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Towards a Web-Based Homework System For Promoting Success of At-Risk Students In A Basic Electric Circuits Course

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Abstract

Electric circuit analysis is often the first calculus-based and discipline-related course for students in electrical and computer engineering and is therefore a gateway course to the discipline. Gateway courses are often plagued by significant student failure rates. This paper outlines the key features of a web-based system that is being developed to help promote student success in a low-cost, easily scaled and transferable manner. In short, the system is intended to identify student misconceptions with regard to basic concepts in electric circuit analysis, to help foster improved metacognitive skill and to provide the student with resources to address their difficulties. While it is expected that all students using the system will benefit, the focus population for the system are at-risk students as identified through a validated electric circuits pre-test.

Introduction

Gateway courses such as electric circuit analysis often exhibit DFW rates in excess of 30%, making them "high-risk" as defined in [1]. While the reasons for such high attrition rates are no doubt numerous, it is hypothesized that one of the most important reasons for student struggles is deficient metacognitive skill. Metacognition may be defined in terms of information processing activities as "the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data on which they bear" [2]. More simply, metacognition can be considered, "knowledge and cognition about cognitive phenomena" [3]. Indeed, as noted elsewhere "students who performed well in high school classes while exerting minimal effort, may not possess the necessary study skills appropriate for a rigorous college environment" [4] and while students often believe their primary need is content-related knowledge, it is often the "prerequisite learning and thinking skills that are basic to content mastery" [5] which a student lacks. These observations point to the importance of fostering metacognitive skill among students. As described later, the system under development will include features designed specifically to measure and promote metacognitive skill.

A second key reason which is hypothesized as to why students struggle in gateway courses in general and in electric circuits in particular is a student's use of faulty mental models. For example, common student misconceptions exhibited in basic circuit analysis tasks include belief that a battery is a source of a constant current, belief that current is consumed and belief that charge flow is a sequential process [6]-[11]. While some of these misconceptions may be readily be corrected, others are more robust [12] requiring considerable intervention to rectify. The system under development has been designed to allow the problem creator to code anticipated errors into a library of common misconceptions for a given concept and to provide various forms of feedback when a student demonstrates a common misconception. The forms of feedback include simple text feedback, links to appropriate readings within the system and "sub-problems" that more tightly focus on a concept helping the student confront his/her misconception in hopes of correcting faulty mental models.

The impetus for developing the system stems from the desire to improve the success rate in the basic circuit analysis course at Montana State University while retaining both the current course content and its rigor. As currently constructed, the circuits 1 course at Montana State University, EELE 201, covers basic circuit quantities, node and mesh analysis, basic circuit theorems, ideal operational amplifier circuits, the complete response of first order RC and RL circuits, sinusoidal steady-state analysis and AC steady-state power. There is a follow-on course that considers topics such as the complete response of second-order circuits, frequency response, Laplace and Fourier techniques, filter circuits and two-port networks. Both four-credit circuits courses have lab components.

There is growing literature regarding the teaching of electric circuits with the importance of conceptual understanding and active learning being prominent themes [13]-[27]. Previous pedagogical developments in EELE 201 include the introduction of active learning methodologies in the form of "project circuits" as described elsewhere [13], [14] and more recently, flipping the classroom. The basic circuits course at Montana State University has grown to serving more than 120 students in the 2016/2017 academic year from approximately 60 students six years earlier. For example, 83 students were enrolled in the fall 2016 semester of the course alone. In addition to the challenges of increased enrollment is the significant disparity in student preparedness for the course.

Focus Population

As a means to better handle the challenges of a growing enrollment without concomitant growth in resources, the idea of developing a textbook- and learning management system –agnostic web-based homework and tutoring system was conceived. While it is expected that the system will benefit all students in the course, the focus population is the group of students identified within the first week of class as at-risk. Exam 1 has been found to be a key indicator of student success in the course as a whole as students failing exam 1 in EELE 201 have been found to rarely pass EELE 201. Indeed, less than 5% of students scoring below 60% on the first exam have been found to pass the course in the seven course offerings considered. Since exam 1 typically takes place approximately one-third of the way through the class, it is highly desirable to identify students at risk much earlier in the class and to offer effective means to foster their success. A variety of measures available within the first week of class have been considered as potential indicators of the likelihood of student success on the first exam and therefore in the class as a whole. The key indicator that will be carried forward is a DC circuit conceptual exam.

