Students' Cognitions When Using an Instructional CD For Introductory Thermodynamics

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Abstract

We collected "think-aloud" protocols and questionnaire data in order to examine students' cognitions while using an instructional CD for introductory thermodynamics. Science majors, who had not previously taken a thermodynamics course, worked with the CD, and while doing so, provided spoken comments on what they were doing and thinking. The data were used to evaluate students' levels of background knowledge, their metacognitive abilities, and the usability of the CD. Furthermore, the students filled out a questionnaire in which they compared using the CD to using a textbook and notes, provided information about the comprehension strategies they used for the CD, textbook, and lecture notes, and made suggestions for improving the CD. Additional data from science students suggests a need to make the CD more effective in engaging metacognitive processing.

Introduction

The distribution of course materials in electronic formats is becoming popular as computer use and Internet access become more widespread, and as trends towards lifelong education and distance education continue to flourish. Furthermore, programming tools used to create computer-based content have become cheaper, and, more importantly, easier to use. It is thus prudent to evaluate how these media are changing students' academic experience.

In prior research [1, 2], we evaluated an instructional CD that is currently included with the book *Thermodynamics: An Engineering Approach* [3]. In addition to presenting the students with text content, tables, and graphs, the CD also includes active learning techniques such as interactive exercises, graphical modeling, physical world simulations, and exploration [2]. The aspect we were most interested in was how students interacted with the CD. In a modified version that we provided to students, the CD automatically recorded each student's interactions in a log file on a floppy disk. These data were used to construct a description of students' navigations (movements) through the CD content. In data collected from five different course sections, with two different instructors at two different universities, 90% of all students' interactions with the CD consisted of going to the next page. However, successful college readers distinguish themselves by forming specific reading goals and jumping back and forward while reading in order to achieve those goals [4]. That type of strategic reading behavior was not observed in our data, and with only the computer logs at our disposal, the question of why students did not behave like expert readers remained unanswered. There were several possible reasons for the apparent absence of strategic reading behaviors. First, the students might have lacked background knowledge, and thus were processing the information in a very basic, linear fashion. Second, they might have lacked the metacognitive reading skills necessary for expert text processing. Third, the CD's user-interface might have made it difficult to go back and forth between sections.

In order to evaluate these three possibilities, we examined the underlying cognitions of students working with the CD. To achieve this, we chose to collect verbal protocols, applying a data-collection method used in human factors usability studies, and in psychological studies, primarily in the fields of expert / novice research, and text comprehension research [5, 6]. Verbal protocols are basically think-aloud protocols, where users are asked to report what they are thinking as they complete a task, without attempting to interpret or summarize the materials for the experimenter, unless those interpretations or summaries are a natural part of their thought processes. The data are collected individually, and are tape-recorded for later transcription. During data collection, the primary role of the experimenter is to prompt the participant regularly to continue to verbalize his or her thoughts.

The use of verbal protocols raised several questions. First, could this method be employed successfully in research involving instructional technology, in which the users' task is fairly complex, involving reading, listening to voice-overs, processing graphical information, and using interactive elements? A related question was ecological validity: Does producing a verbal protocol change how the student uses the CD? If the method was useable and valid, we could apply it to the questions above. Other questions we wanted to answer were how the students thought using the CD compared to using a textbook and lecture notes, and how the CD could be improved to give the students a better learning experience.

Method

Participants

Seventeen undergraduate students were recruited through General Psychology, a general education course that draws a broad range of students, and participated for extra credit in the course. All participants were science majors who had not taken the Introduction to Thermodynamics course. Eight participants were male and nine were female. The mean age was 20.00 years [standard deviation (*SD*) = 2.03].

Materials and Apparatus

The CD was authored by E. E. Anderson [2] and is included with the textbook *Thermodynamics: An Engineering Approach* by Cengel and Boles [3]. The CD contains an overall table of contents, and chapter tables, which are used to select portions of the CD materials. CD screens consist of text, interactive and non-interactive graphics, interactive and non-interactive animations, and multiple-choice and short-response quizzes. Approximately one-third of the pages contain interactive elements. When a page comes up, the user first hears a narration, during which he or she cannot interact with the program. After the narration is over, any interactive elements on the page become useable, and several controls appear. These allow the user to jump one page forward or back, jump to any other page in the subchapter, go to the table of contents for the subchapter, and print the page. The CD program was modified for this study in order to collect time-stamped data records in which the controls the user selected, as well as performance data for the quizzes, were logged. The CD was presented on a laptop computer running a 2.0 GHz Pentium 4 processor, using a 14.1 inch TFT active matrix screen. The narration was played using the notebook computer's build-in speakers. A recording device was used to store the verbal protocols for later transcription.

