1-1-2004

Teaching Engineering Courses with Workbooks

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TEACHING ENGINEERING COURSES WITH WORKBOOKS

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Society expects that a modern college education will turn out students who are analytical, intellectually curious, culturally aware, employable, and capable of leadership.[1] Some important skills needed for all degree programs are problem solving, communication (written and oral), team or group work, learning, and information processing and technology. Instructors feel rewarded and satisfied when they sense that they have made a difference in the life of a student.[1]

All institutions of higher education emphasize that teaching is important and give high priority to developing learning and teaching strategies that focus on promoting students' subject-specific skills, knowledge, understanding, critical perspective, and intellectual curiosity.[2-14] Some of the strategies are active and cooperative learning,[3,11] problem- or case-based learning,[12,13] and teaching through inquiry.[14] Active and cooperative learning is one of the most frequently used teaching methodologies.[15-17] Development of new learning and teaching methodologies should not be interpreted as an obstacle to the research activity of a faculty member and should be fully consistent with the university's research strategy.[18]

As Kennedy[1] suggests, new faculty members soon discover that effective lectures are hard to develop and deliver and take much longer to prepare than they anticipated. Effective teaching incorporates forms of creativity that are not usually thought of as research but which actually analyze, synthesize, and present knowledge in new and effective ways.[1,17]

Traditional methods of learning and teaching embrace lectures, seminars, workshops, and classes, as well as various assignments that require the use of books, handouts, handbooks, and periodicals. As the student advances, incorporation of computers and information technology such as "BLACKBOARD" are developed. Currently, laptop computers are becoming compulsory, and some courses are delivered entirely through the use of computers and information technology with supporting assignments. Some believe that the Internet has the potential of replacing face-to-face teaching, but most courses still use the chalkboard and verbal communication, and teaching and learning methods remain the responsibility of instructor and students.

It is widely recognized that students don't learn as much as we try to teach them. Their native ability, their background, and the match between their learning styles and the instructors' teaching styles determines the level of learning.[17] To maximize the level of their learning, we have to improve the effectiveness of our teaching since, as instructors, we cannot do much about their ability or background.[17,19-21]

Ineffective teaching can cause some students to drop courses, lose self-confidence after getting bad grades, change majors, or in the worst case, change to another institution or give up college altogether. Negative feedback of this nature can also negatively impact future enrollment in engineering degree programs.

To address this problem, two trial workbook projects have been introduced in two sophomore engineering courses at Virginia Tech: 1) introduction to chemical engineering thermodynamics, and 2) chemical engineering simulations. This study presents a first-hand experience with the preparation, use, and assessment of workbook projects that are integrated

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with class group work and the Internet teaching/learning platform BLACKBOARD.

LEARNING AND TEACHING STYLES

In addition to theory, equations, and words, engineering students are encouraged to work with course material that includes real-world applications, pictures, diagrams, and demonstrations.[19] An effective teaching technique should engage students actively, stimulate a sense of enquiry, and encourage them to teach one another.[6-8,14] For example, group work, which is widely used in science and engineering education,[11,17,20,21] promotes problem-based learning and active participation, which can lead to a deep learning that is more likely to be retained. In group-work activity, two or three students can apply a newly learned concept to solve a short problem or to prepare a short essay.

Learning styles involve verbal or visual input modality, sensing or intuitive perception, active or reflective processing, and sequential or global understanding of course material.[17] On the other hand, *teaching* styles involve an instructor's emphasis on factual or theoretical information, visual or verbal presentation, active or reflective student participation, and sequential or global perspective. Learning and teaching styles[17,22,23] are summarized in Table 1. Felder and Silverman[22] emphasize, however, that these dimensions of learning and teaching styles are neither unique nor comprehensive. Balances in various learning styles vary among students and depend on the field or their background. For example, a student may be equally sensing and intuitive or one of these learning styles may be dominant.

A properly prepared workbook makes the content of a textbook more visible, extractable, and relevant for an application or process. The instructor prepares the workbook with all the essential verbal and visual learning elements by using the designated textbook, reference books, and the publishers' web sites.