As a means to establish a baseline measure of a student's understanding of basic electric circuits concepts, the DIRECT 1.0 exam [28], a validated, twenty-nine question, multiple-choice test developed for assessing students' conceptual understanding of DC circuits and uncovering students' misconceptions was used in the fall 2014, 2015 and 2016 offerings of EELE 201. In fall 2014, the DIRECT 1.0 exam was given just days before exam 1. The correlation between the DIRECT 1.0 exam and exam 1 in EELE 201 was found to be strong with a 0.60 Pearson's correlation in fall 2014. This suggests that many students failing exam 1 lacked a conceptual grasp of the course material at the time of exam 1. Because a baseline measure of a student's conceptual grasp of basic circuit concepts upon entering the course is desired in order to both promptly identifying at risk students and to study the impact of the web-based system on their ultimate success in the course, the DIRECT 1.0 exam was administered on day one of EELE 201 in the fall of 2015 and fall of 2016. As expected, the correlation between the DIRECT 1.0 exam and EELE 201 exam 1 dropped (Pearson's correlation of 0.42 in fall 2015 and Pearson's correlation of 0.40 in fall 2016) suggesting that some students were able to correct key misconceptions prior to exam 1. With these measures in hand, the impact of the homework system on the at-risk population and on changes in conceptual understanding of all students will be monitored upon the full unveiling of the system in fall 2017. It should be noted that while the system is being developed at Montana State University, it is being done so with an eye toward broad dissemination as the system is scheduled to be tested elsewhere.

System Components

The system is being developed within the open-source content management system known as Drupal [29]. By developing a web-based system not tied to any textbook, course management system, or even any particular flavor of circuit analysis course, it is hoped that the system will grow in a manner similar to other open-source software and that instructors will be able to tailor it to their needs. The system features the following modules which are either complete or in development: secure login module, course enrollment module, problem creation module, answer parsing module and reporting module.

The system features secure login for instructors and students as well as secure login for the assessment and evaluation expert tasked with evaluating the system's impact on student performance in the introductory circuits course at Montana State University. Each user-type has its own permissions. Once logged into the system, the instructor is able, through the course enrollment module, to create an arbitrary number of users with associated passwords and to enroll them within a course. A screenshot of the login screen is shown in Figure 1.

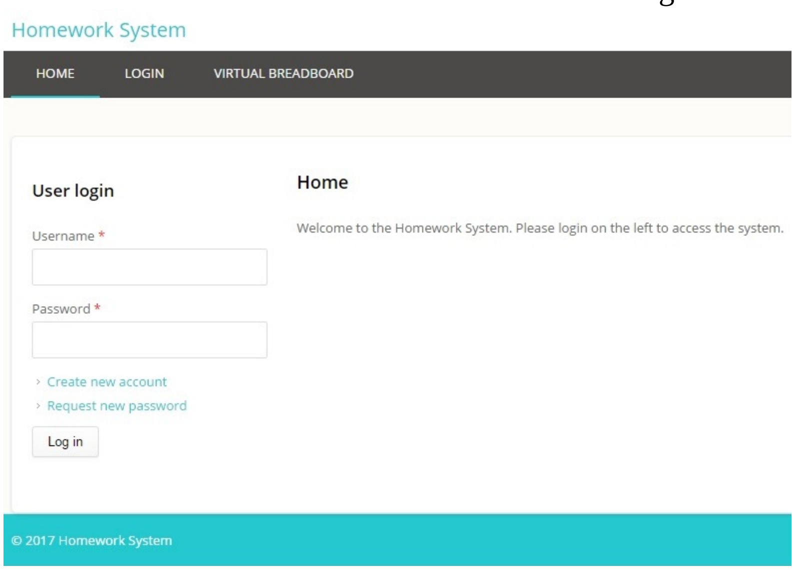

Figure 1: Screenshot of the login interface. Separate permissions have been established for instructors, students and the project evaluator. The virtual breadboard link is provided for students without the need for secure login and leads to a javascript-driven application to help students make the transition from circuit schematic diagram to an assembled circuit on a common circuit breadboard.

