EFFECT OF ASSERTION HEADINGS AND EXPANDABLE EXAMPLES IN ONLINE ENGINEERING TEXTBOOKS ON STUDENT PERFORMANCE AND SATISFACTION

BY

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THESIS

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ABSTRACT

Many engineering courses are transitioning from traditional paper textbooks to online and multimedia instructional modules to present content to students outside of class time. As the use of these online resources expands, research about the effective use and production of these resources should grow in tandem.

Little research has focused on how textbook designs affect students learning in natural study conditions. Students prefer to use textbooks alongside homework or practice exams while studying, but many laboratory studies artificially prevent students from using textbooks while answering questions. Investigations have studied the effects of textbook design on test performance but have not looked at students' motivation to read the textbook, their perception of the textbook's usefulness, or their satisfaction with the textbook in helping learn material for the course. In this thesis, we study the effect of expandable worked examples and assertive headings in online instructional texts on students' learning and affective responses. In addition, we explore whether hand-drawn figures have any effect on student satisfaction and self-efficacy.

Students consistently find worked examples to be useful, but their effectiveness may be limited by an expertise reversal effect, helping novice students but hindering advanced students. Interactive, expandable worked examples can expand to show, and contract to hide, as much detail as students see fit to support their learning.

Section headings provide one means for improving students' ability to extract meaning from textbooks. While most textbooks use noun phrases that indicate the topic or subtopic of the following text, there is evidence that using complete sentence headings that summarize the text in that section (assertion headings) could improve student comprehension. Student feedback in the preliminary phases of our study compelled us to explore whether or not hand-drawn figures have any effect on student course satisfaction and self-efficacy.

We studied these textbook features in an introductory electrical engineering course by assigning students to three different versions of an online textbook. A control group received traditional static worked examples and topic-subtopic headings, one treatment group had expandable worked examples and assertion headings, and the final treatment group had only the expandable worked examples. Although measures of students' performance in the class such as grades on quizzes showed few significant changes, measures of students' attitudes toward the course showed that satisfaction with the materials had improved.

To Katie, for supporting me through thick and thin.

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CHAPTER 1

INTRODUCTION

Textbooks form the backbone of nearly every college course [1]. They are considered an "indispensable resource" by many professors [2]. Novice teachers and those teaching outside their expertise depend on textbooks to an even greater extent [3]. Teachers use textbooks to supplement material covered in class or to provide more information on topics that could not be covered fully in class. Today teachers are pushing basic knowledge acquisition toward out-of-class activities ("flipping the classroom") in order to open up more class time for high-impact instruction [4]. As students are expected to learn more outside of class, the role of textbooks in explaining material has risen in importance. In this context more than ever, teachers need high-quality textbooks that have been proven to be effective learning aids [4].

Current evidence suggests that textbooks are failing their goal of supporting student learning. Most students do not read their textbooks to understand the topic, but rather to reduce anxiety about upcoming exams [2, 5]. Fewer than half of students use their textbooks even once a week [4, 5, 6, 7, 8, 9]. This low usage is partially explained by student perceptions of textbooks. Students must *perceive* a textbook as useful for the textbook to be an effective learning tool [10, 11]. Currently, students generally do not believe that reading the textbook produces a tangible improvement in exam performance [6, 8].

Student perceptions are not entirely to blame for low textbook usage, however. The structure of textbooks also plays a role. College seniors can locate relevant textbook content independently [8], but younger students must be told *exactly* what to study [7, 5]. Since students do not know what material in the textbook is relevant to their exams [9], they favor their instructors' lecture notes over textbooks. Textbooks must clearly signal the boundaries between essential and non-essential information; otherwise students will waste precious study time focusing on unnecessary information, or they may give up on the textbook as a study resource altogether [5]. If educators want students to read textbooks, they must maximize students' ability to learn while engaged with the texts [12].

Increased demand for effective textbooks requires greater knowledge of what makes textbooks a useful tool for promoting student learning [4, 2]. Both private corporations [13, 14] and universities [15] are expanding their exploration of electronic textbooks to reduce costs and increase availability for students. This expanding development of electronic textbooks provides an exciting chance to change students' perception and use of textbooks for the better. Students who encounter new electronic formats with animations, interactive elements, and dynamic content might find that textbooks are still ineffective at helping them study, or they might find that textbooks are evolving into more effective learning tools and will begin to use textbooks more often. Increased textbook usage by students will liberate teachers from spending class time on basic material and allow them to deepen student learning in the classroom.

To explore how to create effective online engineering textbooks, we studied how different textbook authoring styles affected student performance and satisfaction in a first-year engineering course: Introduction to Electronics (ECE 110). Specifically, we studied the effect of assertion headings [16] and expandable worked examples [17] on student performance and satisfaction. We present some background on these interventions before describing the research study, its results, and its implications for instructional practice.

CHAPTER 2

BACKGROUND

2.1 Expandable Examples

Research on the use of textbooks has uncovered some features that students report as being useful for learning [1]. Students consistently rate worked examples [1, 7, 2] as the most useful elements in college science, technology, engineering, or mathematics (STEM) textbooks. A **worked example** shows all the solution steps needed to reach the final answer to a problem and sometimes includes the reasoning behind taking those solution steps. See Table 2.1 for a typical worked example. Worked examples are a common instructional tool to teach problem solving skills in structured domains such as engineering and physics [18]. More so than their classmates, struggling students depend on worked examples to help them learn [19, 18]. Additionally, most students rely almost completely on worked examples and chapter reviews without reading the chapter text at all [2].

Table 2.1: Worked example from algebra.

$5 = 3x - 1$	Solve for x.
$5 + 1 = 3x - 1 + 1$	Add 1 to both sides to eliminate the -1. Attack the object furthest from x.
$6 = 3x$	Add numbers and cancel.
$6/3 = 3x/3$	Since x is multiplied by 3, we divide both sides by 3 to isolate x.
$2 = x$	Do the arithmetic, x is isolated!

Unfortunately for the instructors and authors designing worked examples, the effectiveness of worked examples depends on their specific structural features [20]. Text and images must be properly integrated [21, 18, 22] for worked examples to be most effective. Many worked examples in textbooks lack detail [19, 10] or strategic information [23, 24, 25, 26]. The presence of additional problem-solving explanations can sometimes even hamper learning [27]. Some researchers believe there is no possible algorithm to consistently design effective worked examples [10]. Though much research has been done on worked examples (see Moreno's review [18]), little of it is focused specifically on college-level STEM textbooks.

Development of worked examples is further complicated by the **expertise reversal effect** [28, 21, 29, 30]. Expertise reversal occurs when an educational intervention is effective for low-skill learners, but is less effective for high-skill learners (or vice versa) [31, 32, 33, 34]. To understand expertise reversal, consider the analogy of adding training wheels to a bicycle. Adding training wheels onto the bicycle of a child first learning to ride would greatly assist the child in becoming a proficient rider, but adding training wheels to the bicycle of a Tour de France cyclist would be a debilitating burden on their performance. Likewise, pedagogical techniques that help some students can be ineffective or even detrimental for experienced students. Skilled readers can waste precious cognitive resources on information they already understand [24, 22]. This expenditure of cognitive energy reduces the potential for learning new material.

The expertise reversal effect presents educators with a problem: how can teachers design worked examples to help both novice and experienced students? One potential solution to this problem is the use of **interactive worked examples** [17] with *optional* extra detail. An interactive worked example allows the reader to display or hide extra explanations, allowing experienced readers to bypass redundant material (a contributing factor to expertise reversal). Expandable examples are a promising way to mitigate the expertise reversal effect, but there is little research on developing interactive worked examples for electronic STEM textbooks.

2.2 Assertion Headings

Chapter reviews and summaries are the second-most used textbook element by students [1]. Students frequently fail to understand how the text material fits together. Students frequently cannot discern the overall takeaway message of the text. This failure in comprehension is exacerbated when the text fails to provide **global coherence**. A passage of text has global coherence when a reader can relate each statement in the text back to the main topic of the passage and comprehend the overarching message of the chapter or section. A lack of global coherence often reduces reader comprehension and understanding of the reading material [32, 35].

One way to increase global coherence in textbooks is to improve an important part of textbooks that is already being used by students: section headings [1]. Headings, end-of-chapter summaries and in-chapter reviews can moderate learning and comprehension through global coherence [32, 35].