A student will learn more when teaching is done in his or her preferred style.[17,24,25] For example, if teaching targets both the visual and verbal learners, there is a good possibility that learning is enhanced for the whole group. Felder and Brent[17] have suggested that there is a mismatch between learning and teaching styles since most students are visual and sensing learners but 90-95% of the content for most courses is verbal and most instructors are intuitive learners. Such a mismatch must be addressed for teaching to be effective.[17,22-25]

TABLE 1
Learning and Teaching Styles[17,22,23]

	Learning Styles		Teaching Styles
Input Modality	• *Visual learners:* Prefer to see graphs, diagrams, flow charts, plots, schematics • *Verbal Learners:* Prefer explanations (oral or written)	**Presentation**	• *Visual:* Graphs, Diagrams • *Verbal:* Lecture, reading, discussion
Perception	• *Sensing Learners:* Focus on sensory input, practical, observant • *Intuitive Learners:* Focus on imaginative and conceptual work, theory, and models	**Content**	• *Concrete:* Factual • *Abstract:* Conceptual, theoretical
Processing	• *Active Learners:* Process actively think out loud, and like working in groups •*Reflective Learners:* Process introspectively, work quietly, like thinking and working alone or in pairs	**Student Participation**	• *Active:* Students talk and discuss • *Passive:* Students watch and listen
Understanding	• *Sequential Learners:* Function in continual steps and steady progress, like analysis • *Global Learners:* Need whole picture to function, initially slow, like synthesis	**Perspective**	• *Sequential:* Step-by-step progression • *Global:* Context and and relevance

PREPARING AND WORKING WITH WORKBOOKS

A properly prepared workbook makes the content of a textbook more visible, extractable, and relevant for an application or process. The instructor prepares the workbook with all the essential verbal and visual learning elements by using the designated textbook, reference books, and the publishers' web sites. The verbal elements include all theory and analysis, definitions, synthesis, and related applications. Figure 1 (next page) shows a typical page from a workbook prepared for the thermodynamics course. The visual elements have most of the related graphs, diagrams, schemes, configurations, symbols for process flow diagrams and streams, algorithms, flowcharts, tables, pictures, figures, schematics, plots, analogies, and data. All the predetermined homework assignments come from the textbook and appear with small spaces allocated to each question. The example problems, homework problems, and group work are prepared to relate the verbal and visual elements to each other in an effective way. Most verbal elements are presented with bullets and in categorized boxes. Some of the visual and verbal elements are deliberately left incomplete or missing so the instructor and students can complete them together in the classroom. The quality of a workbook depends on the instructor's experience, the textbook's organization, the level of the course, and feedback from the students.

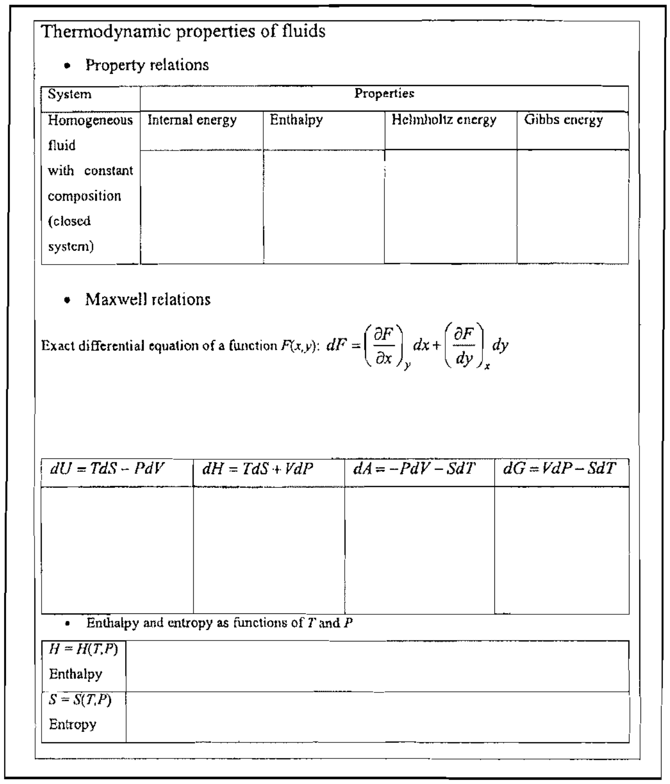
The instructor delivers the lecture with an overhead projector and transparencies of the workbook pages, joining the verbal and visual elements of teaching. Students are exposed to the workbook pages on the screen while they work on them. Problem solving practices are performed in the blank spaces allocated within the workbook. Before assigning homework questions, they are briefly discussed (see Figure 3).