The following problem types may be created using the problem creation module: multiple choice, true or false, free-form and writing. Multiple choice problems are standard multiple choice/multiple select problems in which the choices may be either text or figures. The choices may be presented in random order and the database records both the student input and the time spent on the problem. In a similar fashion, the database records both student input and the time spent on a true or false problem. The free-form problem type presents the question along with associated figures and text input with the potential of both numerical and unit entries. The answer parsing module extracts the numeric data and units with the database record including time spent on a problem and student input. The final problem type is a timed writing exercise. Such exercises pose a conceptual problem to the student and ask him/her to explain their problem solving strategy in a provided text box. The system prompts the user to continue entering their thoughts if a period of 30 seconds elapses without several key strokes. The system will maintain a transcript of the entry for subsequent evaluation by the instructor. The primary reason to include this type of problem during the evaluation of the homework system is that writing provides one of the most clear indications of an individual's metacognitive processes [30]-[33]. The fact that the grading and evaluation of such problems is to be carried out by the instructor instead of automatic grading by the system might limit its use beyond the system evaluation stage. Nevertheless, these types of problems will enable a powerful means to assess metacognitive development of students in the context of the circuits course. Problems of each type may be grouped into a given assignment. The three main assignment types to be used in the study are, Preliminary Assessment Sections, Standard Problem Sets, and Reading and Reflection Exercises.

Preliminary Assessment Sections

As mentioned previously, it is hypothesized that struggling students often lack refined metacognitive skill including limited metacognitive awareness. As described by Tobias and Everson, "Research has shown that learners with effective metacognitive skills are more capable of making accurate estimates of what they know and do not know, of monitoring and evaluating their ongoing learning activities, and of developing plans and selecting strategies for learning new material" [34]. The homework system's Preliminary Assessment Sections (PAS) are being developed to include a variation on the Knowledge Monitoring Assessment (KMA) of Tobias and Everson [35]. The KMA is a simple multiple choice test that allows for a measure of the coherence between an individual's perception of their knowledge in a given domain with their actual performance. In a PAS, the student will be presented with a list of select course outcomes such as those suggested below.

- Rate your confidence to properly apply Ohm's Law.
- Rate your confidence in solving a circuit problem in which the proper understanding of the model of an ideal independent voltage source is key.
- Rate your confidence in solving a circuit problem in which the proper understanding of the model of an ideal independent current source is key.

Upon completion of the survey questions, the student will be presented with several basic problems that target the outcomes in question. After completing the problems and thus the PAS, the system will generate a "metacognitive score," which will provide a measure of the accuracy of a student's perception of their knowledge and their actual knowledge. If certain deficiencies in a student's understanding are identified, he/she will be referred to content (reading and reflection exercises) that is to be reviewed prior to being given a second chance at the PAS. The reporting module is being developed not only to give student immediate feedback regarding the degree to which their perceived content mastery matches their actual mastery, but to provide the instructor, a convenient manner in which to identify struggling students. Preliminary Assessment Sections will be used beginning in the first weeks of class in hopes of making students aware of any deficiencies they exhibit, while offering resources to combat their deficiencies early enough in the course to make a difference.

Reading and Reflection Exercises

Reading and Reflections exercises will be available to all students, but may be required (if the instructor wishes) for students not passing a given PAS. The reading and reflection exercises will contain brief reading sections followed by simple questions to verify the student has a basic understanding of the content. Once completed, the student will have a chance to repeat the corresponding PAS. The reading and reflection sections will contain content related to key misconceptions often demonstrated by struggling students and are meant to supplement typical textbooks which either have conceptual gaps or present incomplete or misleading models and analogies. A recent review by Sangam and Jesiek presents a comparative study of conceptual gaps in popular circuits textbooks [11]. As will be discussed in the Beta-Testing Section, the importance of providing targeted and concise readings for struggling students will be critical to the efficacy of the system for students lacking commitment to invest significant time to study the material.