A questionnaire was constructed for the collection of demographic data, participants' suggestions for improving the CD, and comparisons of the CD to textbook materials and lecture notes (See Appendix B).

Procedure

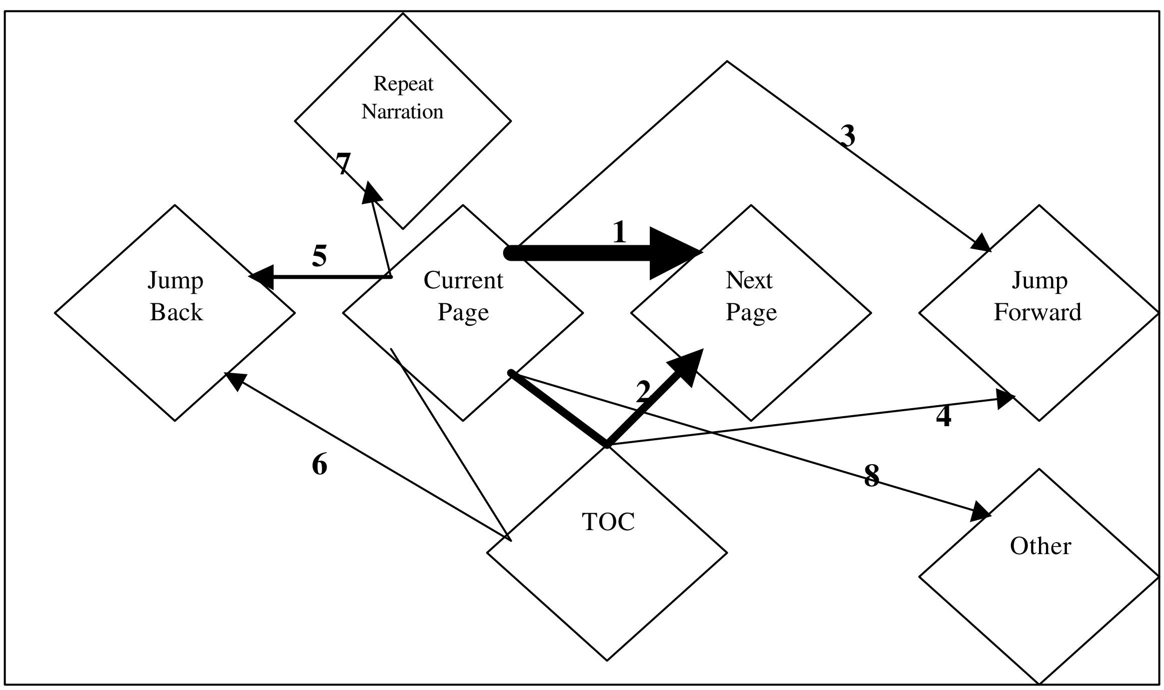
Participants took part in the experiment through individual meetings in a quiet room with the experimenter. Upon arriving on the first day, the participants were given an overview of their tasks for both days, as well as detailed instructions for a "think aloud" task (See Appendix A). They were (falsely) informed that they would take a short test on the covered materials after working with the CD, in order to ensure that they applied themselves to learning the material as if studying for an exam. They then proceeded to complete the think-aloud task, which took between 30 and 60 minutes. Participants worked with one half of one chapter. Half of the participants were given the first half of Chapter 1—*Introduction to Thermodynamics*—and the others the first half of Chapter 2—*Thermodynamic Properties*. These chapters were chosen because they did not require extensive knowledge from prior chapters in order to be understood. On the second day, the participants were given the textbook *Thermodynamics: An Engineering Approach* and were instructed to browse the pages they covered on the previous day for five minutes, in order to be able to compare it to the CD. They were then asked to fill out the questionnaire. Upon completing the questionnaire, they were debriefed and dismissed.