In the presentation, all the related verbal and visual elements support each other and hence stimulate active student participation, easy understanding, and relating the concepts to applications. Lecturing with the workbook incorporates group work on a newly introduced topic by solving a short problem or preparing short essays. This stimulates teamwork and results in the students teaching one another.[20,21] In addition to the group work, the BLACKBOARD multi-user education platform is used with the workbook to provide supplemental course material, assignments, useful sites, text objectives, test solutions, announcements, and communications.

THE WORKBOOK TRIALS

Two workbooks were prepared and distributed to the ChE students at Virginia Tech during the first lecture meeting of two fundamental engineering courses. Although it was not applied in this trial, the Felder index of learning styles[26] or any similar assessment study would be helpful for assessing learning styles of students and for preparing small study groups. Most of the students were sophomores, with small numbers of juniors and seniors in both the courses. The first workbook had 97 pages and was prepared for the textbook *Introduction to Chemical Engineering Thermodynamics*[27] for the thermodynamics course. Some typical pages completed in the classroom from this workbook can be seen in Figures 2 to 4.

In Figure 2, the names of four thermodynamic potentials are given in separate boxes. In an attached box, the system is also defined as a closed system. All the primary properties of pressure P, volume V, temperature T, internal energy U, and entropy S are related to each other in the boxes. After completion, the boxes serve as visual elements containing the related expressions for a well-defined system. In the textbook, this same information is spread out and may necessitate more time and effort for the students to



Thermodynamic properties of fluids

- Property relations

System	Properties			
Homogeneous fluid with constant composition (closed system)	Internal energy	Enthalpy	Helmholtz energy	Gibbs energy

- Maxwell relations

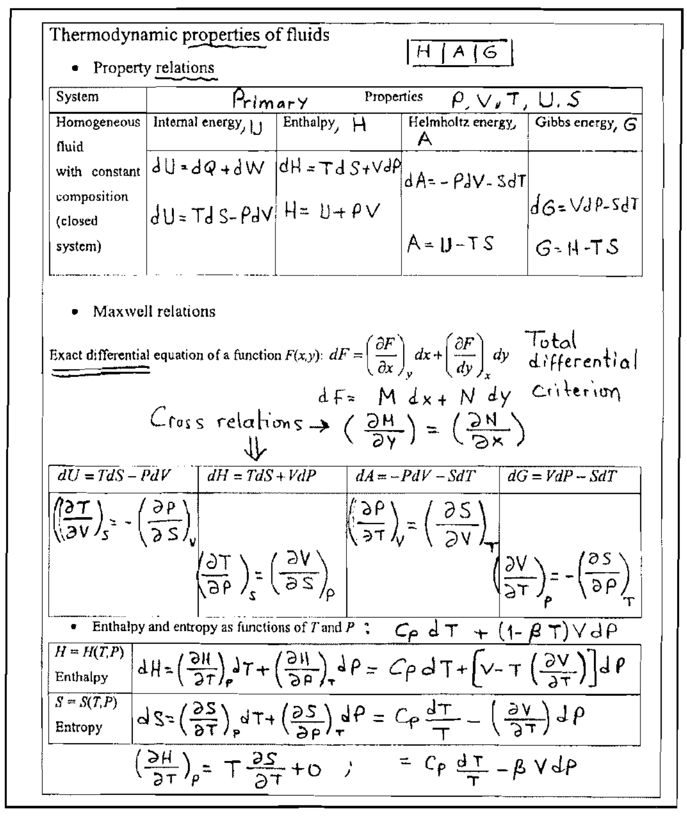
Exact differential equation of a function $F(x,y)$: $dF = \left(\frac{\partial F}{\partial x}\right)_y dx + \left(\frac{\partial F}{dy}\right)_x dy$