Possible methods to improve the global coherence of section headings in textbooks can be found in research on effective science presentations and proofs. Rather than using a short topic-subtopic slide title during PowerPoint presentations like "Diode Current Flow," a presenter can use a complete-sentence assertion title such as "Diodes allow current to flow in only one direction" to improve coherence and learning during presentations [16]. The assertion title provides global coherence by summarizing the content presented on the slide. Similarly, comprehension of mathematical proofs can be improved when the principle of the proof is asserted before the proof itself [36]. Assertion headings appear in some successful STEM textbooks [37, 38], but there is no research on their effectiveness.

2.3 Research Questions

This study examined whether two features of an online engineering textbook would improve or impede a student's ability to understand and learn material from the textbook. We conducted a concurrent mixed-methods study to investigate two research questions regarding assertion headings and interactive worked examples.

Research Question 1: Do expandable worked examples improve academic performance and course satisfaction compared to static examples and mitigate the expertise reversal effect observed in static worked examples?

Research Question 2: Do assertion section headings improve academic performance and course satisfaction in an online engineering text compared to topic-subtopic headings?

While we explored the first two questions, feedback from student volunteers about hand-drawn figures raised a third research question. We used a sequential mixed-methods study to explore the third research question:

Research Question 3: Can hand-drawn diagrams increase student course satisfaction compared to computer-generated diagrams?

CHAPTER 3

METHODS

This study examined a first-year course, Introduction to Electronics (ECE 110). ECE 110 is a required course for Electrical Engineering and Computer Engineering majors at a large, public research university in the American Midwest. ECE 110 was selected for our study because the course instruction team was already dissatisfied with the available textbook options for the ECE 110 curriculum. The ECE 110 instructors planned to write their own instructional text before researchers of this study became involved. These procedures were approved by our university's Institutional Review Board (Protocol #14927) overseeing human subjects research.

3.1 Student Demographics

During the semester our study took place, 445 students enrolled in ECE 110. In this class, 74% of students were freshmen, 19% were sophomores, and 7% were upperclassmen. For gender demographics, 85% of students were male and 15% of students were female. For race and ethnicity demographics, 37% of domestic students were Asian, 58% were white, 7% were Latino, and 3% were any other race (students could select more than one race, some are double counted). Additionally, 31% of students were international students.

3.2 Description of Innovative Materials

To explore the effect of assertion headings and expandable worked examples in an engineering instructional text, the researchers and ECE 110 instruction team collaboratively created online text resources for ECE 110. The ECE 110 course website included course notes and worked examples, which together played the role of a textbook for ECE 110.

Each chapter of course notes covered two 50-minute lectures of material and contained text, figures, headings, a table of contents, and an end of chapter summary, much like an typical textbook. Unlike a typical textbook, the course notes included assertion headings (see Figure 3.1). The text was formal but friendly in tone. Each chapter contained numerous internal links to other parts of the text and external links to other websites. The figures in the course notes were hand-drawn in full color.

Each chapter of the course notes was accompanied by interactive expandable worked examples. Similar to the examples in a standard textbook, the expandable worked examples included a problem statement, full-color computer-generated figures, equations, and explanations of the steps to solve the problem. However, unlike a standard textbook, the expandable worked examples could expand to show small sub-steps and manipulations that would consume too much space in a traditional paper textbook or would be superfluous for more experienced learners. Only problem steps that a student would be expected to show on an exam (expert-level work) were visible by default. Additional explanatory problem steps were hidden by default to avoid distracting the students who did not need more information, but these details could be displayed by clicking a button. All the expandable worked examples were written in an informal tone and explained both the steps taken to solve the problem and the rationale for taking each step. See Figure 3.2 for a sample of expandable worked example content. See Appendix D for a full expandable worked example.

QUANTIZATION

Quantizing samples to levels and then to sequences of bits leads to quantization error.

A sequence of samples like $v[n]$ in Fig. 5 is not a digital signal because the sample values can potentially tak on a continuous range of values. In order to complete analog to digital conversion, each sample value is mapped to a discrete level (represented by a sequence of bits) in a process called quantization. In a B-bit quantizer, each quantization level is represented with B bits, so that the number of levels equals 2^B

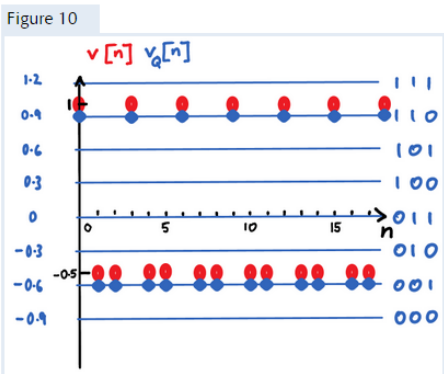


Fig. 10: 3-bit quantization. Overlaid on the samples $v[n]$ from Fig. 5 is a 3-bit quantizer with 8 uniformly spaced quantization levels. The quantizer approximates each sample value in $v[n]$ to its nearest level value (shown on the left), producing the quantized sequence $v_Q[n]$. Ultimately the sequence $v_Q[n]$ can be written as a sequence of bits using the 3-bit representations shown on the right.

Figure 3.1: Sample of the course notes. The topic-subtopic heading is "Quantization." The assertion heading is "Quantizing samples to levels and then to a sequence of bits leads to quantization error."

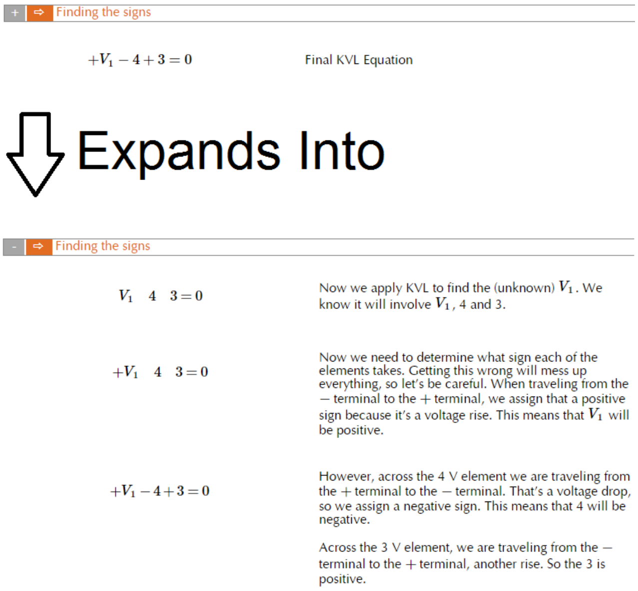


Figure 3.2: Before-and-after picture of part of expandable worked example. Clicking the '+' button expands the sub-steps in a particular problem step. Simple operations like sign conventions in the right column can impede a first-time learner. See Appendix D for a full worked example.

Worked examples were displayed in a two–column format because the ECE 110 instruction team preferred that format and it was easy to produce examples that way. However, displaying information in two columns can impede learning because the reader must integrate multiple sources of information that are spatially separated into a single mental construct. This phenomenon is referred to as the split-attention effect [22]. To minimize potential problems from the split–attention effect, the left column (which contained figures and equations) was designed so that it could be followed independently of the right column (which contained explanations).

3.3 Pilot Study

During the summer before the main study, we conducted a small pilot study to test the course notes and expandable worked examples with undergraduate volunteers. The initial pilot study produced an unexpected finding. Students spontaneously voiced strong opinions about the hand-drawn diagrams in the course notes. Students claimed that the hand-drawn figures were more believable and more attractive than the computer-generated figures in the worked examples. To explore this unexpected finding, we added our third research question: "Can hand-drawn diagrams increase student course satisfaction compared to computer-generated diagrams?" See Figure 3.3 for an example of the difference between hand-drawn and computer-generated figures in our study.

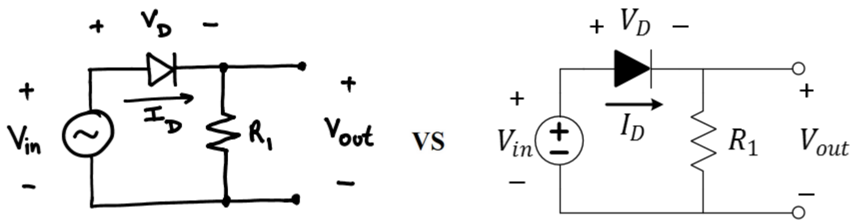


Figure 3.3: Comparison of the same diagram drawn by hand (left) and typeset by computer (right). The author of the course notes has neat, legible handwriting; it was mistaken for a font by one of the students in the pilot study.

3.4 Text Versions

We selected two chapters of course content for examination during the study: *Diodes* and *Sampling*. We selected these chapters because of their timing in the course. Each topic was covered in lecture just after an exam. The ECE 110 instruction team felt that holding our study shortly before an upcoming exam would be unfair to the students and would reduce response rate because students would prepare for exams rather than participate in the study.