Results

Navigation Patterns

Interactions with the software were sorted into eight patterns of movement (see Figure 1). The students could go to the next page directly by clicking on the appropriate button (path 1 in Figure 1), or go to the table of contents, and, from there, to the next page (path 2 in Figure 1). This latter pattern of movement was necessary at the end of all sub-chapters in order to advance to the next sub-chapter. The students could also go more than one page ahead (path 3), either by clicking on a page number for the section they were in, displayed with the other buttons, or by going to the table of contents, and then jumping ahead, into the same or a different section (path 4). Furthermore, the students could go back one page via the appropriate button (path 5), or via the table of contents (path 6). In addition to navigating away from the page they were currently on, they could stay and repeat the narration (path 7), or print the page or exit the program (path 8).

Figure 1. Navigation Patterns While Using the CD



Prior to interpreting the data, we wanted to assess the external validity of the data. For this, we compared the navigation patterns of introductory thermodynamics students, which were available from previous research [1], to the patterns obtained from the students in this study. In our previous research, encompassing a total of five cases, we found that about 90% of the time students navigated to the next page on either path 1 or 2 (see Figure 1 and Table 1). In comparing the distributions found in this study to the distributions found in our previous research, we found that participants showed somewhat more active text processing, particularly looking forward in the text (#3 and #4 in Table 1), and repeating the narration (#7 in Table 1). Nevertheless, correlation analyses showed that the navigation patterns of the current participants correlated highly with each of the previous cases (see Table 1). Therefore, it appeared that participants in the current study used the CD in much the same way as the students enrolled in the thermodynamics courses, indicating that these data had external validity.

Table 1. Page Movements (Percents and Frequencies) and Pearson Product-Moment Correlations for Thermodynamics Students (Cases 1 – 5) and Participants in This Study

Current Page to	Case 1	Case 2	Case 3	Case 4	Case 5	**This Study**
1. Next Page	69.6% $N = 1344$	69.7% $N = 567$	76.0% $N = 7905$	78.9% $N = 15968$	79.0% $N = 7492$	**66.8%** $N =$ **375**
2. Next Page (via TOC)	15.8% $N = 304$	16.1% $N = 131$	16.6% $N = 1725$	15.4% $N = 3126$	16.0% $N = 1522$	**2.3%** $N =$ **13**
3. Forward	1.2% $N = 24$	1.1% $N = 9$	0.6% $N = 59$	0.5% $N = 110$	0.5% $N = 48$	**4.8%** $N =$ **27**
4. Forward (via TOC)	1.1% $N = 21$	1.2% $N = 10$	0.7% $N = 77$	0.7% $N = 136$	0.7% $N = 69$	**12.1%** $N =$ **68**
5. Back	3.3% $N = 64$	5.5% $N = 45$	2.1% $N = 217$	0.7% $N = 147$	0.6% $N = 55$	**0.4%** $N =$ **2**
6. Back (via TOC)	2.8% $N = 54$	1.4% $N = 11$	1.2% $N = 130$	1.3% $N = 270$	1.1% $N = 102$	**1.6%** $N =$ **9**
7. Same Page (Repeats N.)	2.8% $N = 55$	2.5% $N = 20$	1.3% $N = 137$	1.0% $N = 198$	0.5% $N = 52$	**6.8%** $N =$ **38**
8. Other (Print, Quit)	3.3% $N = 64$	2.6% $N = 21$	1.5% $N = 154$	1.4% $N = 290$	1.6% $N = 149$	**5.2%** $N =$ **29**
Correlation With This Study	r =.953*	r =.950*	r =.954*	r =.961*	r =.959*	

Notes. * $p < 0.01$ (2-tailed)