$dU = TdS - PdV$	$dH = TdS + VdP$	$dA = -PdV - SdT$	$dG = VdP - SdT$

- Enthalpy and entropy as functions of T and P

$H = H(T,P)$ Enthalpy	
$S = S(T,P)$ Entropy	

Figure 1. *A typical workbook page for the thermodynamics course.*



Thermodynamic properties of fluids | H | A | G |

- Property relations

System	Primary Properties P, V, T, U, S			
Homogeneous fluid with constant composition (closed system)	Internal energy, U	Enthalpy, H	Helmholtz energy, A	Gibbs energy, G
	$dU = dQ + dW$ $dU = TdS - PdV$	$dH = TdS + VdP$ $H = U + PV$	$dA = -PdV - SdT$ $A = U - TS$	$dG = VdP - SdT$ $G = H - TS$

- Maxwell relations

Exact differential equation of a function $F(x,y)$: $dF = \left(\frac{\partial F}{\partial x}\right)_y dx + \left(\frac{\partial F}{dy}\right)_x dy$ Total differential criterion

$dF = M\,dx + N\,dy$

Cross relations → $\left(\frac{\partial M}{\partial y}\right) = \left(\frac{\partial N}{\partial x}\right)$

$dU = TdS - PdV$	$dH = TdS + VdP$	$dA = -PdV - SdT$	$dG = VdP - SdT$
$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$	$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$	$\left(\frac{\partial P}{\partial T}\right)_V = \left(\frac{\partial S}{\partial V}\right)_T$	$\left(\frac{\partial V}{\partial T}\right)_P = -\left(\frac{\partial S}{\partial P}\right)_T$

- Enthalpy and entropy as functions of T and P : $C_P\,dT + (1-\beta T)V\,dP$

$H = H(T,P)$ Enthalpy	$dH = \left(\frac{\partial H}{\partial T}\right)_P dT + \left(\frac{\partial H}{\partial P}\right)_T dP = C_P\,dT + \left[V - T\left(\frac{\partial V}{\partial T}\right)\right]dP$
$S = S(T,P)$ Entropy	$dS = \left(\frac{\partial S}{\partial T}\right)_P dT + \left(\frac{\partial S}{\partial P}\right)_T dP = C_P\frac{dT}{T} - \left(\frac{\partial V}{\partial T}\right)dP$

$\left(\frac{\partial H}{\partial T}\right)_P = T\frac{\partial S}{\partial T} + 0$; $= C_P\frac{dT}{T} - \beta V\,dP$

Figure 2. *A typical thermodynamic-workbook page with completed boxes for explaining the relations for thermodynamic properties and derivations of the Maxwell relations.*

fully understand it. On the same workbook page, one of the applications from the property relations has been demonstrated through derivations of the Maxwell relations. This associates a new concept with an application. The property relations for enthalpy and entropy are further demonstrated in a categorized way in the boxes.

The first part of Figure 3 relates the key expressions on generalized correlations for liquids to the figure for reduced density taken from the textbook. A short period of time for group work follows this introduction so the students can find the molar volume of ammonia at 310 K. The workbook contains the selected homework problems from the textbook. Before assigning them, they are briefly discussed, with emphasis on the critical points in the allocated boxes for each question. This enables students to start their homework assignments with little or no outside help. Also, they will be able to access the problems in the right location in the workbook when they wish to review the course material and the related problems.

Figure 4 starts with background information on vapor-liquid equilibrium calculations. In the following box, three columns identify the type of calculations, the variables to calculate, and the variables specified for bubble point calculations using the gamma-phi method. The box is related to the block diagram underneath, which indicates how to start, proceed with, and finish the calculations by using Equations 14.8 and 14.10 from the textbook, supplied in the box above. The block diagram and equations are taken from the textbook and provide the necessary connections between the text and the diagram. Therefore students will not be distracted by searching for these equations when learning the block diagram.