We constructed two versions of each worked example from the *Diodes* and *Sampling* chapters. The experimental version included the expansion feature, whereas the control version did not. Without the sub-steps, the control version worked examples had the same level of detail as a typical textbook worked example.

We constructed two versions of both the *Diodes* and *Sampling* chapters of the course notes. The control version of the course notes contained only ordinary topic-subtopic (noun phrase) headings, whereas the experimental text also included assertion (complete sentence) headings (see Figure 3.1). The control version of the course notes contained topic-subtopic phrases in the table of contents, whereas the experimental course notes contained assertions in the table of contents. In both versions of the text, the assertion statements were listed at the end of each chapter as a chapter summary. Chapter summaries are considered good practice for textbook authoring [1], so we included them to avoid bias against the control text. Both versions of the course notes contained identical text and figures; only the table of contents and section headings varied.

We partitioned students into three stratified random groups with equal numbers of freshmen and females. In each chapter, the control group received course notes with topic-subtopic headings and low detail, non-expandable worked examples. The first treatment group received course notes with assertion headings and expandable worked examples. The second treatment group received no course notes and only expandable worked examples to see if text passages would be ignored [39, 2]. Each group received one variant of the content in the *Diodes* activity, and a different variant during the *Sampling* activity (see Table 3.1). This alternating treatment reduces the risk of bias against one text variant because of non-identical groups of students.

Table 3.1: The course materials available to each group of students on each topic. Each group received a different text variant for the two chapters studied, reducing the risk of bias.

	Group 1	Group 2	Group 3	Response rate
Diodes	- Topic-subtopic headings in course notes - 2 Low-detail examples (N=57)	- Assertion headings in course notes - 2 Expandable examples (N=73)	- No course notes -2 Expandable examples (N=74)	204/444 (46%)
Sampling	-Assertion headings - 5 Expandable examples (N=46)	- No course notes - 5 Expandable examples (N=51)	- Topic-subtopic headings - 5 Low detail examples (N=46)	143/444 (32%)

3.5 Quiz and Survey Content

One week before *Diodes* was covered in lecture, we released the experimental versions of the *Diodes* course notes and worked examples to all ECE 110 students via email. Each student was linked to one variant of the course notes and worked examples (Table 3.1). All students were also linked to the same online technical content quiz over the material covered in the *Diodes* chapter and an attitudinal survey about the electronic course materials (See Table 3.2). The students had until the day before *Diodes* was covered in lecture to complete the quiz and survey outside of class time. This timing eliminated the effect of the lecture itself on students' quiz performance. One month after the *Diodes* activity, a second activity was released covering the *Sampling* content, which followed the same format.

Students could take as much time as they wanted to complete the activity (course notes, worked examples, quiz, and survey). Due to the experiment design we could not measure the time it took students to complete each activity, but students in the pilot study took under an hour to complete similar activities. Unlike other studies of reading comprehension [32], students could read each activity's course notes and examples *while* completing the activity's quiz, much like natural studying. For fairness, all versions of the instruction materials were released after that activity's quiz was due. Participation in the study was optional but participation could be credited toward a portion of students' class participation grade in ECE 110, worth 1% of their final course grade. In the *Diodes* activity, 45% of ECE 110 students chose to participate, and in the *Sampling* activity only 32% of students participated.

To explore the satisfaction dimensions of our research question about expandable examples, we included two Likert scale items during the *Diodes* activity: "Rate the usefulness of the expandable worked examples" and "Did you find the expandable features of the examples useful?" These items were repeated in the *Sampling* activity. To further explore satisfaction outcomes with the expandable examples, we asked the free response question "Why did you find the expandable feature helpful or unhelpful?" during the *Sampling* activity (see Table 3.2).

To explore the satisfaction dimensions of our research question about assertion headings, we asked, in the *Diodes* activity, one Likert scale question "What did you think of the complete sentence headings?" . We repeated this question on the *Sampling* activity, and also asked the free response question "Why did you find the complete sentence headings helpful or unhelpful?" to further explore satisfaction outcomes due to the assertion headings.

To explore our research question about hand-drawn figures, we asked one free response question in the *Diodes* activity: "Why do you prefer hand-drawn or computer-generated figures?" (see Table 3.2). The responses to this free response question (see Table 3.3) informed the construction of quantitative Likert scale questions included in the *Sampling* activity (see Table 4.9).

Table 3.2: Summary of activities for each chapter. See Appendix A for the *Diodes* activity and Appendix B for the *Sampling* activity.

	Diodes Activity	*Sampling* Activity
Content Quiz	- 6 conceptual questions - 2 quantitative questions	- 2 conceptual questions - 5 quantitative questions
Likert scale questions	- What do you think of the complete sentence headings? - Rate the usefulness of the expandable worked examples. - Did you find the expandable features of the examples useful? - Do you prefer hand-drawn or computer-generated diagrams?	- What did you think of the complete sentence section headings in the Sampling chapter? - Rate the usefulness of the expandable worked examples for the Sampling topic. Did they help you learn? - Did you find the expandable features of the examples useful? - 9 questions on aspects of hand-drawn figures, influenced by the free response questions in the *Diodes* activity
Free response questions	Why do you prefer hand-drawn or computer-generated diagrams? (160 responses)	- Why did you find the complete-sentence titles helpful or unhelpful? (48 responses) - Why did you find the expandable feature helpful or unhelpful? (48 responses)

3.6 Data Analysis

Three coders analyzed the responses to the free response questions in the *Sampling* activity. Given the small dataset, the author established an initial codebook independently. A second coder applied the codebook to the data. Disagreements were used to refine and finalize the codes and their definitions. To test the trustworthiness of the coding scheme, a third coder coded each response independently before comparing notes with the author. These final comparisons were used to calculate an inter-rater agreement of 75%.

Responses to the free response question "Why do you prefer hand-drawn or computer-generated figures?" from the *Diodes* activity were coded by two researchers. Because we could find no prior research documenting students' preferences, we began coding without an a priori coding scheme. A codebook was developed through an iterative process before codes were finalized. In the first phase of analysis, two researchers cooperatively established an initial codebook for 30 of the 160 responses. Using the preliminary codebook in the second phase, both researchers independently coded 50 of the remaining responses, and used disagreements to refine the codebook. In the third phase, each researcher coded the remaining 80 responses independently and any disagreement was counted against the validity of the coding scheme. Disagreements were resolved through discussion. We obtained an inter-rater reliability of 95% for the final 80 codes. These codes inspired a group of Likert scale questions in the survey in the *Sampling* activity (see Table 3.2 and Appendix B questions 16-24).

We analyzed the nine code-inspired Likert scale survey items from the *Sampling* activity by grouping them into three categories: one for items about neatness and readability, one for items about affective responses, and one for items about credibility. For each pair of survey items, we computed a linear correlation coefficient. For groups of survey items that had at least moderate correlation coefficients ($r > 0.5$) for each pairing, those survey items were combined into a composite score (see Appendix C). No survey items fit into more than one group. We did not conduct an exploratory factor analysis of the data. Responses strongly favoring hand-drawn figures were assigned a value of 3 and responses strongly favoring computer-generated figures were assigned a value of 0. Composite scores of three survey items have values 0–9, composite scores of four survey items have values 0–12.

These composite scores were reduced to a four-point scale of 0-3 (see Tables 4.7 and 4.8). Survey items that did not correlate well with any other survey items were discarded, since we could not establish validity for those items.

Since the first exam preceded the study, we used students' scores on the first exam of the semester to estimate baseline ability and preparedness for each treatment group. We used scores on the *Diodes* and *Sampling* quizzes to measure differences in performance between treatment groups.

According to the Shapiro-Wilk test, quiz and exam scores were not normally distributed. We used the Kruskall-Wallis test rather than Analysis of Variance (ANOVA) to analyze quiz scores and exam scores because ANOVA is sensitive to deviations from normality at small sample sizes. We chose a α value of $\alpha = 0.01$ for the quantitative analysis of quiz scores and exam scores because we were equally concerned with false positive and false negative errors. We measured effect size with Cohen's d since we did not observe large differences in standard deviation of quiz scores or exam scores between groups.

Table 3.3: Codes for responses to "Why do you prefer hand-drawn or computer-generated figures?" The "Computer-Clean and Clear" had shorter, less detailed responses such as *"Easier to understand."* By contrast, students preferring hand-drawn figures had a wider variety of responses often with more emotional reasons for their preferences, such as *"The hand drawn ones just seem friendlier and more welcoming."* See Appendix E for full codebook.

