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Board 205: A Web-Based Writing Exercise Employing Directed Line of Reasoning Feedback for a Course on Electric Circuit Analysis

Prof. James P. Becker, Montana State University, Bozeman
Dr. Douglas J. Hacker, University of Utah

Dr. Hacker is Professor Emeritus in the Department of Educational Psychology and participated in both the Learning Sciences Program and the Reading and Literacy Program.

Christine Johnson

Web-Based Writing Exercises for a Course on Electric Circuit Analysis

Abstract

The use of writing-based exercises in a circuit analysis course has shown promise in aiding students likely to struggle in the course by enhancing their conceptual understanding of topics related to DC circuit analysis [1]. As grading of writing samples and providing personalized feedback can be time-intensive, automating the evaluation and feedback processes through use of emerging techniques in natural language processing (NLP) could open the door for more widespread use of such writing exercises across STEM courses, thus benefiting students in most need of assistance.

In this paper, the development and initial testing of two web-based writing activities that leverage a basic NLP technique to probe student writing related to DC circuits are described. The first writing exercise has students describe what happens to the power of various elements in a resistive circuit as the value of one of the resistors decreases. The second exercise has students consider situations in which the ideal independent voltage and current source models might fail. Both writing exercises are built from a template that includes several metacognitive prompts to spur self-reflection on the part of the user. A rule-based approach was taken to detect evidence of common misconceptions [2] and errors in student responses, as well as to identify sentences that revealed the student was correctly addressing the problems. Based on identified misconceptions or correct concepts in a student's writing, the web-based application selects appropriate directed line of reasoning (DLR) feedback paths to attempt to lead the writer to an accurate understanding of the behavior of the circuits in question.

Key features of the web-based application template as well as details regarding misconception detection and personalized feedback are described. Student impressions of the value of the DLR feedback is assessed using comments provided by the student within the applications. Planned modifications of the web-based writing exercise template based on this formative assessment will be given and address a broader goal of this work – to develop a web-based template that instructors across STEM disciplines, even those without a background in coding, could use to implement their own conceptual writing exercises.

Introduction

Emphasis is often placed on computation-based questions in gateway STEM courses, for example in courses such as electric circuit analysis for electrical and computer engineering students and statics for mechanical and civil engineering students. This is reasonable as, depending upon their major, such students must learn to complete successfully basic calculations of voltage, current, and power in electric circuits or to analyze the forces in structures such as trusses, beams and frames. Computation-based questions allow instructors to adequately assess student mastery of such calculations and developing and grading computation-based exams is straightforward. However, both circuit analysis and statics courses challenge students' conceptual knowledge, yet computation-based exams often fail to probe a student's knowledge of such concepts. Indeed, students can learn to perform the mechanical computations without having a strong conceptual understanding of the underlying phenomena. For example, Venters *et al*. found that students performed at the same level on procedural exams when they had participated in an "explain-a-problem" intervention aimed at promoting self-assessment and communication skills or a control group without the intervention. In the same study, the intervention group performed at a higher level than the control group on a concept inventory [3]. This is an important finding as students without a strong foundation of conceptual understanding may struggle later in their studies when required to perform higher-level learning tasks.

Across many fields of study, writing exercises have been found to elicit common misconceptions [4]-[7], and thus offer a means for instructors to probe the accuracy of a student's conceptual knowledge. The time and effort necessary to grade and provide feedback to students on their writing may explain why the use of writing in gateway STEM courses is limited. Evidence is emerging that writing exercises may not only elicit misconceptions but may in fact be used to improve a student's conceptual understanding [1],[3],[8]-[10] thus creating a compelling case that computation-based homework and exams should be complemented with conceptual-based ones. For example, as described in [1], writing exercises such as the two described herein have been used in handwritten form in an introductory course on electric circuit analysis. Students were given approximately twenty minutes during a lecture period to respond to a given writing exercise whereupon the instructor would collect the exercises and spend 10-15 minutes during lecture discussing a proper way to respond to the writing exercise's main question. During this explanation, the instructor would discuss one or two of the more common misconceptions students tend to exhibit in answering the question. Analysis of student performance on a multiple-choice exam covering concepts relevant to the behavior of electric circuits [11], suggested that students likely to struggle in the course demonstrated superior performance to a similarly composed control group who did not receive a four-writing exercise intervention. While part of the purpose of investigating a web-based approach to writing exercises is to remove the burden of grading the exercises, the possibility of instantaneous and targeted feedback to each student represents perhaps the greatest benefit of the approach. Toward realizing these goals, a pilot study of the web-based form of the writing exercises was carried out in the early part of the spring 2023 semester.

Over the past decade, tremendous strides have been made in the development of Natural Language Processing (NLP) techniques. Common NLP tasks include language translation, document and online searching, email filtering, voice assistants, predictive text, sentiment analysis, and chatbots. Considerable work has also been done on using NLP for the evaluation of writing. While most early NLP-based grading algorithms focused on syntactic analysis (correct structure of sentences) rather than semantic analysis (meaning of sentences), this is rapidly changing. The purpose of this paper is not to review state-of-the-art in semantic analysis, but rather to investigate how a simplistic rule-based approach to analyzing text could be of use in the evaluation of student responses to short, conceptual-based writing exercises.

In general, rule-based NLP approaches are very good at parsing and extracting key information at the sentence level. The rules can grow over time to enhance performance without significant changes to the core system, and deficiencies in an existing system are easily understood as the rules are assembled by the system developer. Furthermore, such an approach does not require the large training corpus of responses employed in state-of-the-art machine learning approaches to semantic analysis [12]. Two potential drawbacks of the rule-based approach are that a domain expert is needed to create the rules that govern the analysis of text, and the rules generated for one problem will not necessarily apply to other problems. As the overarching idea of the web-based writing exercise project is to create a template that instructors are able to use to construct their own writing exercises, these are not considered serious drawbacks. Naturally, as the amount of data in the form of student responses increases for a given writing application, it is possible to develop a hybrid analysis system in which the rule-based approach is augmented with a machine-learning approach such as BERT (Bidirectional Encoder Representations from Transformers) [13].

The remainder of this paper focuses on describing two web-based writing exercises built from an emerging template being developed by the authors as well as pilot testing of the web applications. In terms of technical details, the template uses a combination of html, CSS, and javascript within a Django web framework [14]. The rule-based approach to semantic analysis is implemented with the open-source NLP framework SpaCy [15].