Standard Problem Sets

Standard problem sets are to contain a variety of problems that cover concepts and skill development related to the course outcomes from one or more PAS. What differentiates a problem in a standard problem set from those in a PAS is that those within a standard problem set will simultaneously probe multiple outcomes whereas PAS problems will be more focused and thus contain less element interactivity. For example the problem suggested in Figure 1 would be a basic problem from a standard problem set. The problem of Figure 1 might be stated as follows: Assuming V_s = 5 V, I_S = 2 A and R = 3 Ω, find the values and units that would be displayed on meters 1 and 2 assuming the sources and meters to be ideal.

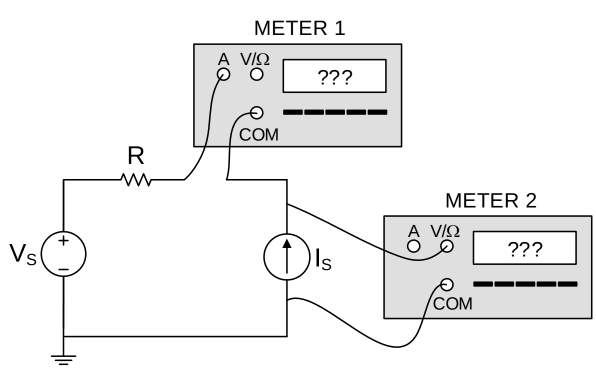

Figure 2: An example problem from a standard problem set. While basic, this problem elicits several common misconceptions from struggling students. Properly identified, a student's misconception will cause the system to present a more focused problem in an attempt to remedy the misconception.

The problem of Figure 2 is certainly basic and yet requires a student to demonstrate an understanding of ideal independent voltage and current sources, the properties of ideal multimeters as well as proper use of Ohm's law. It is likely that instructors can identify common errors a student might make when solving such a problem. Along with a given problem will be coded a library of common misconceptions that a student might make. For example, in the problem above say a student enters 0V for meter 2 believing there is no voltage drop across a current source – an error often seen by students of one of the authors, he/she would be presented with the subproblem such as that shown in Figure 3. The problem of Figure 3 might be stated as follows: Given $I_S = 0.5$ A and R = 10 Ω, find the value and unit that would be displayed on the meter assuming the source and meter to be ideal.

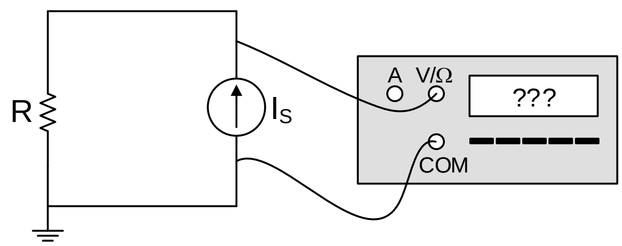

Figure 3: An example subproblem from a standard problem set. In this subproblem a student would be confronted with the need to reconcile how the potential difference across the current source could be zero if it is in parallel with a resistor carrying current.

Once again if the student entered 0V, he/she would then be asked questions such as whether the meter was measuring the voltage drop across the current source, the resistor or both and be forced to reconcile how the potential difference across a current source could be zero if it is in parallel with a current-carrying resistor. Obviously there are many potential misconceptions and system's library will not contain them all. It should be noted that each problem has a textbox allowing a student to enter questions or comments regarding the current problem. The comments will be tagged to the given problem and sent to the instructor for follow-up. If additional common errors are noted by the instructor, the misconception library for a given problem can be expanded. To reduce the opportunity for student mischief, the order of problems may be randomized as well as the actual numbers used in the problems.