Hand - Inviting	Students have a positive affective response
Hand - Relatable	Hand-drawn figures are more similar to what students produce
Hand - Clean and Clear	Hand-drawn is easier to read
Don't Care - Clean and Clear	No preference as long as it is clean and clear to read
Don't Care - Equally effective	No preference as long as both can be understood
Don't Care - Indifferent	No preference
Computer - Relatable	Computer-drawn figures are similar to what the students must produce
Computer - Clean and Clear	Computer-drawn is easier to read

CHAPTER 4

RESULTS

4.1 Performance Outcomes

We used students' scores on Exam 1 to measure differences in ability between treatment groups. We found no statistically significant differences in students' preparation during the *Diodes* and *Sampling* activities (Table 4.1).

We used students' scores on the quizzes to measure treatment effects between groups. Only one statistically significant difference was found: The students given topic-subtopic course notes and traditional examples scored higher than the students given the assertion headings notes and expandable examples on the *Sampling* quiz.

Table 4.1: Pairwise comparisons of quiz and exam scores for each group during the *Diodes* and *Sampling* activities. Effect sizes are the difference in mean score divided by pooled standard deviation (Cohen's d). The letters indicate the group that performed better. Statistically significant results are bolded. TS=Topic-subtopic notes and static examples. AH=Assertive headings and expandable examples. EO=Examples only and no course notes.

Group Comparison	Exam Effect Size d	Quiz Effect Size d
Diodes		
TS vs AH	0.38 AH	0.12 TS
AH vs EO	0.11 AH	0.29 EO
EO vs TS	0.27 TS	0.17 EO
Sampling		
AH vs EO	0.19 EO	0.27 EO
EO vs TS	0.13 TS	0.45 TS
TS vs AH	0.32 TS	**0.72** TS

4.2 Satisfaction Outcomes

4.2.1 Expandable Examples

Students responded positively to the expandable worked examples with more than 80% of students responding favorably (see Table 4.2). The response to the expansion feature itself was even more positive, with 40% of students choosing the most positive response.

Table 4.2: Student responses to Likert scale questions regarding the expandable worked examples. Responses from students in control groups that did not receive expandable examples are not shown. The average score assigns a value of 0 to Bad and a value of 3 to Great.

Question	Bad	Poor	Good	Great	Average (0-3 scale)	Response Rate
Rate the overall usefulness of the worked examples (Diodes)	4 (2%)	32 (16%)	119 (60%)	46 (22%)	2.03	45%
Rate the overall usefulness of the worked examples (Sampling)	3 (2%)	17 (14%)	78 (66%)	21 (18%)	1.98	27%
Did you find the expandable feature of the examples useful? (Diodes)	3 (2%)	17 (9%)	89 (50%)	71 (40%)	2.27	40%
Did you find the expandable feature of the examples useful? (Sampling)	3 (3%)	3 (3%)	53 (50%)	46 (44%)	2.35	24%

Analyzing student responses to the free response question "Why did you find the expandable feature helpful or unhelpful?" yielded a codebook of seven codes. A list of those codes and their definitions is shown in Table 4.3.

Table 4.3: Brief codebook for "Why did you find the expandable feature helpful or unhelpful?" See Appendix E for full codebook. Some responses were assigned two codes.

Code	N	Code Description	Exemplar
Organized	7	Student finds the expandable examples cleaner	*"Doesn't take too much space if you don't need to see the work. Explanations are helpful."*
Work By Myself	10	Encourages student to try the problem before looking at solution	*"The expandable feature allowed me to either work out the problem on my own or click for help if I needed it."*
Detail	13	Likes the level of detail they can get with the expansion feature	*"Sometimes I'm confused with some very basic stuff, and when it happens, these things help me."*
Skip What I Know	4	Student doesn't have to look at information they already know	*"Yes it is helpful because we can open the parts we want to read and close the parts we already know."*
Disorganized	3	Hard to follow, disorganized	*"It was unhelpful because it disturbed the flow of ideas from section to section."*
Autoshow	8	Wishes the problem was fully expanded	*"This is just an extra step. I find it much better if the author just left the equation on the page instead of hiding it first."*
Helpful	10	Misc. positive responses	*"They are great! allow for good interaction"*

The "Detail" code was applied to statements that revealed students' appreciation for the level of detail they could get with the expansion feature. The presence of the "Detail" code indicated that some students benefited from the large number of sub-steps shown in the expandable examples. Many students struggle with only a single sub-step [19], and can be without recourse if that sub-step is not shown in a worked example.

The "Skip what I Know" code was applied to statements where the student mentioned the ability to skip or ignore the collapsed portions of the example easily. The presence of this code indicated that some students liked being able to easily ignore superfluous information. The presence of this code was expected from the worked examples literature [18].

Together the "Skip what I Know" and "Detail" codes capture the potential mitigation of expertise reversal, supporting our hypothesis for Research Question 1. Two exemplar quotations reveal the differences in how students reacted to the expandable examples based on their level of expertise. When asked why they found the expandable examples helpful, one student responded, *"Yes, it is helpful because we can open the parts we want to read and close the parts we already know."* This more advanced student did not want to be distracted by superfluous information and uses the expansion feature to avoid superfluous information. In contrast, a less advanced student responded to the same question with, *"Sometimes I'm confused with some very basic stuff, and when it happens, these things help me."* Without the ability to view sub-steps, students might end up missing a basic concept or forgetting a trivial manipulation [19], and they may be unable to find this information in other places.

The "Work by Myself" responses indicate that breaking up the example into phases (and hiding the details) may promote healthier study habits. These responses were unexpected because we had not found prior evidence from the literature suggesting this result. Some students slowed down and attempted problems on their own rather than copying the solution steps. When asked why he or she found the expandable examples helpful, one student responded, *"You are given a hint in the right direction of how to solve the problem, but are not just given the answer straight away. This discourages me from just looking at the answer without really giving the problem a shot."* With the inclusion of multiple sub-steps, students can open them individually, allowing themselves the challenge of solving the next part of the problem before viewing the solution.

The "Organized," "Disorganized," and "Helpful" categories did not contain any unexpected surprises or answer any of our research questions. Hence, we choose not to elaborate on them.

4.2.2 Assertion Headings

The affective response to the assertion headings was both strong and positive (see Table 4.4). Most students (more than 85%) rated the assertion headings as more useful than ordinary topic-subtopic headings. "Great! Much better than normal headings" was the most common response.

Table 4.4: Results for the free response question "What do you think of the complete-sentence headings?" asked in both the *Diodes* activity and the *Sampling* activity. The vast majority of students prefer the assertion headings, with around half choosing "Great! Much better than normal headings." Average score assigns a value of 0 to "Bad" and a value of 3 to "Great."

Question	Bad	Poor	Good	Great	Average (0-3 scale)	Response Rate
What do you think of the complete-sentence headings? (Diodes)	2 (1%)	12 (7%)	73 (40%)	94 (52%)	2.4	40%
What do you think of the complete-sentence headings? (Sampling)	4 (4%)	11 (10%)	41 (38%)	51 (48%)	2.3	24%

A majority of the respondents to the free response question indicated that the assertion headings helped them comprehend the text. Thirty five of the 40 responses to the question "Why did you find the complete-sentence titles helpful or unhelpful?" were positive (see Table 4.5).

Table 4.5: Codes for free response question "Why did you find the complete-sentence titles helpful or unhelpful?" Full codebook in Appendix E.

Code	N	Code Description	Exemplar
Summary	15	Headings provide takeaway main points after reading	*"Rather than simply mentioning the general ideas covered in the section, the complete-sentence titles also gave insight into what exactly we should take away from each section."*
Prepare	10	Headings help the student know what to pay attention to.	*"It was a good indication of the main idea that I needed to get out of the notes."*
Navigation	2	Heading help student find the information	*"If I want to know how to compute a certain thing or want to understand a certain topic, I can scan the titles."*
Problem Solving	2	Heading help the student solve problems	*"They are applicable and can help me solve problems!"*
Content	6	Headings provide extra information	*"The complete sentence titles give more information about the subject at hand."*
Unhelpful Length	5	Sentence headings are too long	*"It was too much to read."*

The "Summary" and "Prepare" responses to the free response question "Why did you find the complete-sentence titles helpful or unhelpful?" indicated that the assertion headings gave students a take-away main point. Students (especially novices) are not yet skilled at discerning what information is vital and what information is tangential, and the assertion headings helped students identify key information. Students expressed two subtly different views on this aspect. Some students used the headings as a way to verify they had read correctly *after* reading (Summary), others used the headings as guideposts to inform them what they should look for in the text *before* reading (Prepare). Together the data from these codes support our hypothesis for Research Question 2: The assertion headings successfully increased global coherence in the course notes.

