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Development of an Open Access Multi-Tier Question App for Improved Learning in Introductory Circuit Analysis Course

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Abstract: Circuit Analysis is a critical course for various engineering disciplines that introduces students to the problem-solving approach that is an essential part of engineering curricula. It is a required and cornerstone course for electrical and computer engineering majors which often presents students with significant challenges due to its abstract concepts and mathematical complexities. Practice is the key to developing and mastering circuit analysis problem solving skills, which also plays a pivotal role in overall student success in this course and later in many upper-level courses. Traditional teaching methods, which heavily rely on lectures and static assignments, often fail to sufficiently accommodate this important need. The traditional approach with static homework assignments significantly limits the scope of practice and cannot provide quick feedback. In addition, for a moderate to large class size, it becomes extremely difficult for an instructor to grade large volumes of assignment questions and makes it hard to track and identify the exact nature of an individual student's deficiency in applying theoretical concepts to solve a particular type of question.

App-based learning offers a dynamic alternative, enabling students to engage with contents and assignments interactively and intuitively. In this project, we have designed and developed an open access, freely available computer application (hereafter referred as the 'App'), which serves as an auto-generating question bank integrating various major topics of Circuit Analysis problems arranged in tiers that are based on different levels of difficulty. The App includes major circuit analysis question categories including problems on simple Series-Parallel DC Circuits, Complex DC Circuits (Nodal and Mesh Analysis), Linear Circuit Theorems (Thévenin, Norton, Superposition), 1st-order Transient Circuit analysis, and AC (Sinusoidal) Circuit Analysis. Thirty base questions were designed under each topic (or chapter) which are divided into three tiers or difficulty levels – easy, medium and hard, with 10 questions at each level. The total number of base questions for all five chapters adds up to 150. Base questions are programmed to randomly alter the parameters of certain components in a circuit through predefined ranges and steps, resulting in auto-generated variants of the base questions and their corresponding answers. This empowers the App to automatically generate thousands of question variations. The App provides instant feedback when an answer is entered for a given question. An advanced feature of the App includes real-time learning progress tracking. A chart on the main window displays the number of questions successfully completed in each difficulty level under each chapter.

We have conducted a pilot run by implementing the App during the fall 2024 semester where students from two sections of a Circuit Analysis course at Kennesaw State University (KSU) have participated in our study. An assessment was carried out at the end of the semester by analyzing student surveys. A set of survey questions were designed to capture student perception of the App's impact on their learning as well as their user experience with the App. The survey questions consisted of both Likert scale and free-response questions. The responses to the Likert scale questions were analyzed using descriptive statistics (e.g. mean, median, mode and frequency distribution). The free-response questions have been analyzed using thematic analysis. A detailed anatomy of the App, its features, and results from our pilot run implementation are presented in this paper. By facilitating rigorous practice via auto-generated questions on demand, providing

instant feedback, and tracking progress in real-time, the App can serve as an indispensable tool for learners in introductory Circuit Analysis courses. Our results indicated that the App made an overall positive impact to the students' problem-solving skill development and learning process with room for further improvements that can potentially make it even more impactful.

Introduction:

A course in circuit analysis provides the foundational knowledge and skills needed to understand and analyze electrical circuits. It is a required course for electrical and computer engineering majors, serving as a stepping-stone to more advanced studies in these majors, and it is also a critical course for other engineering disciplines. Besides teaching students, the foundational knowledge of electrical circuits, circuit analysis introduces students to essential problem-solving skills, including analytical thinking, logical reasoning, and mathematical modeling. This course also equips students with the analysis skills required to test potential solutions during the design of an electrical system.

Circuit analysis is challenging for students because it involves abstract concepts and complex mathematics. The interconnected nature of circuits means that each component influences the entire system, making it difficult to understand. This complexity can pose a high intrinsic cognitive load on students, potentially overwhelming their working memories and impeding the necessary formation of schemas in long-term memory [1, 2]. For this reason, problem-solving practice is the key to developing and mastering circuit analysis topics. Traditional teaching methods, which heavily rely on lectures and static assignments, often fail to sufficiently accommodate this important need. The traditional approach of static homework assignments significantly limits the scope of practice and cannot provide timely feedback. In addition, for a moderate to large class size, it becomes extremely difficult for an instructor to grade large volumes of assignment questions as well as identify the exact nature of an individual student's deficiency in applying theoretical concepts to solve a particular type of question. Another shortcoming of the traditional approach is the broad availability of textbook solution manuals and solved homework questions on the Internet, which tempts students to copy these solutions rather than solve them independently.

App-based learning offers a dynamic alternative, enabling students to engage with contents and assignments interactively and intuitively. In this project, we have designed and developed an open access, freely available computer application (hereafter referred as the 'App'), which serves as an auto-generating question bank integrating various topics of Circuit Analysis problems arranged in tiers that are based on levels of difficulty. The App is compatible with both the latest generation of Windows and Mac OS platforms. The App includes questions assessing major circuit analysis topics such as Series-Parallel DC Circuits, Complex DC Circuits (Nodal and Mesh Analysis), Linear Circuit Theorems (Thévenin, Norton, Superposition), 1st-order Transient Circuit analysis, and AC (Sinusoidal) Circuit Analysis. Thirty base questions were designed under each topic (or chapter) which are divided into three tiers or difficulty levels – easy, medium and hard, with 10 questions at each level. The total number of base questions for all five chapters adds up to 150. Each of these base questions is programmed to randomly alter certain parameters in a given circuit through a predefined range of values, resulting in auto-generated variants of a base question and its corresponding answers. This empowers the App to automatically generate thousands of question variations. The App provides instant feedback when an answer is entered for a given question. In addition, it integrates step-by-step solutions which can be viewed by students while studying and

practicing. An advanced feature of the App includes real-time learning progress tracking. A chart on the main window displays the number of questions successfully completed in each difficulty level under each chapter and tracks the number of attempts made to successfully solve each problem.