It is expected that most students in the circuits course will be able to complete many of the problems without assistance in the form of subproblems. On the other hand, it is anticipated that providing problems that adjust to a student's current understanding and cognitive load capacity through fading and other techniques [34]-[36] is just what is necessary to meaningfully assist at-risk students.

Coding a Free-Form Problem

To provide a feel for the problem creation interface, an example of a free-form input question along with screenshots of the corresponding problem creation interface input are shown in Figures 4 through 6.

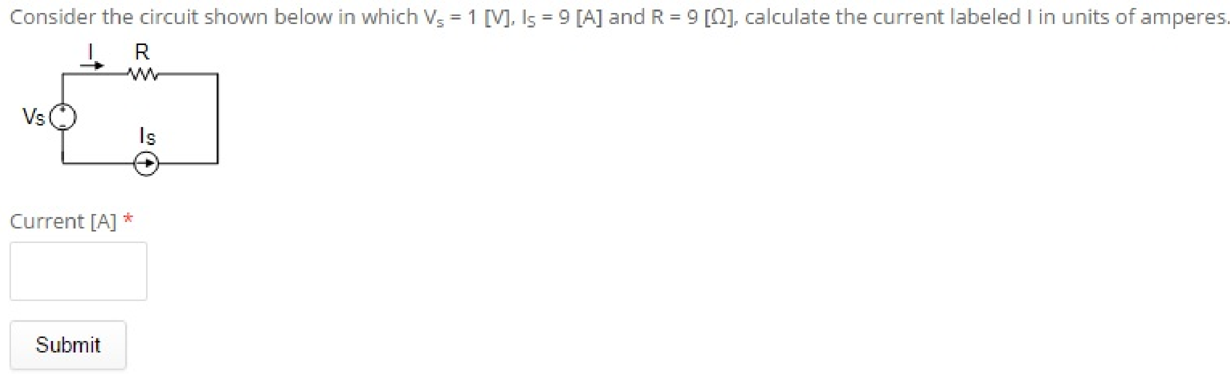

Figure 4: Screenshot of an example free-form problem. Though in this case the units are given, free-form problems allow for the input of both a value and unit to be evaluated using the answer parser.