The other codes did not help answer our research questions, or had too few responses to merit analysis.

4.2.3 Hand-drawn Figures

Student responses to the first Likert scale item "Do you prefer hand-written or computer-generated diagrams?" favored computer-generated diagrams (see Table 4.6), but the free response questions painted a more complex picture (see Table 3.3). Based on the free response question "Why do your prefer hand-drawn or computer-generated figures?" we created three hypotheses and survey items in the *Sampling* activity to address each one. First, we hypothesized that students prefer hand-drawn figures for affective reasons, such as a perception of caring from the instructor (items 16, 17, 22). Secondly, we hypothesized that students prefer computer-generated figures for reasons of legibility (items 19, 21, 23 and 24). Last, we hypothesized that hand-drawn figures may raise trust concerns for students (items 18 and 20).

The code-inspired Likert scale items from the *Sampling* activity yielded more precise information about some of the themes discovered during the free response question "Why do you prefer hand-drawn or computer-generated figures?" We combined items involving legibility (see Table 4.7) into a composite index of 3 items, and also combined items about emotional response (see Table 4.8) into a composite index of 4 items. The correlation coefficients between these items can be found in Appendix C. The items are shown with

Table 4.6: Likert scale question "Do you prefer hand written or computer-generated diagrams?" from the *Diodes* activity. Preference for computer-generated figures can be seen.

Greatly Prefer computer-generated	Slightly prefer computer-generated	Slightly prefer hand-drawn	Greatly prefer hand-drawn	Don't Care	Response Rate
33 (15%)	63 (29%)	38 (18%)	19 (9%)	62 (29%)	40%

the student response that inspired the creation of that survey item in Table 4.9.

Table 4.7: The legibility composite index of the survey items 19, 20 and 24 from the *Sampling* activity: "computer-generated figures are easier to read than neat, legible hand-drawn figures," "I am more likely to pay attention to a computer-generated figure than to a neat, legible hand-drawn figure," and "computer-generated figures are easier to interpret."

Strongly Prefers computer-generated	Slightly Prefers computer-generated	Slightly Prefers Hand-drawn	Strongly Prefers Hand-drawn	Overall (0-3 scale)
14 (15%)	44 (47%)	32 (35%)	3 (3%)	1.25

Table 4.8: The emotional composite index of survey items 16, 17, 20 and 22 from the *Sampling* activity: "Hand drawn figures are more inviting and less intimidating," "Hand-drawn figures make me feel like the instructors care more about my learning," "Hand-drawn figures are more credible," and "Hand-drawn figures help me learn how to draw those figures better for myself." A positive emotional response to the hand-drawn figures can be seen.

Strongly Prefers computer-generated	Slightly Prefers computer-generated	Slightly Prefers Hand-drawn	Strongly Prefers Hand-drawn	Overall (0-3 scale)
8 (9%)	15 (16%)	58 (62%)	12 (13%)	2.2

The emotional composite index was composed of four survey items and examined the emotional response to hand-drawn figures (see Table 4.8). Responses indicate that students feel more confident with, more cared for by, and more invited by hand-drawn figures. The index favored hand-drawn figures over computer-generated figures by about 3:1. From these results alone, we cannot determine whether the positive emotional responses will lead to increased textbook use or increased performance on exams. Research shows a relationship between a student's perception that their professor cares about them personally and higher motivation to engage in the course [11]. We were particularly encouraged by one response from a student who responded that the hand-drawn figures made them feel that the professor cared about their education (see Table 4.9).

The legibility composite index was composed of three survey items and examined the value of neatness and readability in figures (see Table 4.7). Responses favor computer-generated figures over hand-drawn figures by about 2:1. Some students may have been comparing computer-generated figures in ECE 110 to all the hand-drawn figures they had seen in previous classes, and some may have been comparing them to only the hand-drawn figures from the ECE 110 course notes. Negative experiences with sloppily drawn figures in previous classes may have amplified the intensity of response to these survey items.

Two of the survey items in the *Sampling* activity had no notable correlations with any other survey items (see correlations in Appendix C). We decline to draw any conclusions from Item 23 and Item 20 from the *Sampling* activity. Full statements of the survey items can be found in Table 4.9.

Item 18 and item 20 were designed to measure the same idea, student tendency to believe what a textbook figure says is accurate and true. The large difference in response for two reversed questions may indicate affirmation bias. Students may have interpreted "credible" to be unrelated to "less likely to have errors" and the very small correlation coefficient between responses to items 18 and 20 ($r = 0.02$) supports this interpretation.

Table 4.9: The Likert scale items from the *Sampling* activity, with exemplar quotations and their corresponding codes.

#	Survey Item	Inspiring Response	Code
17	Hand-drawn figures help me learn how to draw those figures better for myself	*"Easy to compare to my diagram"*	Hand-Relatable
16	Hand-drawn figures make me feel like the instructors care more about my learning	*"Feels as if the person cared for the education.[sic]"*	Hand-Inviting
22	Hand-drawn figures are more inviting and less intimidating	*"The hand drawn ones just seem friendlier and more welcoming"*	Hand-Inviting
20	Hand-drawn figures are more credible	*"Hand-drawn perceived as more accurate"*	Pilot Study
24	I am more likely to pay attention to a computer-generated figure than a neat, legible hand-drawn figure	*"I don't really know, I find that I'm less likely to glaze over them though"*	Hand-Inviting
21	computer-generated figures are easier to interpret	*"Easier to read"* (occurred verbatim 4 times in the sample)	Computer-Clean and Clear
19	computer-generated figures are easier to read	*"Easier to read"*	Computer-Clean and Clear
18	computer-generated figures are less likely to have errors	*"Hand-drawn perceived as more accurate"*	Pilot Study
23	Neat, legible hand-drawn figures are less cluttered than computer-generated diagrams	*"A little cleaner hand drawn than the computer, the symbols on computer are more spaced out and clutter up the diagram a little"*	Hand-Clean and Clear

CHAPTER 5

DISCUSSION

5.1 Expandable Examples

The quantitative results do not show much statistical significance, but the free response answers are over 90% in favor of expandable examples. Based on the coding results, students value the expandable examples for the reasons we hypothesized they would, choosing to use or ignore the expansion sections depending on their own preparedness for the particular problem at hand. Responses to "Why did you find the expandable feature helpful or unhelpful?" like this one "*Yes it is helpful because we can open the parts we want to read and close the parts we already know*" support our hypothesis for Research Question 2. Novice students could access the detail they needed to solve the problem, but advanced students could skip the details they already knew. With no prompting, students recognized this purpose of the expandable examples.

Surprisingly, the expansion steps acted as a speed bump for students; they attempted the problem, instead of copying the solution. Students know they need to solve problems independently in order to succeed, but often succumb to the temptation of copying solutions [40]. With expandable examples students can more easily resist the urge to use the entire solution, but if they get stuck, they have the option to view the key part of the solution. Expandable worked solutions could bring extra value to online solution manuals, encouraging students to work through the solutions rather than look for quick answers.

Only two responses to "Why did you find the complete-sentence titles helpful or unhelpful?" commented that the assertion headings made it easier to find information when searching through the text. Perhaps this theme was not common because electronic textbooks and web browsers already have automatic search for keywords, so finding relevant information is not as difficult. Since each activity covered only one chapter, finding relevant information to solve a problem was less difficult (since students needed to search only one chapter).

Creating detailed worked examples can be difficult for an expert, because trivial manipulations for experts are stumbling blocks for novice students. Experts must make tacit, "overlearned" knowledge explicit [41]. The author must be diligent to show every step, perhaps working with novice assistants to produce step-by-step examples.

5.2 Assertion Headings

Since there is consistent evidence showing that students prefer to read summaries of chapters over the whole body of the text [1, 2], it is important that educators developing textbooks consider the amount of time it takes students to study when creating and evaluating the usefulness of pedagogical materials [12]. Students are concerned with whether a particular passage helps them solve the problem at hand and do not want to waste time reading unnecessary information in the text. By scanning the headings for relevance to their current task rather than reading the whole section, students can spend less time looking through irrelevant materials. In this small study, the assertion headings did not have any significant effect on quiz performance, but the free-response questions indicate that the assertion headings helped students focus on the important parts of the material while they were reading the text. Given the small amount of extra writing involved, assertion headings may be a quick and easy way to add value to textbooks and increase their use.