The other workbook has 84 pages and was prepared for the textbook *Numerical Methods for Engineers,*[28] used in the simulation course. Figures 5 and 6 (next page) show some typical pages completed in the classroom from this workbook. In Figure 5, matrix operations are introduced with an emphasis on multiplication of matrices. This concept is explained with a figure using the indices of coefficients matrix and the two vectors for unknowns and constants related to each other with the arrows. Next to that box, the computer code for multiplication is supplied.

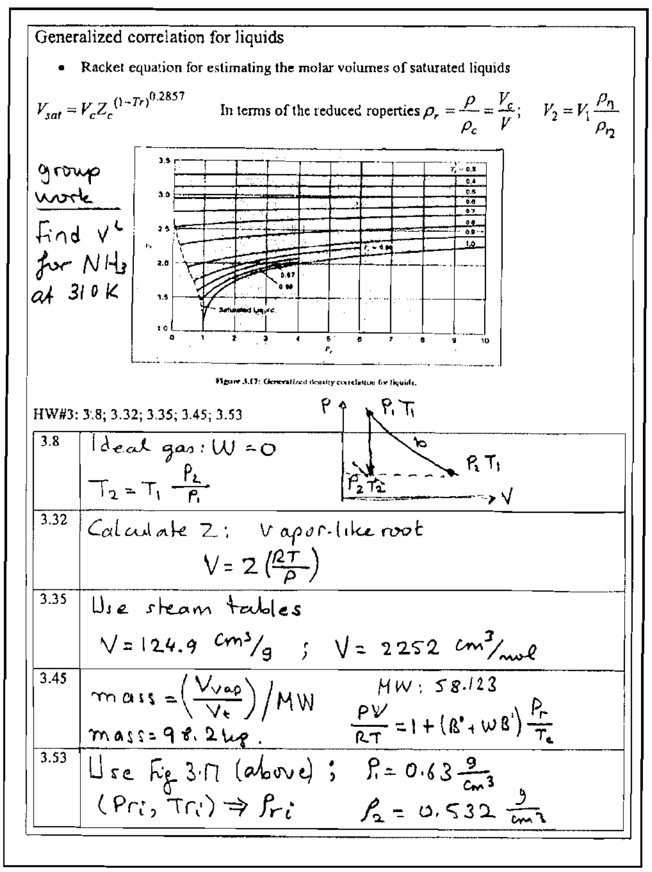


Figure 3. A workbook page containing a figure and homework problems to be assigned from the textbook for the thermodynamics course.