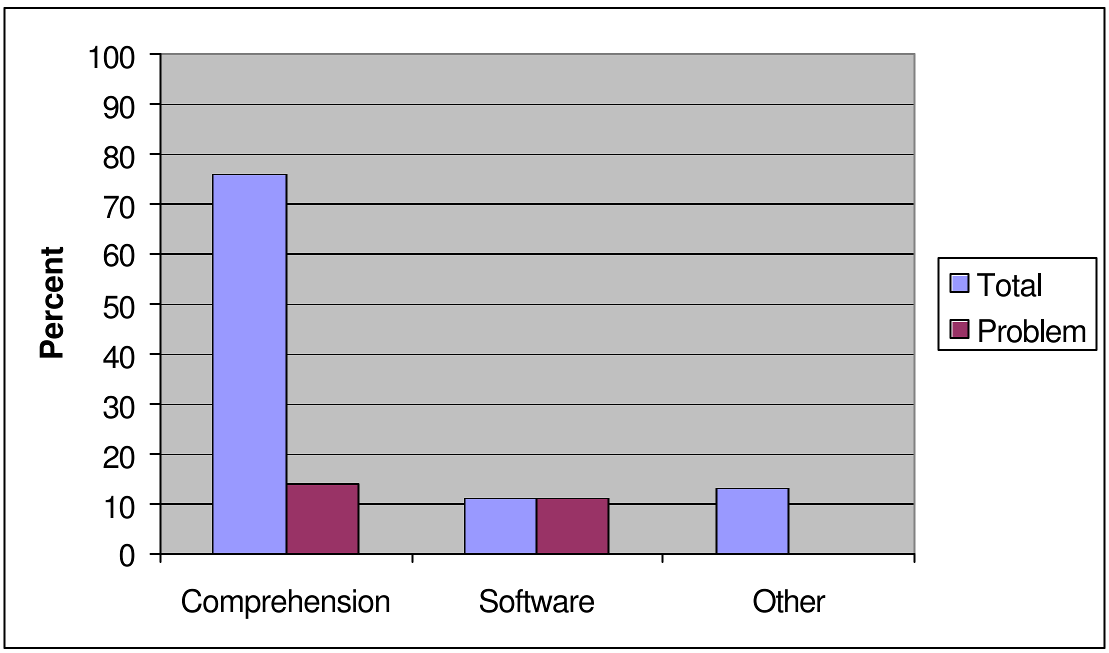
Cognitive Strategies and Software Usability

The previous findings, summarized in Table 1 and generally replicated in the present study, posed a puzzling situation and raised several possible causes of difficulty. In particular, it did not reveal whether the absence of look-backs to earlier elements in the CD, or jump-aheads to check for later information, was due to

1. students' lack of background knowledge,
2. students' weak metacognitive reading skills, or
3. limitations in the CD format.

These possibilities were addressed using the think-aloud data. The 17 participants in this study produced a total of 1296 verbalizations, at a rate of about 1.75 verbalizations per minute. See Figure 2 for a summary. Seventy-six percent of the comments that participants made were about comprehending the text. Only 14% of the comments expressed comprehension difficulty. The relatively low proportion of comments expressing confusion indicated that the materials were comprehensible. On the other hand, the comments that were made consisted largely of a reiteration of the content on the screen, either through reading the text out loud, or describing or summarizing the text, narration, a graph, or interactive element. Regarding possibility #1 above, the verbal reports indicated that participants were not drawing on background knowledge. This may have been because participants did not have a strong knowledge base on which to draw, or because they did not see the connections between the current material and background knowledge that they possessed.

Figure 2. Types of Comments in the Verbal Protocols



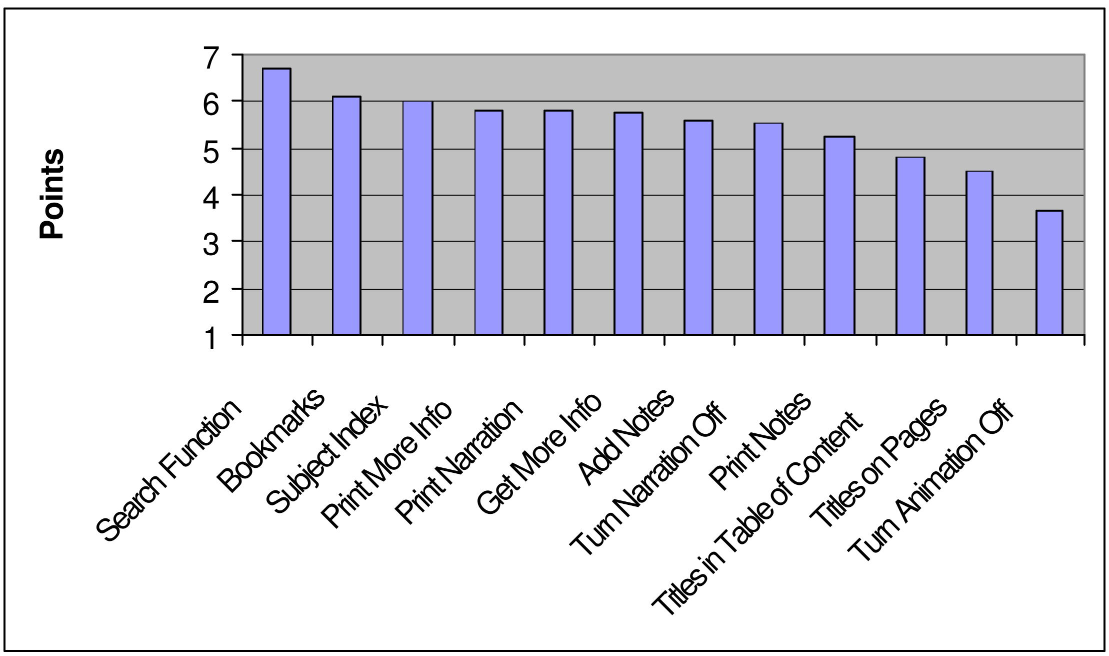
Regarding possibility #2, the verbal reports indicated that participants were not applying metacognitive strategies that would link prior, current, and anticipated information in the CD modules into integrated and coherent cognitive representations. In addition, these participants navigated through the modules in a generally linear fashion similar to the navigation patterns of thermodynamics students. Taken together, these findings indicated a relatively low level of cognitive sophistication on the part of these learners in terms of the metacognitive strategies [4, 5, 7] that they applied to understanding these science texts.