Outline of the Conceptual-Based Writing Exercise Template

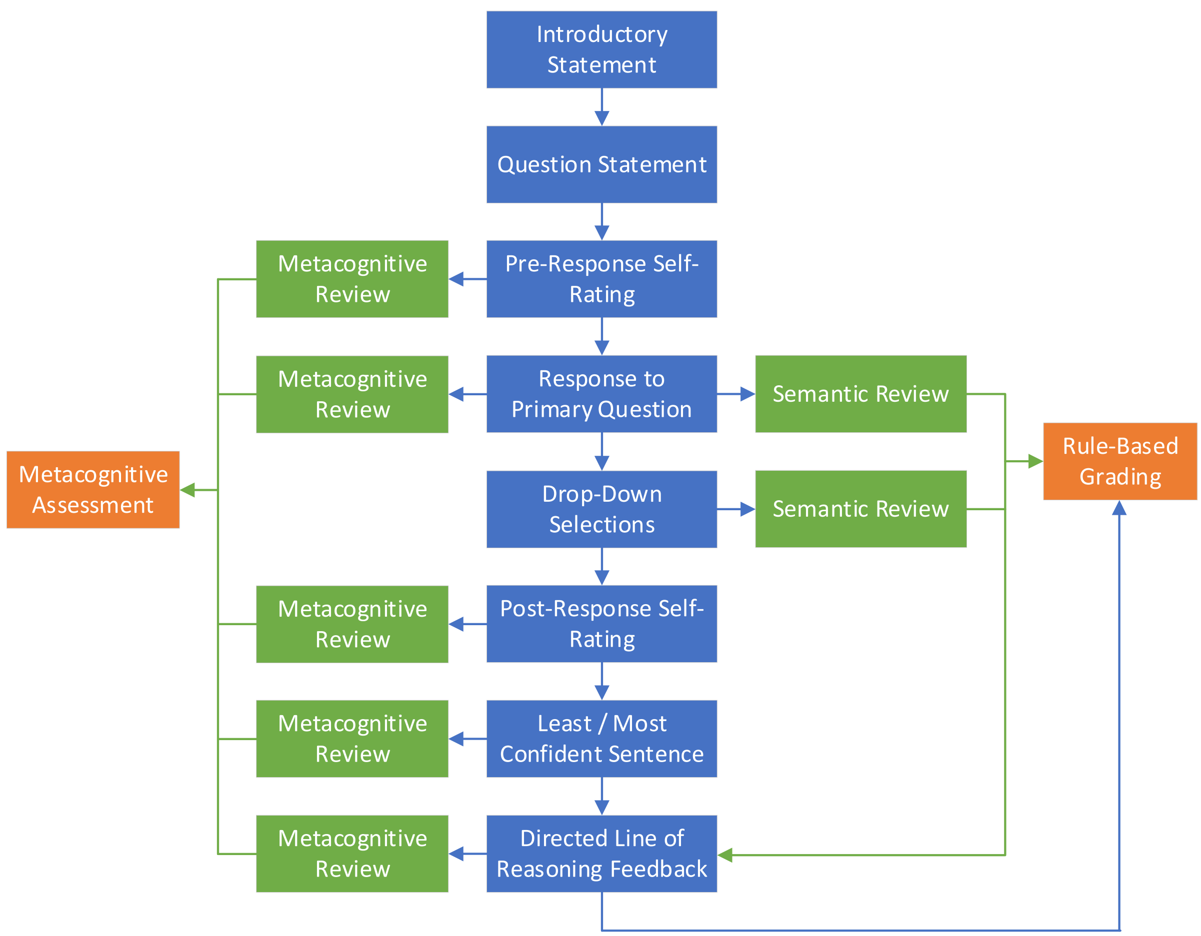


Figure 1: Flow chart representation of the web-based writing exercise template. The blue path represents the steps a student takes in completing the exercise.

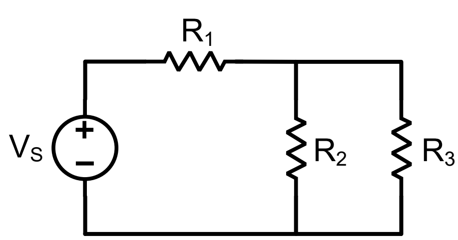
A flowchart of the elements of the web-based writing application template as well as the two types of review that are carried out on a student's responses is provided in Figure 1. The center path (blue boxes) represents the elements pertaining to content shown to the student as well as input requested of the student. The green boxes to the right of the center path represent instances in which the application applies a method to infer meaning from a student's response. The green boxes to the left of the path represent locations at which a set of rules are employed to identify instances in which a student's language is suggestive of metacognitive activity. The semantic and metacognitive reviews are described in a subsequent section. As portrayed in Figure 1, a writing exercise begins with a brief introductory statement to provide the student with the general idea behind the question's underlying concept. The two writing exercises described herein are introduced with the following statements.

For writing exercise one: *This exercise has you ponder what happens when a change is made to one of the elements in a circuit. After you read the question, but before you answer it, you will be asked to estimate your understanding of the question and your ability to answer it correctly.*

For writing exercise two: *This exercise has you ponder what it means when an independent source is claimed to be ideal and how in practice, no source is ideal. There are two main questions to this exercise, after you read the questions, but before you answer them, you will be asked to estimate your understanding of the questions and your ability to answer them.*

Experience with the first writing exercise over several semesters in paper format demonstrated that while most students appeared to grasp the underlying intent of the question, it was felt that the introductory statement would help students who might otherwise miss the point of the exercise's main question(s). Once the student reads the Introductory Statement and selects a continue button, he/she is presented with the main question(s) of the writing exercise. Figure 2 and Figure 3 contain the Question Statement for writing exercises 1 and 2, respectively.

