical Engineering at Virginia Polytechnic Institute and State University. He received his Ph.D. from the Department of Chemical Engineering at University of Birmingham, UK. He teaches senior design, separation processes, thermodynamics, transport phenomena, and simulation. His long-term research focus is coupled transport processes in physical and biological systems and stability analysis of transport and rate processes. He is the author of a book titled "Nonequilibrium Thermodynamics: Transport and Rate Processes in Physical and Biological Systems" published by Elsevier in 2002 and over 85 peer-reviewed publications.