Regarding possibility #3, only 11% of the total comments were related to confusion or difficulty with the software or technology, indicating that the software was reliable and fairly easy to use. Additional insight into possibility #3 came from responses to several open-ended questions and rating tasks, in which participants provided some very specific suggestions for improving the software, which are presented next.

Change Suggestions

Participants rated twelve suggestions chosen in advance by us, based on students' comments in previous studies (See question #9 in Appendix B) using a 7-point Likert-type scale (1: not important at all; 7: very important). All twelve suggestions exceeded a neutral rating of 3.5. See Figure 3. The suggestions with the highest ratings were to include a search function for all the content of the CD, to allow for setting bookmarks (that could later be returned to for easy viewing), and including a subject index. Even the lowest rated suggestion—i.e., ability to turn the animation off—received a rating indicating that participants considered it an important suggestion.

Figure 3. Rating of Suggested Changes (7-point Scale – 1: not important at all; 7: very important)



An open-ended question (See question #8 in Appendix B) was presented to participants prior to asking them to rate our suggestions (question #9) in order to avoid biasing their responses. The open-ended responses yielded mainly the same suggestions as those we asked participants to rate, as well as several additional improvements:

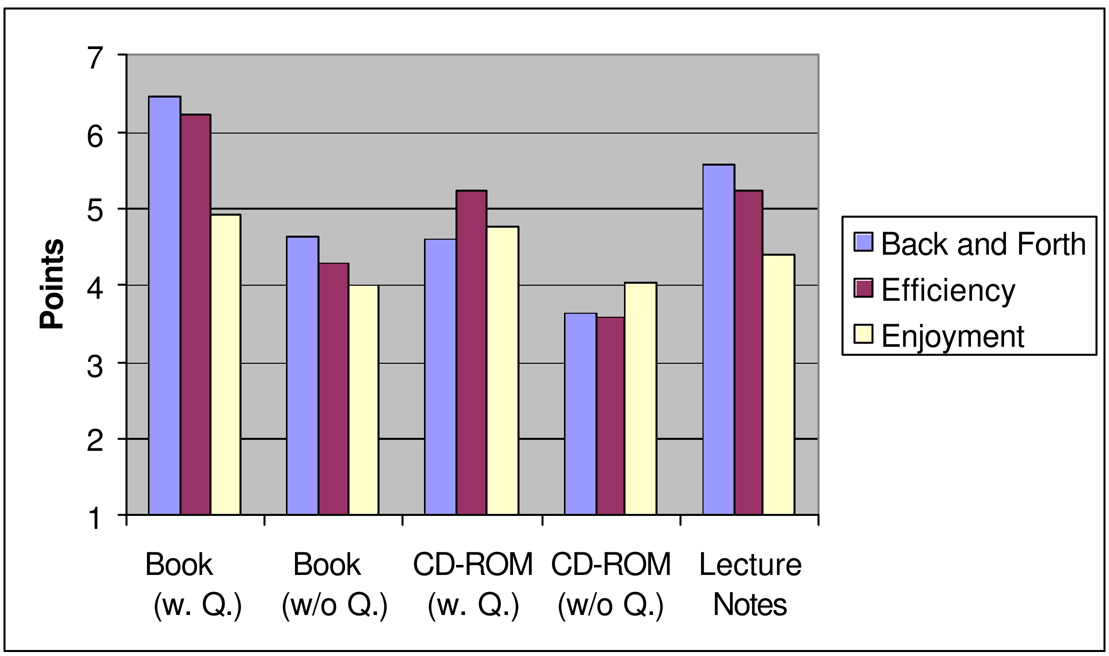
- adding a *Next Button* to the final page in the chapter or section (thus eliminating having to go to the Table of Contents to go to the next page);
- adding a *Repeat Button* for the narration (which not everybody noticed can be accomplished by clicking on the same page again);