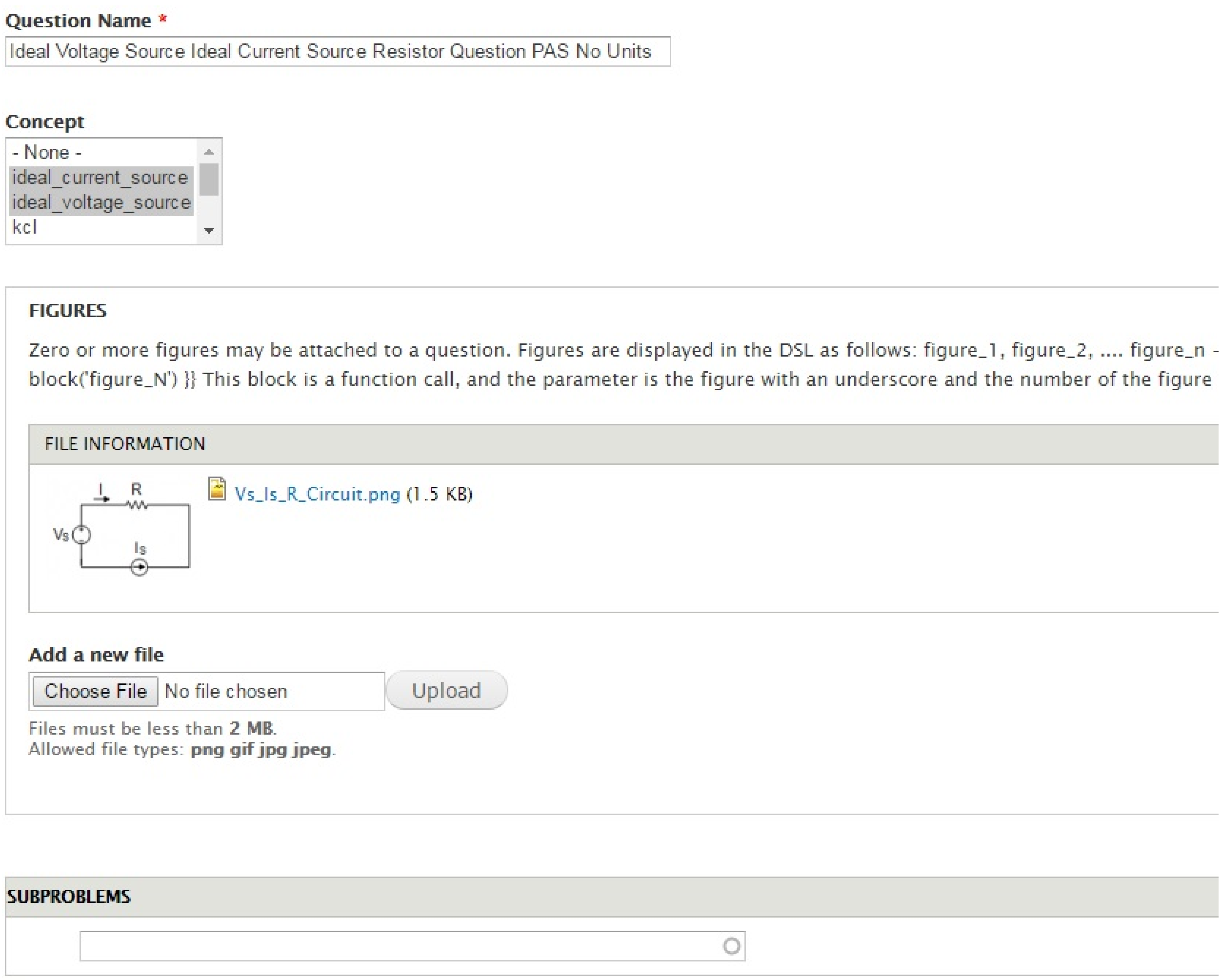

Figure 5: Screenshot of an excerpt of the problem creation interface. The problems title includes PAS which denotes to the problem creator that this is a problem to be assigned in a so-called preliminary assessment section. The problem creator has selected ideal current source and ideal voltage source as concepts he wanted tagged to the particular question. Tagging questions in this manner facilitates functions associated with the system's reporting module.

The problem of Figure 4 asks the user to enter the value of current I, as depicted in the circuit. The student must understand the correct models for an ideal independent voltage source, ideal independent current source, and resistor as well as the fact that the current is the same throughout a simple series circuit. Figures 5 and 6 show screenshots of the interface an instructor would use to create such a problem. Figure 5 displays that the problem creator gives a title for a given question, may select tags for a given problem indicating which concepts are tied to a given problem, may upload one or more figures for a problem and may include subproblems which are presented to the student if he/she makes a specific error tied to a coded misconception. Figure 6 presents the sections of the interface (Answer Parser, Question and Parameters) to build a problem in the Domain Specific Language (DSL) which uses the PHP templating engine known as Twig.

DSL Code (Answer Parser)

```
{% set answer = -Is %}
{% set correct_answer = (current.value == answer) %}
{% set valid_answer = (current.value != null) %}

{% if current.value == null %}
{% feedback %}
You must enter a value.
{% endfeedback %}
{{ retry() }}
{% endif %}
```

DSL Code (Question)

```
{# Render the question  #}
{% block question %}
Consider the circuit shown below in which V<sub>s</sub> = {{Vs}} [V], I<sub>S</sub> = {{Is}} [A] and R = {{R}} [Ω], calculate the current labeled I in units of amperes.
  {{ block('figure_1') }}
{% endblock %}

{% block answers %}
  {{ forms.input("current", "Current [A]", "text", 5, "value") }}
{% endblock %}
```

The DSL Code to render a question and its input.