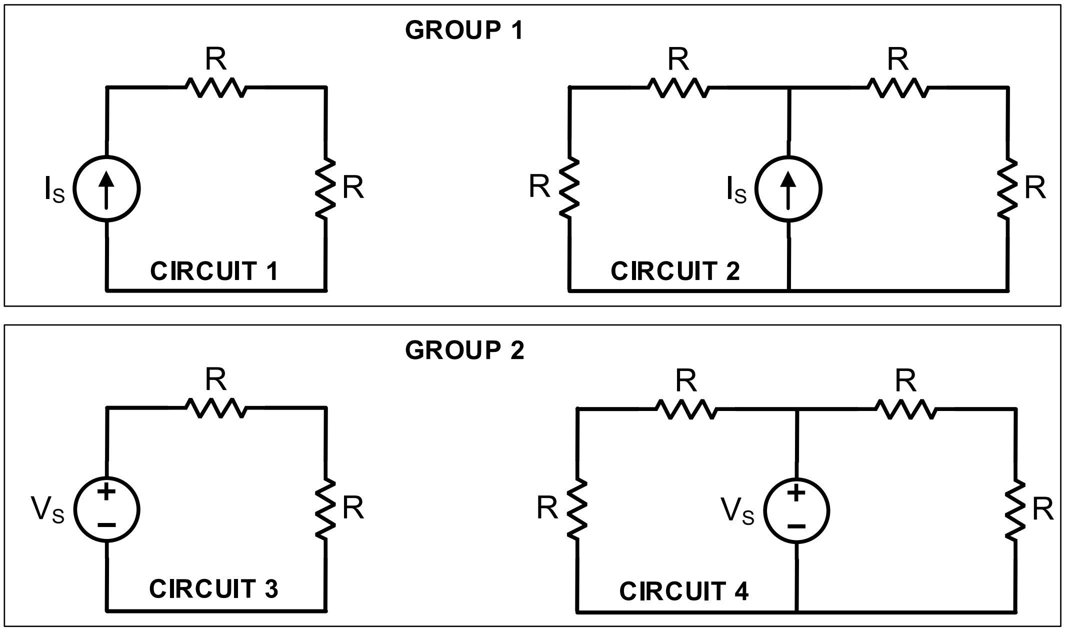
Consider the circuit shown below and assume that the elements are ideal. *Explain what happens to the power associated with V_S, R_1, R_2 and R_3 as the resistance of R_2 decreases while the other component values (V_S, R_1 and R_3) remain unchanged.* Thoroughly explain the rationale supporting your conclusions, using equations only as necessary.



It is your thought process that is the most important, so write what you are thinking and respond to all prompts given. You will have approximately twenty minutes to complete the problem.

Figure 2: Question Statement for writing exercise 1.

You have been asked to consider the following four circuits assuming ideal elements and that all resistors are of equal value.



In which circuit, CIRCUIT 1 or CIRCUIT 2, is the current source less likely to act ideal if the two circuits are built and tested using resistor values from very small to very large? Briefly explain your reasoning.

In which circuit, CIRCUIT 3 or CIRCUIT 4, is the voltage source less likely to act ideal if the two circuits are built and tested using resistor values from very small to very large? Briefly explain your reasoning.

It is your thought process that is the most important, so write what you are thinking and respond to all prompts given. You will have approximately twenty minutes to complete the problem.

Figure 3: Question Statement for writing exercise 2

(1) Rate your perceived understanding of the question in which a rating of 100% means you completely understand the question.
(2) Rate your perceived ability to correctly answer the question by selecting the appropriate response.

I am completely confident — I am quite confident — I am somewhat confident — I have little confidence — I am not at all confident

Figure 4: The Pre-Response Self-Rating questions. The Post-Response Self-Rating questions add the words, "Now that you have answered the question" to the beginning of the two questions.

The intent of the writing exercises is to encourage students to go beyond simply reciting memorized equations and rather to reflect on the meaning and implications of the equations, models, and concepts that are used in circuit analysis. In addition, various prompts are inserted within the writing exercises to spur metacognitive activity. For example, the two self-rating questions of Figure 4 are asked both before a student responds to an exercise's Question Statement (Pre-Response Self-Rating in Figure 1) and after their response to the exercise's Question Statement (Post-Response Self-Rating in Figure 1).

Broadly speaking, the concept of metacognition refers to how one reflects upon and controls their own mental processes. In common parlance, it is sometimes referred to as "thinking about thinking." While metacognition finds many definitions, it is common to distinguish between two types of metacognition, namely, knowledge of cognition and regulation of cognition [16],[17]. Since the two questions ask for a self-assessment of understanding, they relate to the knowledge of cognition component of metacognition. The web application stores this information for future assessment purposes – at present the recorded values do not figure into any feedback provided to the student.

After submitting the pre-response self-assessments, a student is presented again with the main question(s) of the exercise and provided a text box for entry. If thirty seconds goes by without any text entry, a reminder message pops up to encourage a student to write what they are thinking. Experience with the first writing exercise in hard copy format demonstrated that a significant percentage of students would fail to address what happens to the power of <u>each</u> element of the question, addressing only one or two elements and not all four. To ensure that students address all four elements, the following drop-down selections are provided in the web version of the first writing exercise.

To summarize, your response supports the following conclusions as the resistance of R_2 decreases:

The power associated with V_S: decreases, increases, or stays the same
The power associated with R_1: decreases, increases, or stays the same
The power associated with R_2: decreases, increases, or stays the same
The power associated with R_3: decreases, increases, or stays the same

Figure 5: The Drop-Down Selections for writing exercise 1.

To aid in deciphering student responses to the second writing quiz, rather than having a student respond to the questions related to Circuits 1 through 4 in a single text box, separate text boxes are presented to the student in discussing the group 1 circuits (Circuits 1 and 2) and the group 2 (Circuits 3 and 4). Similar to what was done with writing exercise 1, after a student addresses the group 1 circuits, the second writing exercise provides drop-down selections as shown in Figure 6. A complementary set of questions is given below the text box for the group 2 circuits. Again, the drop-down selections are intended to ensure students provide a complete response to a writing exercise's main question(s) and have the added benefit of making it easier to interpret a student's response, and thus, as suggested in Figure 1, a student's response to the drop-down selections forms part of the semantic review and can be used to inform the choice of the Directed Line of Reasoning (DLR) feedback paths. Once the student submits their textual and drop-down selection responses, they are given similar post-response self-assessment questions, again to allow a means to investigate a student's knowledge of cognition.

Select the option supported by your response.