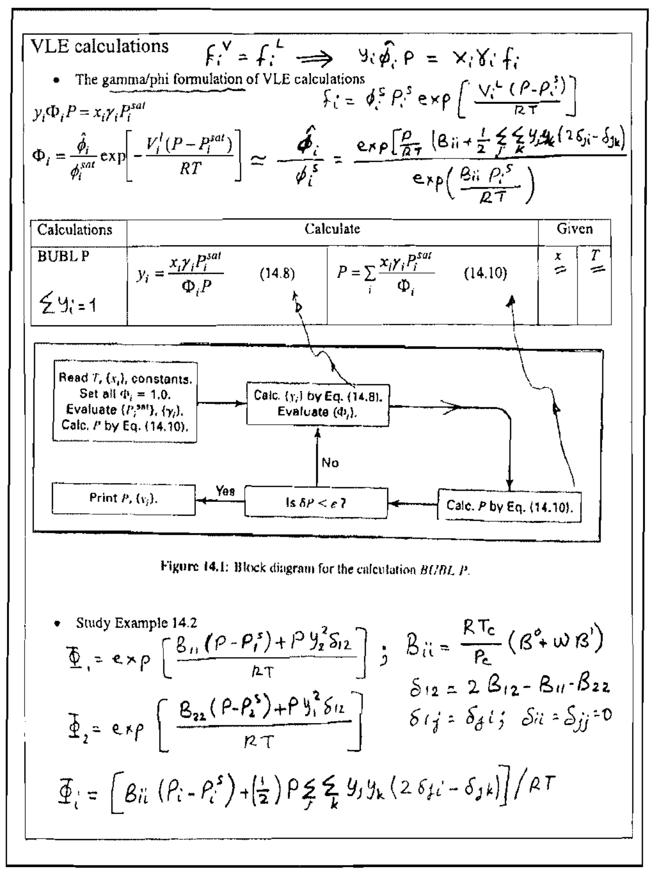


Figure 4. A typical thermodynamic workbook page on vapor-liquid phase equilibrium calculations completed in the classroom. From the flow chart shown above, the steps of the algorithm of bubble point calculations are discussed in the classroom.

For applying the rule of multiplication, a short group work is carried out first and then linear algebraic equations are represented in matrix form. This form is constructed in a set of two linear algebraic equations, and a 2-by-2 coefficients matrix is created. Following this, the concept of inverse matrix in introduced.

Figure 6 demonstrates the introduction of optimization. Here, 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 the dimensions from an old Greek temple.

Some of the anticipated benefits of the workbooks are

- A detailed syllabus is an integrated part of the workbook and helps the students jointly and effectively use the textbook and workbook.
- It provides students with objective and vision statements, main definitions, graphs, diagrams, and data in a more apparent and categorized way than the textbook (see Figures 2 and 3). It presents the course material as a package of verbal and visual elements and helps reach the students with various learning styles. This leads to effective use of the textbook.
- It makes note-taking easy and provides more time for the students' critical thinking and interactions with the instructor. This enhances deep understanding of the course material.
- It reduces the mismatches among the teaching/learning styles of the instructor, textbook, and students and increases the visual elements, hence stimulating effective teaching and learning.
- Working on the workbook with the instructor stimulates the students' interest as the instructor and students unfold the missing visual and verbal elements in the right location and moment.
- It provides easy access to definitions, analyses, applications, synthesis, graphs, diagrams, figures, tables, data, and worked and tested examples leading to an effective learning and review of the course material.
- It provides the homework assignments with brief descriptions in boxes to relate them to the concepts of the chapter.

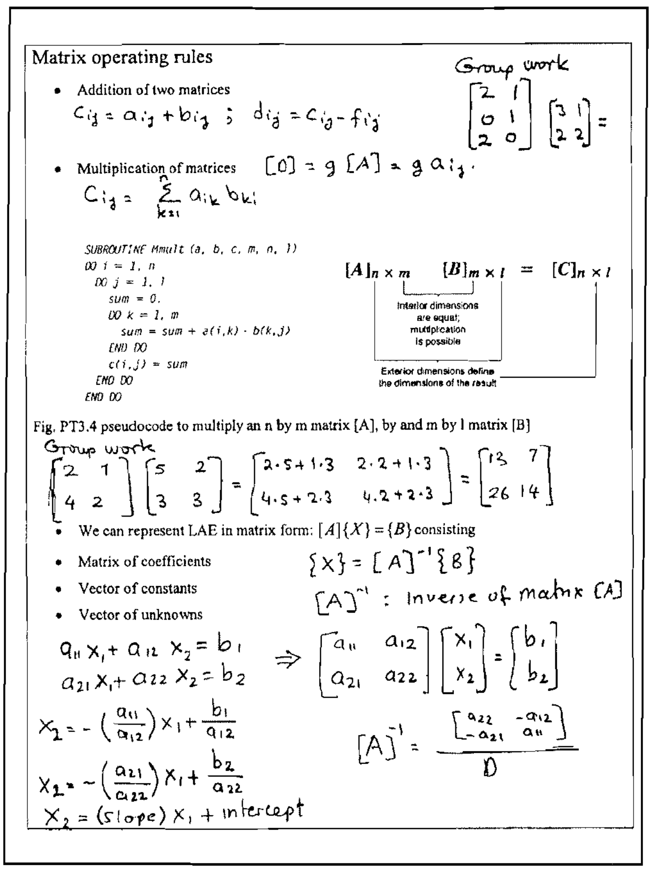


Figure 5. A completed page on the matrix operations from the workbook for the simulation course.