Unfortunately, the possible effect that assertion headings have on the author of the textbook while writing could not be studied. Because the author of the course notes wrote them with the assertion format in mind, we suspect having assertions in mind influenced his style of writing. We suspect that conforming to the assertion form constrains the writing of the text, forcing the author to maintain global coherence for each passage. Many textbook chapters have crowded sections with too many ideas jockeying for prominence and meandering passages with no main thesis. The author of the course notes casually reported that writing with the assertion format in mind caused him to focus his writing. Additional research is needed to investigate this idea.

5.3 Hand-drawn Figures

The majority of students agreed that hand-drawn figures allow them to be more confident in their own ability to draw similar figures from the material. This theme came as a surprise to us. It appears that a sort of vicarious self-efficacy [11] effect may be generated by the hand-drawn figures. Though a computer-generated figure and a hand-drawn diagram represent the same circuit, students feel a hand-drawn figure is easier to replicate and compare to their own work. Since students do most, if not all, drawings of circuits on paper in introductory courses like ECE 110, hand-drawn diagrams in the course notes or textbook may affect the quality of student drawings or the ability of students to turn computer-generated images into their own drawings without having seen someone else do it first. A future study could investigate the effect of hand-drawn figures in course notes on the quality of circuit sketches produced by students.

Students' responses to "Hand-drawn figures make me feel like the instructors care more about my learning" were encouraging. To succeed, students need to feel that their instructors care about them [11]. Perhaps students inferred their instructors cared more because students know that neatly drawn figures take time to make and believe that only a caring instructor would spend the time to make a nice figure. Another possible explanation is that simply knowing someone personally created the figure may affect students emotionally. Drawing figures *neatly* entails an extra time cost to authors compared to computer generation, and also imposes consistency problems on larger works with multiple authors. Our results do not suggest changing all textbook figures to hand-drawn ones. However, figures students are expected to replicate might be more effective if they are hand-drawn in the textbook.

5.4 Limitations

We had no control for time-on-task in any of the experiments, given the natural studying design of the study. Furthermore, the short (1 hour) time of exposure to the content was not long enough for students to deeply learn the material, so we did not expect a large difference in quiz scores between groups. If students in one group during the *Sampling* activity preferred the text variant they got in *Diodes*, they could potentially access another group's course notes since the pages were not secured. The change in response rate between the *Diodes* activity and the *Sampling* activity also confounds results. The demographic makeup of students participating in the two activities may have shifted (for example, it is possible that only students who really needed the participation credit participated in the *Sampling* activity).

Some students may have ignored the assertion headings, or members of the control group may have found the end of chapter assertions equally helpful. Prior experience with the technical content topics was not controlled for, nor did we perform any rigorous pretest/posttest comparison. The implicit difference in difficulty of the content between the *Diodes* and *Sampling* topics may also muddy results, as well as the more heavily numerical nature of the content quiz for the *Sampling* activity. The example problems in the *Sampling* activity in general contained fewer steps than those in the *Diodes* activity, offering fewer opportunities to use the expansion feature.

Assertion headings were used in all the chapters of the course notes, but only two chapters of the course notes were controlled for and studied. This prior exposure moderates any effect of inexperience with the medium itself, but also muddies the resulting opinions and performance differences.

The assertion headings and expandable examples did not appear to have any performance effect in the *Diodes* activity, but they did appear to be disadvantageous to some students in the *Sampling* activity. Since the student spent about an hour with the *Sampling* topic, the mean scores with its quantitative questions are much lower than the mean scores on the more conceptual *Diodes* topic. One possible explanation is that the scores were so high on the *Diodes* quiz that there was no room for improvement (there were many perfect scores), but a difference could be seen on the more difficult *Sampling* activity. Similar to McNamara's study [32], it is possible that some students actually performed better when exposed to less coherent materials. It is possible than even a small difference in initial preparation by the Assertion Headings group could have had a large impact on performance in the much more difficult *Sampling* activity.

There may have been some common biases that affected our finding of mostly positive ratings of the materials. The positive responses may be an instance of the Hawthorne effect, in which any change from the norm is rated favorably simply because it is novel [42]. Though the middle number on a Likert scale item nominally represents an unremarkable item, many ratings of people and products (such as teacher evaluations [43]) tend to skew positive. This person positivity bias may also have affected our results. When asked if they agree or disagree with a statement, people tend to agree; this affirmation bias (also called acquiescence response bias) [44] also may have skewed the evaluations of the course materials.

CHAPTER 6

CONCLUSIONS

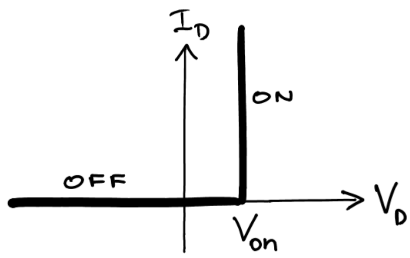
The textbook innovations explored in this study had a marked affective impact on students. The effect on students' feelings toward the instructor, self efficacy, and self-regulation indicate these techniques are worthy of further investigation (given the low additional cost of implementation over traditional textbook writing). Due to several confounding factors and the exploratory nature of the experiments, no firm conclusions can be drawn on the influence of these textbook writing styles on student performance or willingness to read their textbook more. However, the survey responses are encouraging.

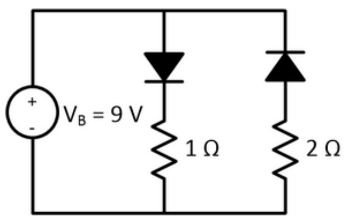
The changing nature of textbooks with technological innovations provides an unprecedented opportunity to change the perception of textbooks and increase their use. To help textbooks evolve from costly and unhelpful materials to exciting and valuable resources, additional research on textbook construction is warranted.

APPENDIX A

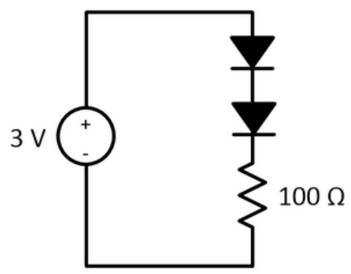
DIODES QUIZ AND SURVEY

All diodes in this activity are to be treated with the large-signal model. It has an I-V curve that looks like this:

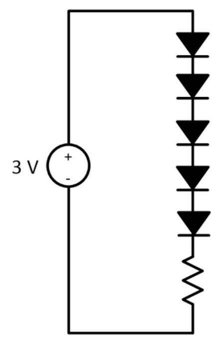




1. What group are you in?
2. Which of the two diodes is ON? Treat both diodes with the large-signal model having a V_{on} of 0.7 Volts
   - The left diode is ON
   - The right diode is ON
3. Does current flow through the resistor? Treat both diodes with the large-signal model having a V_{on} of 0.7 Volts.

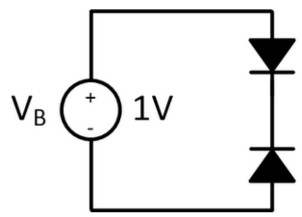


- No, there will be no current in the resistor
- Yes, there will be some current in the resistor



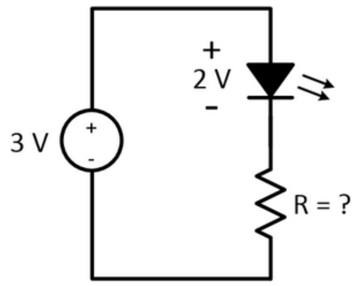
4. Does current flow through the resistor? All the diodes may be treated using the large-signal model with a V_{on}=0.7 Volts.

   - No, the current through the resistor will be zero
   - Yes, current will flow through the resistor



5. Which of the diodes is ON? Treat both diodes with the large-signal model having a V_{on} of 0.7 Volts.

- Both the top and bottom diodes are ON
- The top diode is OFF and the bottom diode is ON
- The top diode is ON and the bottom diode is OFF
- Both the top and bottom diodes are OFF



6. What resistance (in ohms) must the current limiting resistor have if the diode's $V_{on} = 2$ Volts and the current through the diode is 20 mA? NOTE: This diode is not an ordinary silicon diode, it has a different V_{on} than the diodes in the other problems.

7. Under the large-signal model, which of the following is true?

- A large-signal model diode absorbs energy when ON
- A large-signal model diode never absorbs energy
- A large-signal model diode absorbs energy when off or on, but more when on.