DSL Code (Parameters)

```
{# Set our base parameters #}
{% set Is = random(9) + 1 %}
{% set R = random(9) + 1 %}
{% set Vs = random(9) + 1 %}
```

Parameter setup written in DSL Code. Set all your variables to be displayed with the question and used to determine correct solutions. This is especially useful for rand

Time Allowed

[ ] seconds

Time allowed to finish a question. Enter in seconds

Figure 6: Screenshot of a second excerpt of the problem-creator interface in which the problem creator completes sections for the Answer Parser, Question and Parameters sections. For this problem, random values between 1 and 10 are created for the variable Is, R and Vs corresponding to the current source, resistor and voltage source. The question rendering code includes simple HTML tags for subscripting.

Beta-Testing

Various features of the system have been beta-tested with the Spring 2017 EELE 201 class including the secure login, course enrollment, problem creation, and answer parsing modules. The reporting module is currently under development. During one 50-minute session in the third week of class, students logged into the system for the first time, individually worked through a preliminary assessment section containing various problem types and completed an anonymous survey regarding their initial experiences with the system. The main goals of the survey were to determine student impressions of the virtual breadboard portion of the system which they had used on multiple occasions earlier in the semester, their preferred mode of asking for help in science, engineering and math courses and their commitment to using a web-based tutoring system that held the promise of identifying their misconceptions and helping correct them. Survey results regarding student experience with the virtual breadboard, not described here, will be used to hone this javascript-based feature for use in Fall 2017. There were 31 respondents out of 40 students present on that day.

One question of the survey asked students to rank their preferred method of seeking help in science engineering and math courses given the following five options: visiting the instructor, visiting the teaching assistant, emailing the instructor, asking a classmate and completing a web search on the topic in question. Table 1 present the survey results to this question.

Option	**Top choice**	**Second choice**	**Third choice**	**Fourth choice**	**Last choice**
Asking a classmate	32.3%	25.8%	19.4%	12.9%	9.7%
Completing a Web search	25.8%	25.8%	12.9%	12.9%	22.6%
Visiting the instructor	25.8%	22.6%	22.6%	19.4%	9.7%
Visiting the teaching assistant	6.5%	16.1%	19.4%	22.6%	35.5%
Emailing the instructor	6.5%	12.9%	29.0%	35.5%	16.1%

Table 1: Students ranking of their preferred method of seeking help in science, engineering and math courses. N=31.

Asking a classmate for help was either the top choice or second choice of approximately 58% of the class, followed by completing a web search (~52%), visiting the instructor (~48%), visiting the teaching assistant (23%) and emailing the instructor (19%). Interestingly, while completing a web search scored high as first and second choices, nearly a fourth of the students ranked it their last choice.

A second question asked: *When you do not understand a concept in one of your math, science or engineering courses, what reason(s) would cause you not to seek assistance? (For example: Are you too busy? Are you uncomfortable in asking questions of the instructor? Do you figure it is an unimportant question?)* The responses to this question were reviewed to find the frequency of various themes. Table 2 collects the common themes and counts their frequency. A given response from a student could contain multiple themes.

Theme	Counts
Time / Too busy	16
Pride / Too easy / I should know it	7
Fear / Shyness / Discomfort	5
Schedule with instructor doesn't align	5
Don't know what to ask	2
Importance of questions	1

Table 2: Common themes students indicated as reasons for not seeking assistance along with the frequency of a given theme within the 31 responses. A given response could touch on more than a single theme.

A third question asked: *A web-based circuit analysis tutoring system is being developed to accurately determine the concepts with which the user struggles and to provide corresponding resources (brief web-based readings and targeted practice problems) to help the user master the difficult concepts. Assuming that use of the system is NOT required, how much time would you be willing to spend in the web-based tutoring system to help you succeed in EELE 201? This is time in addition to what you currently spend in EELE 201.* Table 3 displays the options given to the student and the percentage of students selecting a given option. Students were able to select only one option.

Option	Percentage of students selecting option
I would only use the system if it were required and counted as part of my course grade.	9.7
I would be willing to spend only one hour or less per week using the system.	38.7
I would be willing to spend between one and two hours per week using the system.	25.8
I would be willing to spend between two and three hours per week using the system.	16.1
I would be willing to spend more than three hours per week using the system.	9.7

Table 3: Amount of time a student would commit to using a web-based circuit analysis tool beyond the current time spend in the class.