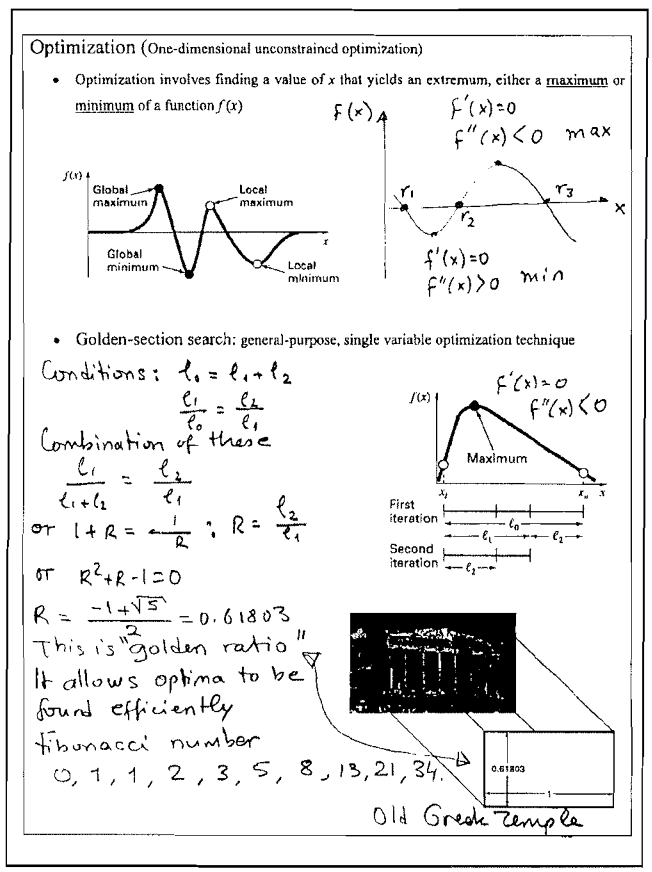


Figure 6. A completed page for optimization in the workbook for the simulation course.

ASSESSMENT OF THE WORKBOOKS

Proper assessment of the workbooks is essential for measuring their true level of effectiveness and developing the best procedure for a particular course. Therefore, a workbook will gain a level of maturity only after it is tried with an assessment study. It is the author's intention to seek, through a research proposal, a true assessment study from professional organizations such as the Center for Excellence in Undergraduate Teaching and the Center for Survey Research at Virginia Tech. Only after such an assessment study will the true effectiveness of workbook methodology be known.

Table 2 displays a preliminary questionnaire prepared by the author, along with responses in percentages for the thermodynamic and simulations courses carried out after twelve weeks with the workbooks. All the questions are treated with the same weight. For the thermodynamics course, 47 students responded and for the simulations course, 31 students responded.

The following responses deserve reviewing:

- Around 94% of students agree or tend to agree that the workbook enhances problem-based learning, subject-specific skills, and deep understanding
- Around 90% of them agree or tend to agree that the workbook reduces mismatches between learning and teaching styles and offers a balanced teaching for various learning styles
- Around 85% of the students agree or tend to agree that the workbook stimulates active learning and group work
- Around 95% of the students agree or tend to agree that overall, the workbook is beneficial in effective learning

Only 36% from the thermodynamics and 20% from the simulation class disagree or tend to disagree that the workbook does not replace the textbook.