The current source of CIRCUIT 1 will likely act less ideal
The current source of CIRCUIT 2 will likely act less ideal

Does your chosen current source act less ideal when the resistor values are very small or very large?

The current source acts less ideal when the resistor values are very small.
The current source acts less ideal when the resistor values are very large.

Figure 6: The Drop-Down Selections for the group 1 circuits of writing exercise 2. A complementary set of selections are given below the textbox for the group 2 circuits.

Final metacognitive prompts are given prior to a student receiving feedback on their response. The student is presented with the text of their response as well as their drop-down selections and asked the following questions.

Read through your response to the question. Identify the sentence from your response (by clicking on it) with which you have the least confidence and explain why you question its accuracy.

Read through your response to the question. Identify the sentence from your response (by clicking on it) with which you have the most confidence and explain why you are convinced of its accuracy.

As depicted on the flowchart of Figure 1, a student's responses to these questions are subject to the metacognitive review. In the next section, details of the semantic and metacognitive reviews are described.

Semantic and Metacognitive Reviews

The semantic and metacognitive reviews are depicted in green in the flow chart of Figure 1. The metacognitive reviews completed on the pre-response and post-response self-assessments have been described previously and are based on self-scores provided by the student. A similar self-scored assessment is given after a student has completed the correct solution DLR feedback path. Beyond these self-assessments, a rule-based approach has been implemented at the sentence level in an attempt to determine a partial "meaning" of a student's response and whether the student exhibits language that suggests active metacognition. Within the rule-based approach to semantic analysis, two distinct points of view were taken. For writing exercise one, rules were crafted to identify errors on the part of the students. For example, below are two rules employed in the writing exercise one web application, along with associated lines of python code to catch a misconception using the SpaCy NLP library [15]. The first rule examines each sentence of a student's response to the primary question to detect evidence of a so-called "sequential" misconception and the second to detect an error in thinking about the resistance in the circuit.

```
IF sentence includes “R1 comes before R2 and so changes in R2 do not
affect R1" THEN "class = Misconception_sequential"
pthyon code: pattern = [{'LOWER':'before'},{'LOWER':'r2'}]
```

```
IF sentence includes " equivalent resistance of the circuit increases as
R₂ decreases." THEN "class = resistance_error"

python code: pattern = [{'LOWER':'equivalent'},{'LOWER':'resistance'},
{'is_ascii':True,'OP':'?'},{'is_ascii':True,'OP':'?'},
{{'LOWER':'circuit'},{'LOWER':'increases'}]
```

The python code for the sequential misconception is applied to each sentence of a student's response and looks for a simple two-word sequence. The second example of python code includes two '?' operators to allow a matching of 0, 1, or 2 ascii-based tokens between the word 'resistance' and 'circuit'. Rules for misconception detection were developed based on an examination of over 100 responses to the first writing exercise. Further details of the rule-based approach to misconception detection in the first writing exercise as well as a comparison of the performance of the rule-based approach to one using machine learning may be found in [2]. As a final comment on the rule-based approach, a text-preprocessor was developed and employed to standardize the raw responses of students. This was helpful in reducing the number of rules necessary for misconception detection. For example, the abbreviations 'rtot', 'req', and 'r123' found in student responses were all transformed into 'equivalent resistance' prior to the application of the rules.

A student's drop-down selections may also be used to interpret meaning. For example, a student who believes that only the power of R_2 is affected with changes in the value of R_2 exhibits a "localized" misconception, failing to appreciate that an electric circuit is a system. As suggested in [2], detection of such misconceptions often requires considering the net meaning of multiple sentences together. While a rule-based approach could be used for such a purpose, in the current approach since the meaning of a sentence is considered in isolation, the localized misconception is identified if the student indicates through drop-down selection that only resistor 2 experiences a change in power. A total of seven misconceptions are considered in the analysis of responses to writing exercise one. While hundreds of students had taken the first writing quiz in paper form prior to developing the rules for its web-based version, considerably fewer had taken the second writing exercise. A different approach, therefore, was taken in developing the semantic rules for analyzing the responses to writing exercise two.

Instead of identifying examples of misconceptions, for the second writing exercise, rules were crafted that sought to identify examples of sentences that would contribute to the development of a correct answer. Three such rules follow, the first of which is applied only to a student's answer to the group 1 circuits, and the second two apply only to the group 2 circuits.

```
IF sentence includes “total current in the circuits is the same" THEN
"class = total_current_key"

IF sentence includes “total potential in the circuits is the same"
THEN "class = total_potential_key"
```

```
IF sentence includes “power associated with the voltage source" THEN
"class = power_key".
```

Identification of a sentence in the power_key class for example, would suggest the student had the idea that considering the power provided by the voltage source was key to answering the question regarding circuits 3 and 4 of writing quiz two. As noted previously, SpaCy, the open-source NLP framework used in developing the rules, allows one to craft rules that allow for multiple different words to exist between key words in a sentence. For example, a single rule could be created that would place both of the following sentences in the power_key class.

“The power associated with the voltage source is important to the answering the problem.”

“The power of the voltage source increases when the source sees a small resistance.”

Of course, the same rule would place the following sentence in the power_key class as well, an undesired result.

“The power of the voltage source is unimportant in this problem.”

With additional responses for the content expert to analyze, the rules may be changed or augmented as necessary.

In addition to the semantic review, rules were constructed and implemented to look for evidence of statements suggesting the writer was engaging in active metacognition. Prior to developing the rules, an expert on writing and metacognition examined the responses of over fifty students to the first writing exercise and identified a list of more than one hundred sentences that conveyed active metacognition on the part of the writer. From this list, three sets of metacognitive rules were developed. One set was established to look for statements of confidence such as the following.

• “I understand the information clearly”
• “I am convinced it is accurate”
• “Since we know”

A second set was developed to identify statements that expressed doubt such as the following three phrases.

• “I don't know for sure”
• “can get confusing mentally”
• “I feel I don't have enough strong reasoning”

Finally, a third set of rules was developed to look for statements suggesting metacognitive activity but that were ambiguous in terms of confidence versus doubt.