To put the results of the survey in better perspective, a few details regarding the delivery of EELE 201 during the spring 2017 term should be described. The course is flipped, in that students are expected to come to class having watched one or more short (~5-15 minutes long) instructor-created videos, which are assigned for each of the three 50-minute lecture periods per week. The beginning of class consists of either a 5-10 minute quiz regarding the assigned videos, answers to questions regarding the videos and/or an introduction to the in-class activity (ICA) for the day. Once the ICA has been handed out, students self-assemble into groups of two to four to work on the activity. The instructor and a teaching assistant are there to answer individual questions. Typically once or twice per period, the instructor gains the attention of the entire class to discuss a key point, or a common question. Students submit their ICA individually either at the end of the period or at the beginning of the next. Additional practice problems from the course text are suggested, but not required. The class has a 1 hour and 50 minute lab once per week. Clearly, working with classmates and asking questions are highly encouraged. Any inferences regarding the quality of the teaching assistant in EELE 201 from the results of table 1 should be disregarded. While not always the case, the teaching assistant in the spring 2017 offering of the course is highly regarded and considered integral to the success of students. As the surveys were anonymous, only general observations may be made and not directly tied with an individual's current standing in the course.

As suggested in Table 3, slightly over 48% of students committed to one hour or less per week with the system beyond their normal classwork. It is apparent therefore that unless made part of a student's grade, the system must be found by the student to be an efficient means to improve their performance or it will be unused. As noted previously, as the results were anonymous, it is not possible to link individual responses with personality traits. It could very well be that the 10% indicating that they would not use the system unless it were required are the very students in most need of extra help. In a similar fashion, those indicating a significantly greater commitment to using the system may be the self-regulated learners in least need of the system.

Lack of time is a predominant theme in the results of Table 2 and underscores the importance that the system be developed to make it clear to a student that there is a significant return on investment of their time spent within the system. Students identifying pride, shyness, not knowing what to ask and doubting the importance of their questions may find a web-based system particularly helpful as it does not force the student to confront their misgivings regarding seeking help from another person. The system could be particularly powerful in that it will help students develop a more accurate metacognitive awareness, a key step to becoming a self-regulated learner. Finally, since the system is to be available to students at all times and from any location with access to the web, issues related to conflicting schedules should be largely mitigated.

One issue alluded to earlier is that the very students in most need of the extra assistance, may be the ones least likely to meaningfully use the system unless its use forms a significant portion of the grade. Based on the current format of EELE 201, required use of the system beyond specific allocated times is not planned. For the full unveiling of the system in the Fall of 2017, four one-hour sessions of lab time are to be committed to having students use the system. Beyond that, use of the system will be at the discretion of the student. One feature of the reporting module that is being developed is to track the frequency with which a student uses the system, the total time spent in the system and the specific content that is accessed by the student. By doing so, an analysis may be performed to identify the level of commitment a student devotes to the system and the corresponding impact that the system has. It would be certainly possible to require students to use the system on their own out of class time, and depending on the course format, this may be the preferred manner.

Conclusions

This paper describes the elements of a web-based system being developed to help foster metacognitive skill and the development of correct mental models regarding electric phenomena among students in courses covering basic circuit analysis. The system has been developed using the content management system Drupal and allows an instructor to enroll students and assign various problem types. When fully realized, the system will provide prompt feedback to students regarding their capabilities in properly applying the basic concepts and provide resources in the form of brief readings and targeted problems specific to the help a given student needs. The results of student surveys suggest that a web-based system may be a very valuable tool for students perceiving either lack of time and personal misgivings such as shyness and pride as major impediments to seeking help. That being said, student surveys also suggest that targeted feedback that makes the system's value readily apparent to the student will be necessary for many to devote time to the system if it does not form a direct contribution to their grade. Just as the results of Table 1 reveal, it seems solid policy is to afford the student with a variety of ways to receive help; the web-based system described being one which is readily scaled to large classes and transferable to other institutions.

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