- adding explanations for the answers for interactive questions (instead of just getting the comments "right" or "wrong");
- slowing down the narration.

Participants' Comparisons of Study Materials

In order to compare students' perceptions of the CD to a course textbook and lecture notes, we asked them to make several ratings (See questions 10, 15, and 16 in Appendix B), using 7-point Likert-type scales (see Figure 4). We asked them how often they moved back and forth (1: not at all; 7: very often), efficiency in using the materials (1: not efficient; 7: very efficient), and whether they enjoyed using the materials (1: strongly dislike it; 7: enjoy it very much). Rated highest was the textbook, with comprehension questions after each chapter, with a 5.88 point average, and lecture notes, with a 5.08 point average. The CD, with practice questions, was third, with 4.86 points, and textbook and CD, both without questions, were ranked the lowest, with 4.31 and 3.76 points, respectively.

Figure 4. Comparison of Studying Materials for Going Back and Forth, Efficiency, and Enjoyment



Three questions (see questions 12, 13, and 14 in Appendix B) asked participants to list comprehension strategies that they could apply when faced with difficulties comprehending their textbooks, lecture notes, and CD materials. Table 2 summarizes the frequencies of participants' responses. Overall, participants suggested somewhat more strategies for textbook difficulties, perhaps reflecting greater familiarity and facility with those materials. One noteworthy difference was in the *Make Notes* strategy, which participants suggested frequently for textbook difficulties but not for CD materials, pointing to a qualitative difference when processing the two kinds of materials, and a potential limitation to the CD format. The CD materials also may have been perceived as somewhat incomplete, compared to the textbook, as evidenced by higher frequencies for the strategy of *Using Other Sources to Understand*.

Table 2. Self-Report Frequencies of Using Specific Comprehension Strategies When Having Difficulty Comprehending Textbooks, Lecture Notes, and CD Materials

Comprehension Strategy	Book	Lecture Notes	CD
Read again	11	5	12
Read aloud	1	0	0
Read slowly	4	1	0
Break into smaller parts	1	0	1
Rephrase	1	4	1
Look for explanation (forward)	2	0	0
Help menu	0	0	1
Highlight main points	4	2	0
Make Notes	8	2	4
Make visualization	3	0	1
Test comprehension with questions	3	0	4
Ask friend for explanation	5	8	2
Ask instructor for explanation	4	8	1
Use other source to understand	7	11	11
TOTALS	**54**	**41**	**38**

Discussion

We have shown that verbal protocol data can be used to investigate students' cognitions when working with instructional media, without losing external (i.e., ecological) validity. Interestingly, the number of comments about problems with the CD relating to its technical aspects was fairly low, indicating that students were not appreciably hindered by the CD.

As to the main purpose of the study, the overall data indicated that students were engaged with the materials, but the verbal protocols portrayed them as having fairly weak metacognitive processing skills and weak background knowledge, as most of their comments were related to fairly basic cognitive processing skills, with the vast majority being about reading and summarizing the materials. The suggestions for changing the CD indicated that the students desired more tools for searching the CD and for indexing information in the CD. Improving the navigation and search options that are built into the CD may assist students in becoming more effective learners. These changes also might improve the overall experience of working with the CD, thus putting it in a better position to compete with the traditional forms of instructional media, namely the textbook and the students' lecture notes. In these data, the latter media were ranked higher than the CD.

The navigation and verbal-protocol data suggest that engineering students are linear learners that seldom apply analytic metacognitive reading strategies. In order to confirm this possibility, we administered two scales to engineering students and humanities students. One scale discriminated between transaction readers and transmission readers [8]:

- **Transaction** readers challenge the author and critique the content. Emphasis is on constructed meaning, and the use of subjective and objective critical standards.
- **Transmission** readers expect the author to transmit accurate information. Emphasis on text-driven meaning. Readers use objective critical standards.