• “I realized something while writing it”
• “In order to determine”
• “my answers rely on each other”

Semantic analysis is carried out to select the feedback path that a student should follow to come to a proper understanding of a writing exercise and, while not explored here, can also be used to establish a grade for a student on a given writing exercise. In this work, the metacognitive review is currently being investigated as a means to quantify the degree to which a student reflects on their understanding of a given exercise, thus giving a measure of their knowledge of cognition. The metacognitive prompts are embedded within the applications to encourage self-reflection in the hope of fostering self-regulation of learning as that has been shown to be a key attribute of effective learning [18].

Directed Line of Reasoning (DLR) Feedback

As was noted in the previous section, semantic analysis of student responses to the first writing exercise pertained exclusively to misconception detection. For each type of misconception/error that was detected in writing exercise one, a student was led through the specific "feedback path" that attempted to dispel the student of the misconception/error. The errors considered are: the sequential misconception, the constant voltage error, the ideal independent voltage source error, resistor combination errors, localized misconception, precedence of current misconception, conservation of energy error. A detailed account of these errors and the relative success of using two NLP techniques at detecting them is described in [2]. After completing any misconception path(s) relevant to a given student's response, the student would be taken through a DLR path describing a proper means to respond to the question. Both within each DLR path intended to dispel a specific misconception as well as the correct solution DLR path, various multi-select questions are posed to engage students in the process of building their understanding rather than simply have them read a complete explanation. For the second writing exercise only two feedback paths were constructed, the first leads a student through a correct solution of the question regarding the group 1 circuits and the second considers the correct solution to the question regarding the group 2 circuits. The feedback paths include several multi-select questions to engage students and include personalization if the semantic analysis identified sentences containing correct ideas in answering the question, for example if a student explored the idea of finding an equivalent resistance.

Preliminary Testing of Two Writing Exercises

During testing in the spring 2023 semester, a total of 26 students completed the first writing exercise and 24 completed the second. The exercises were administered during lab time under the observation of the lab instructor and with the specific instruction not to use a calculator and to complete all work within the application. No technical issues arose during testing. As the work involved human subjects, approval of all ethical and experimental procedures and protocol was granted by the Institutional Review Board of Montana State University.

Pre-Response Self-Rating Versus Post-Response Self-Rating Versus Post DLR Confidence

As noted previously, students rated their perceived ability to correctly answer the primary question of the writing exercise after reading the question but before answering it and then again after answering it. After completing their DLR path(s), they were asked the following question with the same five options to choose from as in the pre- and post-response self-rating questions:

Now that you have gone through the solution process, rate the confidence you have in your understanding of the correct answer to the problem.

I am completely confident *I am quite confident* *I am somewhat confident* *I have little confidence* *I am not at all confident*

Figure 7 displays bar graphs of student responses, and Table 1 captures the median, mean and standard deviation for the three self-ratings for writing exercise 1. In Table 1, a score of 1 corresponds to a student not at all confident, whereas a score of 5 corresponds to a student who is completely confident. As can be seen from both the bar graphs and from the table, more students rated themselves as more confident <u>before</u> they answered the question of writing exercise 1, with all but two of the 26 students rating themselves above "somewhat confident" in their ability to answer the question correctly. The student self-ratings after responding to the writing exercise 1 question dropped, with 10 of the 26 students rating themselves "somewhat confident" or below. The spread in the data increased in the post-response case. Because post-response judgments tend to be more accurate once students have either successfully or unsuccessfully retrieved information relevant to the question, these results appear to suggest that students were overconfident upon first reading the question [19].

TABLE 1: Self-Rating Score on Writing Exercise 1

Writing Exercise 1 N=26	**Median**	**Mean**	**Standard Deviation**
Pre-Response	4	4.27	0.60
Post-Response	4	3.62	1.06
Post-Feedback	4	3.88	0.95

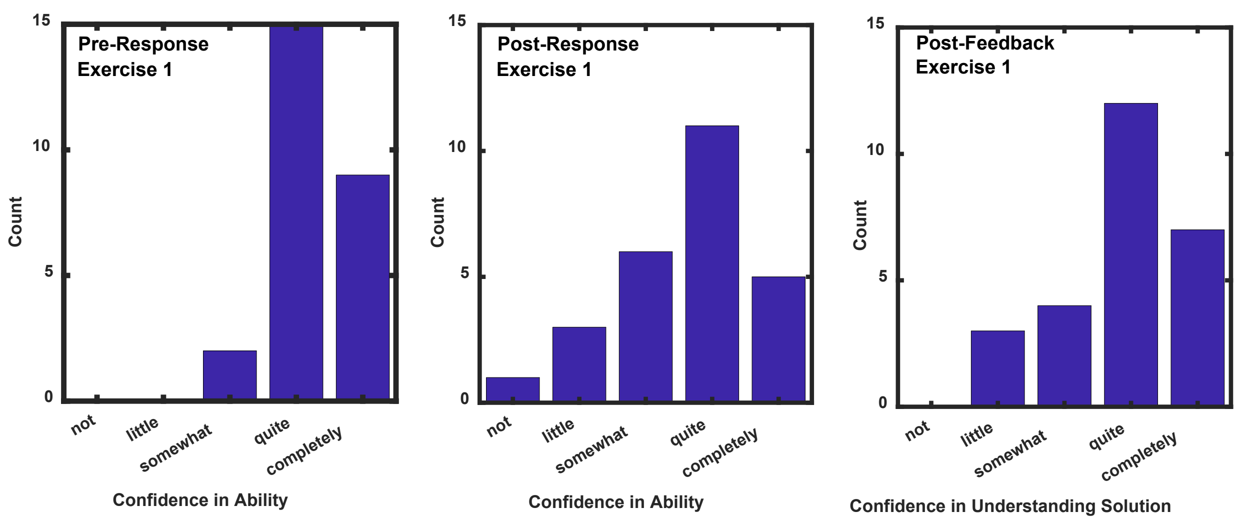


Figure 7: Bar graphs for the Pre-Response Self-Rating, Post-Response Self-Rating, and the Post-Feedback Self-Rating of writing exercise 1.

The expectation is that the DLR feedback paths should help lead a student to a proper understanding of how to address the problem and indeed there were 19 students who were quite or completely confident post-feedback as compared with 16 post-response. Although the differences are not large, they do trend in the expected direction. In addition to the post-feedback self-rating, students were asked within the web application whether the feedback was helpful and to make any suggestions to improve the web application. To attempt to address the question as to why the post-feedback confidence was not as high as might be expected, the comments regarding the feedback made by the seven students rating themselves as "little" or "somewhat" in their post-feedback confidence are now considered.