8. In the large-signal model, when a diode is OFF, it acts like...

- A generic element with $V_d = -V_{on}$
- An open circuit
- A piece of wire
- A resistor

9. Which is true?

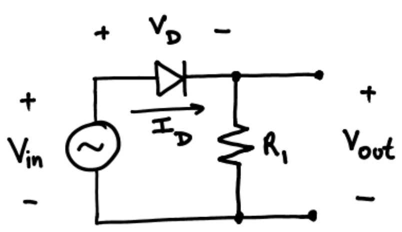
    - In a diode, current flows from the anode to the cathode
    - In a diode, current flows from the cathode to the anode

10. Rate the overall quality of the course notes. Did they help you learn?

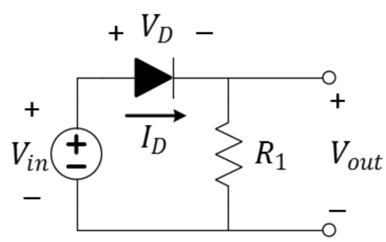
    - 1 Terrible. I couldn't learn anything from the course notes
    - 2 Poor. I had trouble learning from the course notes
    - 3 OK. I learned from the course notes about as well as most other texts
    - 4 Awesome. The course notes made everything easy to understand
    - XX Don't care/ Didn't read

11. Rate the usefulness of the expandable worked examples

    - 1 Useless. The worked examples did not help me understand anything
    - 2 Poor. These are below average in their ability to help me learn
    - 3 OK. These are above average in their ability to help me learn
    - 4 Very useful. These are some of the best worked examples I've ever used
    - XX Don't care/Didn't Use



VS



12. The lecture notes are hand-drawn, the worked examples are typeset by computer. Do you prefer hand-written or computer-generated diagrams?

- 1 Greatly prefer computer-generated
- 2 Slightly prefer computer-generated
- 3 Slightly prefer hand-drawn
- 4 Greatly prefer hand-drawn
- XX Don't care

13. Why do you prefer that type of diagram?

14. What did you think of the complete-sentence section headings?

- 1 Bad. Long headings were useless and in the way
- 2 Poor. Ordinary headings are better
- 3 OK. A little better than ordinary headings.
- 4 Great! Much better than normal headings
- XX Don't Care/didn't notice
- YY The notes I saw did not have the sentence headings

$$+V_{in} - V_{on} - V_{out} = 0$$

15. Did you find the expandable features of the examples useful?

- 1 Terrible. The expanding makes the worked examples much harder to use
- 2 Poor. The expanding makes them a little worse than a static example.
- 3 OK. The expanding makes them a little better than a static example

- 4 Great. The expansion makes the worked examples much more effective
- XX Don't Care/Didn't use
- YY The examples I saw didn't have these

APPENDIX B

SAMPLING QUIZ AND SURVEY

1. What group are you in?

2. Human beings can hear sounds at frequencies up to 20,000 Hz. If we want to digitally record music that contains the entire human auditory range, what minimum sampling frequency would we need (in Hz)?

3. A certain square wave can be approximated (with reasonable accuracy) as $\sin(t)+1/3\sin(3t)+1/5\sin(5t)+1/7\sin(7t)+1/9\sin(9t)$, with t being measured in seconds. What is the minimum sampling rate we would need (in Hz) to capture this level of accuracy?

   - $0.22Hz$
   - $2Hz$
   - $2.865Hz$
   - $9Hz$
   - $18Hz$

4. We are using a 4-bit quantizer with 16 evenly spaced levels to capture the range of currents from $-4mA$ to $+4mA$. What is the second-highest current level (in mA) represented on this scale?

5. If we have a signal $y(t) = 5 + 0.33\cos(100t) + 1.5\sin(40t)$, what is the minimum sampling rate (in Hz) we would need to fully capture this signal?

   - 20 Hz
   - 24.46Hz
   - 40 Hz
   - 50 Hz

- 100 Hz

6. Which sequence represents the samples of the function $s(t) = 1+\cos(4t)$ at a sampling rate of 2 Hz? (t is measured in seconds, the first sample is taken at $t = 0$)

   - 2 0 2 0 2 0
   - 1 -1 1 -1 1 -1
   - 0 1 0 -1 0 1
   - 2 -2 2 -2 2 -2
   - 2 2 2 2 2 2

7. What is the minimum number of bits (per sample) to quantize a voltage to one of 64 levels?

8. If we want to store an uncompressed single channel 3 minute long song with a sampling rate of 44100 Hz using 24-bit quantization, what will the file size be (in MB). $1MB = 10^6B$

9. If a sinusoidal signal is sampled at exactly the Nyquist rate, we are taking:

   - 1 sample every 2 cycles
   - 1 sample every cycle
   - 2 samples every cycle
   - 4 samples every cycle

10. Rate the overall quality of the course notes chapter on Sampling. Did they help you learn?

    - Terrible. I couldn't learn anything from the Sampling notes
    - Poor. I had trouble learning from the Sampling notes
    - Fair. I could learn from the Sampling notes about as well as other texts
    - Awesome. The Sampling notes explained everything great.
    - XX: Don't care/ didn't read

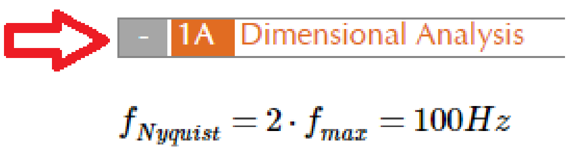
11. Rate the usefulness of the expandable worked examples for the Sampling topic. Did they help you learn?

    - 1 Useless. The worked examples did not help me understand anything
    - 2 Poor. These are below average in their ability to help me learn
    - 3 OK. These are above average in their ability to help me learn
    - 4 Very useful. These are some of the best worked examples I've ever used
    - XX Don't care/Didn't Use

12. What did you think of the complete-sentence section headings in the Sampling chapter?

    - 1 Bad. Long headings were useless and in the way
    - 2 Poor. Ordinary headings are better
    - 3 OK. A little better than ordinary headings.
    - 4 Great! Much better than normal headings
    - XX: Don't Care/didn't notice
    - YY: The notes I saw did not have the sentence headings

13. Why did you find the complete-sentence titles helpful or unhelpful?



14. Did you find the expandable features of the examples useful?

- 1 Terrible. The expanding makes the worked examples much harder to use
- 2 Poor. The expanding makes them a little worse than a static example.
- 3 OK. The expanding makes them a little better than a static example
- 4 Great. The expansion makes the worked examples much more effective
- XX Don't Care/Didn't use
- YY The examples I saw didn't have these

15. Why did you find the expandable feature helpful or unhelpful?

16. Hand-drawn figures make me feel like the instructors care more about my learning.

    - Strongly Agree
    - Mildly Agree
    - Mildly Disagree
    - Strongly Disagree

17. Hand-drawn figures help me learn how to draw those figures better for myself.

    - Strongly Agree
    - Mildly Agree
    - Mildly Disagree
    - Strongly Disagree

18. Computer-generated figures are less likely to have errors.

    - Strongly Agree
    - Mildly Agree
    - Mildly Disagree

- Strongly Disagree

19. Computer-generated figures are easier to read than neat, legible hand-drawn figures

    - Strongly Agree
    - Mildly Agree
    - Mildly Disagree
    - Strongly Disagree

20. Hand drawn figures are more credible.

    - Strongly Agree
    - Mildly Agree
    - Mildly Disagree
    - Strongly Disagree

21. Computer-generated figures are easier to interpret.

    - Strongly Agree
    - Mildly Agree
    - Mildly Disagree
    - Strongly Disagree.

22. Hand drawn figures are more inviting and less intimidating.

    - Strongly Agree
    - Mildly Agree
    - Mildly Disagree
    - Strongly Disagree

23. Neat, legible hand drawn figures are less cluttered than computer-generated diagrams.

    - Strongly Agree

- Mildly Agree
- Mildly Disagree
- Strongly Disagree

24. I am more likely to pay attention to a computer-generated figure than to a neat, legible hand-drawn figure.

    - Strongly Agree
    - Mildly Agree
    - Mildly Disagree
    - Strongly Disagree

APPENDIX C

CORRELATIONS

Table C.1: Pearson correlation r between each of the Likert scale questions during the *Sampling* activity. Correlations greater than 0.5 are bolded.

	Emotional index				Legibility index				
	22	16	17	20	19	24	21	18	23
22	1	0.46	**0.6**	**0.61**	0.42	0.39	0.3	0.47	0.47
16		1	**0.69**	**0.51**	0.35	0.37	0.15	0.14	0.32
17			1	**0.54**	0.41	0.39	0.27	0.11	0.34
20				1	0.22	0.24	0.19	-0.02	0.35
19					1	**0.54**	**0.58**	0.31	0.17
24						1	**0.55**	0.21	0.17
21							1	0.11	0.1
18								1	0.17
23									1

APPENDIX D

EXPANDABLE EXAMPLE

Though the true usefulness of the expandable example does not translate well to a paper thesis, the collapsed and expanded versions of one example are included here.