Some examples of written comments on the questionnaire are:

- *I do not have any suggestions but I think the workbook is an excellent idea. It helps a great deal in truncating and stating all the information in each chapter.*
- *One way I think the workbook may be improved is to carry examples not included in the book. This would provide examples in addition to other problems given in the book. Many times I have already done book examples by the time we get to them in class.*
- *Sometimes space becomes too small or notes become a little confusing; attendance still seems the student responsibility. Overall, I believe the workbook is a great learning tool!*
- *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.*
- *Workbook allows instructor to go over topics very quickly because notes are already in front of you. I think it would be more useful to go over each concept in detail and make sure every-*

TABLE 2
Preliminary Questionnaire for Assessment of the Workbooks (WB)
1-disagree; 2-tend to disagree; 3-tend to agree; 4-agree; 5-not applicable

		Thermodynamics %					*Simulations %*				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1	You have used WB in previous courses	75	10	2	0	13	58	13	3	10	16
2	WB contains a detailed syllabus	0	0	17	81	2	0	3	20	74	3
3	WB contains subject schedule from the textbook	0	4	13	77	6	0	6	23	71	0
4	WB provides objective, mission, and vision statements	0	0	23	73	4	0	6	19	75	0
5	WB provides related chapter and section readings	0	13	36	49	2	0	13	39	48	0
6	WB provides subject-related examples and homework problems	0	2	0	96	2	0	0	6	94	0
7	WB provides concepts, definitions, and working equations	0	2	19	79	0	0	0	23	77	0
8	WB enhances problem-based learning	0	4	23	71	2	0	3	45	52	0
9	WB enhances subject-specific skills and deep understanding	0	4	43	51	2	0	6	52	42	0
10	WB enhances problem-solving skills	0	17	36	45	2	0	6	35	59	0
11	WB makes it easy to locate subjects, definitions, and applications	0	4	30	64	2	0	0	42	58	0
12	WB relates a subject to data, tables, diagrams and figures	0	0	13	85	2	0	0	19	81	0
13	WB facilitates easy course note-taking	0	2	11	85	2	0	6	9	85	0
14	WB facilitates effective review of subjects and related problems	0	0	30	68	2	0	0	34	66	0
15	WB reduces mismatches between learning and teaching styles	2	4	51	39	4	0	13	26	61	0
16	WB reduces mismatches between textbook and instructor styles	0	2	47	49	2	0	6	32	62	0
17	WB offers a balanced teaching for various learning styles	0	6	45	45	4	0	6	32	62	0
18	WB encourages regular attendance	6	9	36	45	4	3	3	32	62	0
19	WB stimulates active learning	4	6	45	43	2	3	13	42	42	0
20	WB stimulates group work	0	9	42	49	0	0	9	35	56	0
21	WB facilitates higher grades from the tests	0	13	34	49	4	0	3	49	42	6
22	WB facilitates higher grades from the assignments	0	0	19	77	4	0	0	35	65	0
23	WB does not replace the textbook	4	32	19	45	0	0	20	33	47	0
24	WB stimulates effective use of the textbook	4	11	40	43	2	0	6	35	59	0
25	With group work and blackboard, WB becomes more effective	2	11	47	36	4	0	3	32	65	0
26	Overall, WB is beneficial in effective learning	2	0	26	68	4	0	3	16	81	0

one understands. The workbook also closely mirrors the book. If you don't understand the book, you probably will not understand the workbook.

• *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 a good idea and an excellent study tool.*

• *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 helps 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.*

CONCLUSIONS

Preparation of the workbook, using it along with the group-work activity and BLACKBOARD, and a preliminary assessment study have been presented here. The assessment study indicates that the workbook methodology may be an effective strategy in learning and teaching. Most of the engineering students who took the courses in thermodynamics and simulation have found the workbooks beneficial in undergraduate engineering teaching. This is mainly because the workbooks, integrated with group work and BLACKBOARD, may help reduce the mismatches in teaching and learning styles, and may increase interactions between students and faculty, hence stimulating active and collaborative learning and effective teaching. The workbook trials need a true and coordinated assessment study, however, in order to measure their level of effectiveness in reducing the mismatches between learning and teaching styles.

ACKNOWLEDGMENTS

The author thanks Professor Erdogan Kiran for reading the manuscript and providing constructive comments, and the students Samuel F. Ellis and Michele A. Seiler for their help in preparing Table 2.

Note: *Electronic sample copies of workbooks for the courses on thermodynamics and simulations are available in PDF format upon request to the author at ydemirel@vt.edu.*

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