"I feel like the feedback would have been helpful if I didn't feel defeated in the beginning. I would have taken time to read the questions and read the feedback while adding notes to what I wrote down to bridge my confusion."

This comment was made by a student who began to use an ipad to work on the problem outside of the web application. The student was gently reassured that they were to complete all their reasoning inside the application and that a perfect answer wasn't sought, but simply a collection of thoughts was what was important. The student became flustered and obviously did not respond well for the remainder of the exercise.

"This quiz helped me think more critically about the content of this class and has shown me where to improve."

This is a positive comment and one that suggests the student was significantly engaged in metacognitive reasoning. Perhaps the student recognized his/her own deficiencies and their response to the confidence question reflected this.

"It was helpful I would just like to take this circuit and test this scenario in the real world with a potentiometer in place of R2."

This is another positive comment, but one that leaves some doubt as to whether the student is truly convinced of the solution.

"I'm not sure how it could be improve [sic], for me it was difficult to focus on and read blocks of texts after I misses [sic] questions."

This comment seems to indicate that the student did not completely follow the text and thus it is reasonable that the student would not exhibit great confidence in their understanding of the correct solution.

"It was helpful."

This is another positive comment, but one that does not shed any light on why the student wasn't more confident in their understanding.

"Definitely helpful need to put more time in going over the fundamentals again."

Another positive comment that also indicates a student's appreciation for their imperfect knowledge, which could influence their post-feedback confidence score.

"If I had taken the time to properly analyze the circuit, it would have been far clearer that decreasing R2 would actually lead to increased power dissipated by R1, as opposed to the opposite as I had originally claimed."

This comment reflects that the feedback led the student to a proper understanding of at least part of the correct solution. Again, it could be the case that the student's post-feedback confidence reflects more upon their appreciation of their general limitations in approaching the problem unaided.

Figure 8 presents similar bar graphs and Table 2 collects similar data for the second writing exercise. Recalling that students followed two correct-solution DLR feedback paths (one for the group 1 circuits and one for the group 2 circuits), there are four bar graphs. As in the case of writing exercise 1, students' confidence fell upon completing the exercise. It is interesting to note that both the pre-response and post-response confidence scores of writing exercise 2 are lower than their corresponding values in writing exercise 1. To look into a possible explanation, student self-perception of their understanding of the questions of writing exercise 1 and writing exercise 2 was considered. As given in Figure 4, students rated their understanding on a 100-point scale in which a rating of 100 indicated that the student was completely confident in their understanding of the question. Table 3 and the frequency polygons of Figure 9 summarize the results. The median value of 95 for both pre-response (92.5 mean) and post-response (92.3 mean) ratings indicate that students were very confident in their understanding of the question of writing exercise 1. Contrast this with the corresponding pre-response (80 median, 74.4 mean) and post-response (72 median, 71.9 mean) ratings for writing exercise 2. The frequency polygraphs demonstrate clearly the decreased confidence in students' understanding of the question in exercise 2, both in their pre-responses and post-responses. The decreased confidence in understanding the question may have influenced students' confidence in writing exercise 2.

TABLE 2: Self-Rating Score on Writing Exercise 2

Writing Exercise 1 N=24	**Median**	**Mean**	**Standard Deviation**
Pre-Response	3	2.96	0.75
Post-Response	3	2.67	0.87
Post-DLR1 Feedback	4	4.13	0.80
Post-DLR2 Feedback	4.5	4.29	0.86

TABLE 3: Confidence in Understanding Problem Question in Writing Exercises 1 and 2

Ex 1: N=26 Ex. 2: N=24	**Median**	**Mean**	**Standard Deviation**
Ex. 1 Pre-Response	95	92.5	8.4
Ex. 1 Post-Response	95	92.3	7.8
Ex. 2 Pre-Response	80	74.4	20.1
Ex. 2 Post-Response	72.5	71.9	17.7

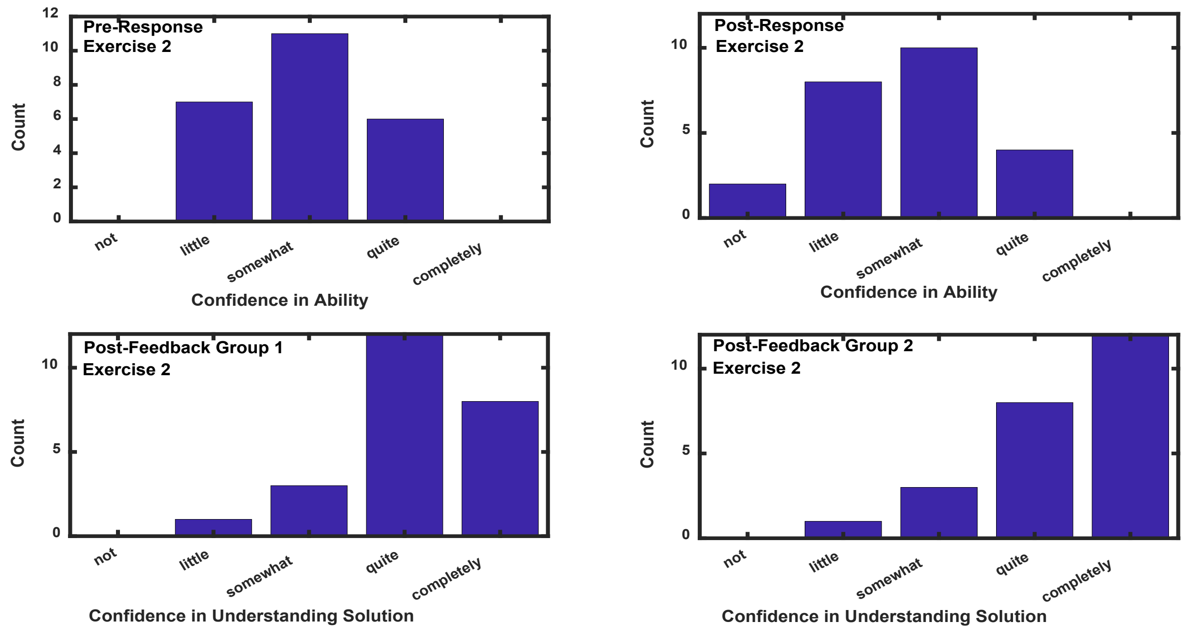


Figure 8: Bar graphs for the Pre-Response Self-Rating, Post-Response Self-Rating, and the Post-Feedback Self-Rating of writing exercise 2. The Post-Feedback Group 1 pertains to the feedback on the group 1 circuits and similarly for the Post-Feedback Group 2 bar graph.