DIODES

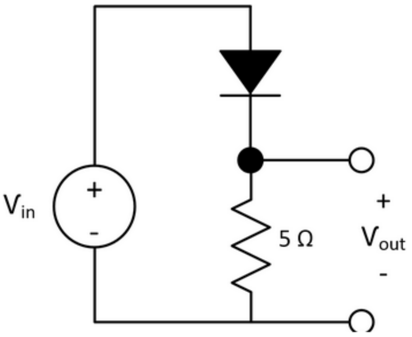
A DIODE PROBLEM WITH UNTERMINATED LEADS

LEARN IT!
PRE-REQUISITE KNOWLEDGE

To understand this section, you need to know the following concepts:

- Diodes
- Ohm's Law

Goal	Diodes Solve the for V_{out} assuming the large signal model for the diode

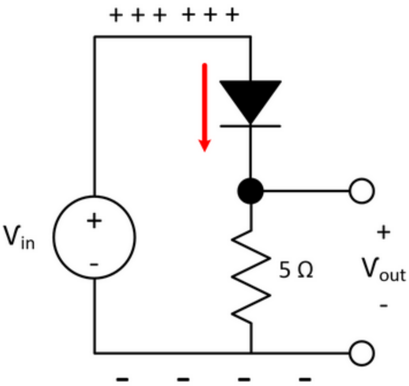


If $V_{in} = 1.7V$ in the diode circuit below, what is V_{out}, assuming the large signal model for the diode $V_{on} = 0.7V$

a. $0V$
b. $0.7V$
c. $1V$
d. $1.7V$
e. $2.4V$

+ ? What should we do about those terminals?

Part 1 Guess diode mode



The first thing to do when a diode is connected to a DC source is guess if it will be on or off.

Since the $+$ end of the source is connected to the back of the diode, and the source is larger than 0.7V, we'll take "on" as our 1st guess

+ 1A Compute values using KVL

$$+V_{in} - V_{on} - V_{out} = 0$$

Apply KVL. The source is positive, the voltage drop across the diode and resistor are both negative.

★

$$V_{out} = 1.7 - 0.7 = 1.0V$$

Just plug it in to solve.

+ ! What about what's attached to the terminals?

Figure D.1: Fully collapsed example

DIODES

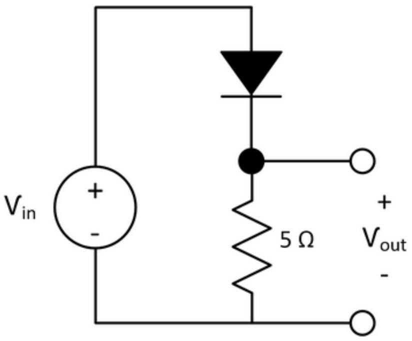
A DIODE PROBLEM WITH UNTERMINATED LEADS

LEARN IT!
PRE-REQUISITE KNOWLEDGE

To understand this section, you need to know the following concepts:

- Diodes
- Ohm's Law

Goal Diodes
Solve the for V_{out} assuming the large signal model for the diode



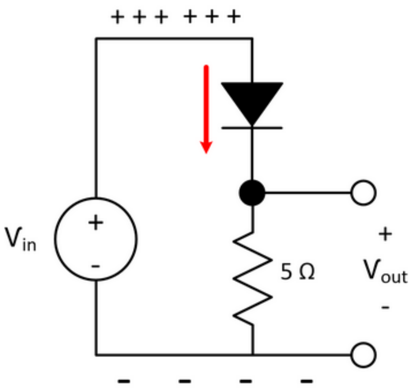
If $V_{in} = 1.7V$ in the diode circuit below, what is V_{out}, assuming the large signal model for the diode $V_{on} = 0.7V$

a. $0V$
b. $0.7V$
c. $1V$
d. $1.7V$
e. $2.4V$

- ? What should we do about those terminals?

This looks a lot like a typical diode problem, though those un-terminated leads are different from some previous problems. We will not worry about them just yet, but they will make Kirchoff's current law useless to us in this problem.

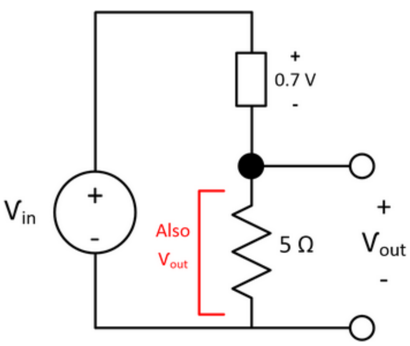
Part 1 Guess diode mode



The first thing to do when a diode is connected to a DC source is guess if it will be on or off.

Since the + end of the source is connected to the back of the diode, and the source is larger than 0.7V, we'll take "on" as our 1st guess

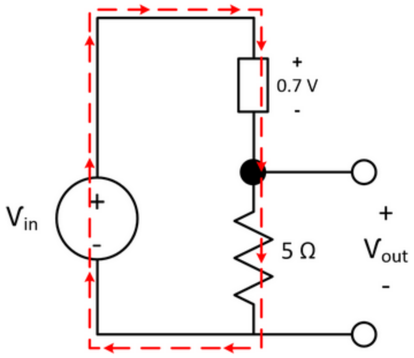
- 1A Compute values using KVL



Since we guessed the diode was ON, replace the diode with a $0.7V$ drop generic element.

We want V_{out}, but it isn't an element we have. But whatever V_{out} is connected to, we know that it has the same voltage as the resistor. They are in parallel, so $V_{out} = V_R$

Figure D.2: Fully expanded example (continues on next page)



Now we can use a KVL loop to find the voltage across the resistor

- ? Why this loop?

I choose a clockwise loop so that V_{in} will be positive in my KVL equation

$$+V_{in} - V_{on} - V_{out} = 0$$

Apply KVL. The source is positive, the voltage drop across the diode and resistor are both negative.

$$V_{in} - Von = V_{out}$$

Subtract the desired variable V_{out} over to the other side to isolate

★

$$V_{out} = 1.7 - 0.7 = 1.0V$$

Just plug it in to solve.

- ! What about what's attached to the terminals?

One might ask "But what about whatever is attached to those terminals? Won't that affect the voltage across the resistor?" No, because KVL is always true for any loop, regardless of what other stuff is attached to that loop.

What we do lose, though, is now we can't know what the current in the diode and source is, because KCL has unfindable unknowns in it now. so the circuit WILL be affected in some way.

Figure D.2: Continued

APPENDIX E

CODEBOOKS

Table E.1: Codebook for the free response question “Why do you prefer hand-drawn or computer-generated figures?” from the *Diodes* activity.

Code	Definition
Hand - Inviting	Prefer hand-drawn figures because they are more inviting/less intimidating. Students have a positive affective response to the author or instructor through the figure
Hand - Relatable	Prefer hand-drawn figures because they are more similar to what student themselves produce. Figure is more comprehensible because it is similar to students' own work
Hand - Clean and Clear	Prefer hand-drawn because it is cleaner or clearer to read. Figure is more comprehensible because it is easy to interpret.
DC - Clean and Clear	No preference as long as it is clean and clear to read
DC - Equally effective	No preference, both forms are equally effective. Students can understand either.
DC - Indifferent	No preference and no reason discussed
Computer - Relatable	Prefer computer-generated figures because they are similar to what the students must produce
Computer - Clean and Clear	Prefer computer-generated because it is cleaner or clearer to read

Table E.2: Full codebook for the free response question "Why do you find the expanding feature of the examples helpful or unhelpful?" asked during the *Sampling* activity.

Code	Definition
Organized	Student finds the expandable examples cleaner, not taking up too much space
Work By Myself	Encourages the student to try solving the problem themselves
Detail	Student likes the level of detail they can get with the expansion feature, shows all the steps, step-by-step, etc, small and basic things are shown. See the whole thing and all the reasoning
Skip What I Know	The student doesn't have to look at information they already know, can avoid looking at things they don't want to see.
Helpful	Miscellaneous positive responses, indicating the expandable examples were more practical, made learning easier, or were easier to understand.
Disorganized	Hard to follow, cluttered, disorganized

Table E.3: Full codebook for the free response question "Why do you find the complete-sentence headings helpful or unhelpful?" from the *Sampling* activity.

Code	Definition
Summary	(What HAVE I learned) headings provide a summary ,takeaway main points
Prepare	(What WILL I learn) helping the student prepare to take in the following section. Know what to pay attention to.
Navigation	find the information they are looking for, or skip information that is not relevant to them
Problem Solving	Heading help the student solve problems or answer questions
Content	(What IS here)The headings provide extra information, or make information more clear or easy to understand
Unhelpful Length	Student thinks the sentence headings are too long or too much to read.

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