Linear learners would be more likely to score higher on the transmission dimension. The second scale quantifies students' use of analytic and pragmatic metacognitive strategies [9]:

- **Analytic** strategies are related to cognitive analyses of text – e.g., inferring information missing in the text, noting new works, posing questions about the text, anticipating information.
- **Pragmatic** strategies include practical things to do to make information easier to find – e.g., underlining, highlighting, annotating.

Our preliminary analyses suggest that engineering students strongly favor a transmission model over a transaction model, compared to humanities students. Quite surprisingly, engineering students score significantly higher than humanities students in their use of analytic strategies – those strategies most closely associated with metacognitive processing in text. Although these analyses still need to be completed, they suggest to us that the CD materials, while good, fail to evoke and engage the full metacognitive processing potential of thermodynamics students. Thus, serious consideration of further revisions to the CD may be warranted.

Appendix A: Think-Aloud Instructions

While you work with the CD-ROM, we would like to ask you to constantly say what you are thinking. Here is an example for a literature student reading a literature text:
(Reads first sentence)
"I just see that as a lead-in … and I'm expecting to find out what that is is all about."
(Reads second sentence)
"I'm gonna learn about carpet … I'm gonna learn about the effects of carpeting in the classroom."
(Reads third sentence)
"I'm adjusting the scenario that I expect … a little … by-by expecting this to be the argument in favor of … why we ought to carpet perhaps."

You should just report what you are thinking, where you are looking on the screen, the problem you are working on, etc. Do not try to interpret or analyze the text or problem. Just say what's going through your mind. If you don't say anything for more than 60 seconds, you will be prompted by the experimenter to continue talking. The first 5 minutes will be a warm-up, in which you can ask the experimenter questions, and he will tell you how to do it right, if there are any problems.

Appendix B: Questionnaire

1. Gender
2. Age
3. Major
4. Number of completed college credit hours
5. Number of Science and Engineering credit hours
6. How would you rate your computer skills compared to your fellow students?
7. Please estimate how many hours per week you use (work or play) a computer.
8. If you could make changes to the CD-ROM, what would these be? Please provide at least four, and give a short description of each change.
9. Below is a list of possible changes. Please rate each one for how important this change would be to make it more likely that you use the CD-ROM (i.e., make the CD-ROM more efficient and enjoyable to work with).

Inclusion of the titles for all pages in the table of contents
Have a title for each page appear in the small list of pages on each page
Inclusion of a subject index
A search function for the whole CD-ROM
Ability to set bookmarks for easy reference later
Ability to turn narration off / on
Ability to turn animation off / on
Ability to print transcription of narration
Ability to add notes to a page
Ability to print self-made notes
Ability to get further information for each page
Ability to print page with further information

10. How often do you go back and forth (e.g., skip some pages or go back some pages in a book) using the following studying materials?

Book (with questions at the end of each chapter)
Book (without questions at the end of each chapter)
Lecture Notes
Multimedia CD-ROM (with quizzes)
Multimedia CD-ROM (without quizzes)

11. Please describe briefly why you go back and forth as much as you do for the

Book (with questions at the end of each chapter)
Book (without questions at the end of each chapter)
Lecture Notes
Multimedia CD-ROM (with quizzes)
Multimedia CD-ROM (without quizzes)

12. When you read a **book**, and have difficulties comprehending the material, you might use strategies for better comprehension. Please list as many strategies as you can below.
13. When you work with **lecture notes**, and have difficulties comprehending the material, you might use strategies for better comprehension. Please list as many strategies as you can below.
14. When you work with an instructional **multimedia CD-ROM**, and have difficulties comprehending the material, you might use strategies for better comprehension. Please list as many strategies as you can below.

15. Please rate the general **efficiency** (quantity of learning within the same amount of time) of the following studying materials.
Book (with questions at the end of each chapter)
Book (without questions at the end of each chapter)
Lecture Notes
Multimedia CD-ROM (with quizzes)
Multimedia CD-ROM (without quizzes)
16. How much do you **enjoy** working with the different learning materials?
Book (with questions at the end of each chapter)
Book (without questions at the end of each chapter)
Lecture Notes
Multimedia CD-ROM (with quizzes)
Multimedia CD-ROM (without quizzes)

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