From reviewing student responses, it seems students struggled with what might distinguish an ideal independent source from a practical one. While this was discussed during lecture, it seems relatively few students retained this lesson. One could consider revising the Introductory Statement of writing application 2 to include mention that a student should consider power in their response, but this immediate spoon-feeding is not necessary when considering the following particularly insightful post-feedback comment of one of the students.

"Understanding this assignment is a way to write out your own understanding of a concept about circuits and receive feedback on how the concept should be understood is very helpful. Initially I was having a hard time understanding what the question was asking. Learning in class I did not focus on non-ideal vs ideal. I focused on what question was being asked and executing the calculations. This feedback/assignment is putting focus on remembering to understand what the circuits represent and why were [sic] reference them the way we do. It would be nice if there was an opportunity before the feedback to give a hint and allow a second attempt. If there was a hint about power it would have jogged my mind."

Before discussion of a proposed revision to the template based on the pilot testing of the two writing exercises, a final observation should be made regarding student self-assessment of their experience with writing exercise two. Despite their relative lack of confidence in their understanding of the writing exercise's question, after receiving feedback as to the correct approach to responding to the problem, as portrayed in Figure 8, 20 out of 24 student felt quite or completely confident in their understanding of the correct solution to the writing exercise 2. The following post-feedback comments provide added insight.

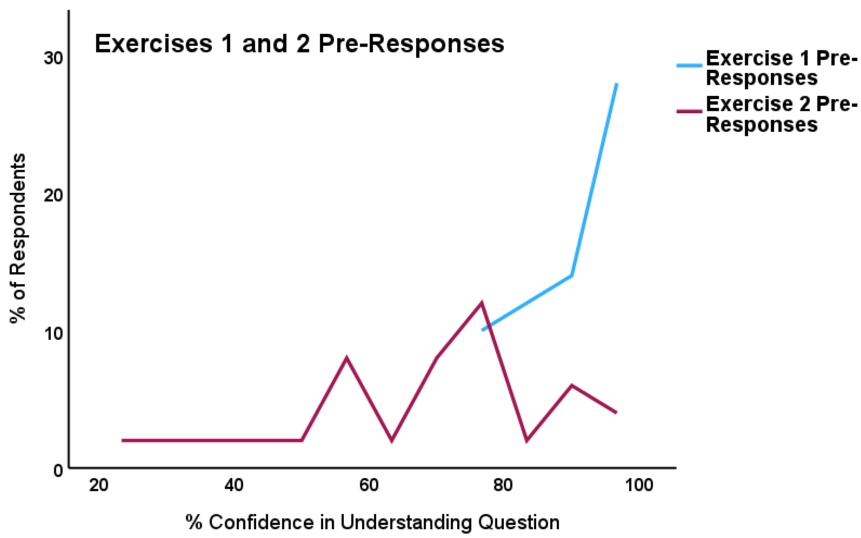
This makes a lot more sense, it is all power related.

This feedback was helpful and I now understand the reasoning on why a circuit causes a source to be less ideal and believe I have true understanding now at this point

I'm pretty confident now in the idea that the main flaw with ideal sources is not being able to output an infinite amount of power. This causes issues and is where the root of all of these questions comes from.

The idea that potential difference in a circuit with a current source effects power was helpful.

The idea of lower resistance has more current which leads to more power was helpful.



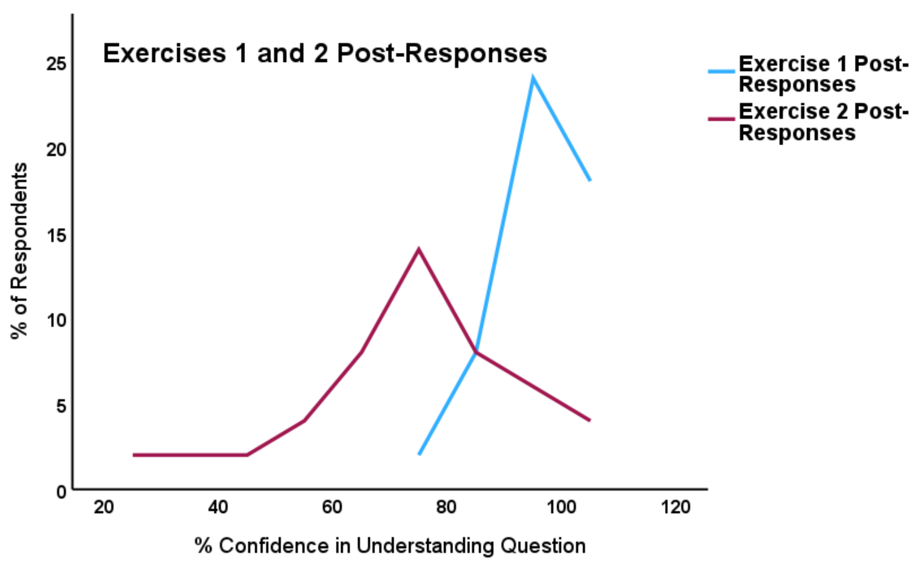


Figure 9: Frequency polygons for the Pre-Response Self-Rating and Post-Response Self-Rating regarding understanding the question posed in writing exercise 1 and in writing exercise 2.

Proposed Revisions to the Template and Future Work

While a couple of typographical errors were caught during pilot testing of the writing exercises, no technical issues arose. Writing exercise 1 has been given in paper format to hundreds of students and the responses to the web-based offering appear typical. Writing exercise 2 has been given in paper format, but to considerably fewer students. A review of approximately 50 handwritten responses to writing exercise 2 revealed that approximately 15% of students discussed power considerations – a key concept when contrasting ideal source models to practical components. From a review of the semantic analysis of the web-based version responses, just over 20% (5/24) of students discussed the concept of power in their answers. Therefore, approximately 80% of students would have benefited from a hint about power being a key consideration and allowed a second chance to respond. Based on these observations of writing exercise 2, a revision to the proposed flow chart is depicted in Figure 10. In Figure 10, focus is placed on the student flow through the application and so while there will be the same metacognitive and semantic reviews as noted in Figure 1, for simplicity reference to them is left off Figure 10.

With the revised template, prior to the post-response self-rating stage, semantic analysis of a student's response to the Primary Question is used to scour a student's response for evidence that a key concept such as power in writing exercise 2 was addressed. If the rule-based analysis identifies the key concept was addressed, the writing exercise will proceed as previously described and tested. If on the other hand, the key idea is not addressed, the application will provide the student with a hint regarding the key concept and then allow a second attempt. A total of two attempts are to be allowed. Such an added feature to the template should assure that students are given the best chance to attack the problem without initial spoon-feeding. A comparison of pre-response self-ratings as well as the two responses to the Primary Question in the two attempts of students who initially miss the key concept in the problem would provide insight into the importance and effectiveness of the hint.

As noted earlier, students were instructed to complete all of their work within the application and not to use a calculator. The intent in implementing these instructions is to capture as closely as possible all of the thought a student puts into answering the problem and to eliminate the use of a calculator as a crutch, for the problems are to be treated conceptually rather than quantitatively. The rule of excluding calculators had been used with hundreds of students in previous semesters who completed the first writing exercise in paper form. Never had there been a complaint with the policy on calculators, nor were there during the spring 2023 testing of the web-based writing applications and so this policy is to be maintained. In the future, while students will be instructed to complete all of their work within the application, should a student begin to do "scratch work" outside of the application, the scratch work will be collected and potentially considered in evaluating their overall effort. This modification to the testing protocol is to accommodate those students who feel it necessary to complete work outside of the application.

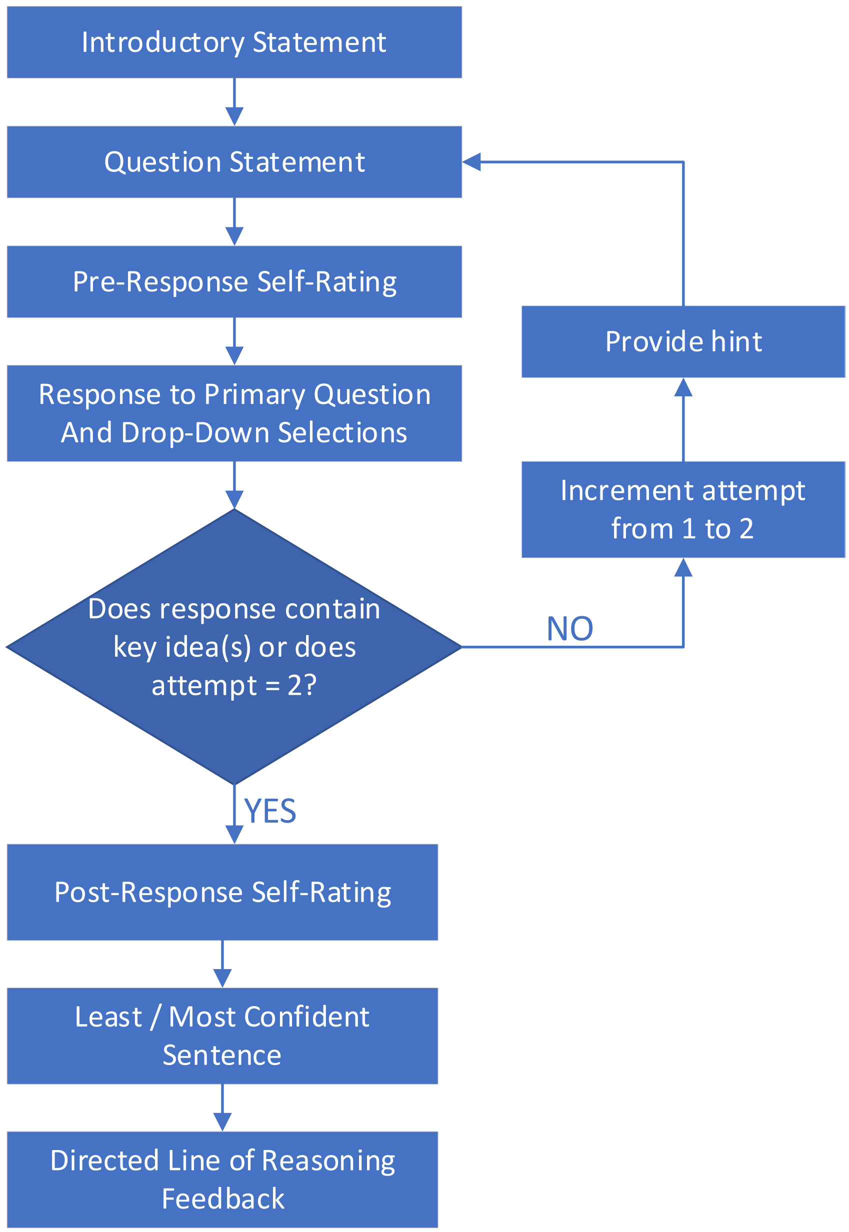


Figure 10: A revised flow chart representation of the web-based writing exercise template. The semantic and metacognitive reviews of Figure 1, while still present in the revised template, are not depicted.

Conclusions

Features and initial testing of two web-based writing exercises addressing conceptual knowledge in the study of electric circuit analysis were presented. The writing exercises use a rule-based NLP approach to analyze a student's response, seeking evidence of the presence of misconceptions as well as mention of important concepts necessary to answer correctly the questions posed in the writing exercises. Based on this simplistic form of semantic analysis, each student is directed into one or more feedback paths that seek to dispel misconceptions a student may have and ultimately lead the student to a better understanding of the concepts underlying the questions. In addition to semantic analysis, a rule-based approach was implemented to identify statements suggesting metacognitive activity on the part of the student. Plans are underway to analyze the metacognitive data. Student feedback regarding the writing exercises was positive, and based on student comments, a revision to the template underlying the applications will be pursued. In cases in which a student's response suggests they missed the key concept(s) necessary to properly address the writing exercise's question, a hint will be provided and the student given a second chance to respond.

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