There are other computer-based applications that provide students with the opportunity to practice problem-solving of circuit analysis questions. These include commercial applications that are used to supplement the content of textbooks. An example of this is the Mastering Engineering digital learning platform that accompanies the Nilsson and Riedel textbook [3]. This platform provides step-by-step problem solving, immediate feedback and analytics tools to track student progress. Similarly, WileyPLUS is a digital learning platform the supports the Irwin and Nelms textbook [4]. This platform features adaptive practice, immediate feedback and progress tracking. The App provides similar features, but the open access format of the app means that it has the benefits of having no cost, which increases accessibility. A circuit analysis computer-based application from the academic domain is Circuit Tutor which offers a step-based approach to solution generation [5], that is, each major step of solution is evaluated immediately as opposed to the more common answer-based approach to solutions and feedback. The designers of this application used controlled, randomized experiments to quantitatively compare improvement in post-test scores over pre-test scores and observed statistically significant differences for students who used Circuit Tutor compared to students who used paper homework [6, 7], or WileyPLUS [8, 9, 10] for various circuit topics analysis topics. Additionally, student surveys indicated a strong preference for Circuit Tutor over both WileyPLUS and paper homework [6, 7, 8-10]. The scope of topics of the App and Circuit Tutor are similar, though the random nature of their circuit generation approach will yield more unique problems, and the step-based approach to feedback will be more interactive for students. However, the App does provide questions that are explicitly tiered in difficulty, which provides the advantages of enhanced student engagement and academic performance [11] especially for students who have low background knowledge [12]. Also, although Circuit Tutor is free, access to this application is permission-based.

Hypothesis and Objectives:

Hypothesis: We hypothesize that implementation of an interactive, auto-generating question bank App will enhance students' problem-solving skills, engagement, and overall performance in Circuit Analysis courses. Specifically, it is hypothesized that students who use the App will demonstrate greater proficiency in solving complex Circuit Analysis problems. The immediate feedback provided by the App can help students recognize and correct mistakes without waiting for an instructor's help and it is expected to reinforce the understanding of the underlying concepts related to a given problem – thus fostering deeper conceptual understanding and better retention of problem-solving techniques. In addition, the ability to practice virtually an unlimited number of dynamically generated questions, track progress, and receive real-time feedback will increase student engagement in Circuit Analysis courses. Finally, we anticipate that the continuous practice opportunities and tiered question difficulty levels will prepare students more thoroughly for assessments, resulting in improved test-taking performance, and consequently demonstrating a better academic performance in the course.

Objectives: The primary objectives of this work-in-progress project are to – (i) develop an App that can facilitate auto-generation of questions to facilitate students' practice, (ii) evaluate the

effectiveness of the App, specifically assess the impact of the App on students' ability to solve Circuit Analysis problems at varying levels of complexity, (iii) collect feedback using surveys to understand student perceptions of the App's usability, effectiveness, and impact on their learning experience, and (iv) identify strengths, weaknesses of the App's design and features, and identifying areas for improvements to improve student satisfaction and usability.

Methods (App Design and Development):

Question Bank Development: The first step of this project was to identify major topics in an introductory circuit analysis course and develop a pool of questions on those topics. We have identified five major topics (or chapters), each focusing on a key area of circuit analysis. These chapters were carefully chosen to cover the fundamental topics of the course and are designed to align with the typical syllabus for an introductory Circuit Analysis course. These five topics/chapters are:

(i) Series-Parallel DC Circuits
(ii) Complex DC Circuits (Nodal and Mesh Analysis)
(iii) Linear Circuit Theorems (Thévenin, Norton, Superposition)
(iv) First-Order Transient Circuit Analysis
(v) AC (Sinusoidal) Circuit Analysis

30 questions were designed and developed for each of these chapters, which are divided into three difficulty levels: easy, medium, and hard. Therefore, for each chapter, there are 10 questions at each difficulty level, leading to a total of 150 questions spanning across all five chapters. This structure ensures that students can progressively build their understanding of each topic, starting with simpler problems and gradually moving to more complex ones.

During the development of each question, certain circuit components in a problem were chosen as variables. The values of these components are altered randomly by the App to generate sibling questions, thus creating a huge number of random practice questions on demand. Therefore, these 150 questions in our developed question pool serve as the "base" questions. For each base question, a range for the values of the chosen variable circuit components was defined. A minimum value, a maximum value, and a suitable step size were determined, which results in varied final answers corresponding to differing variable values. Additionally, sample solutions for each question at two different values of the variables were calculated and recorded for App integration and verification.

App Design and Features: The App was designed with the goal of creating a dynamic, self-learning, and practicing environment for students. It is currently compatible with the Windows platform. However, Mac OS users can use a Windows emulator to run the App. The Graphical User Interface (GUI) of the App is shown in Fig. 1. This section explains the key components and features of the App, functions of various regions within its interface and how to interact with it. The overall visual design of the App is aesthetically simple yet functional. The clean interface avoids visual clutter and makes use of clear fonts, and color-coding to highlight important elements (e.g., correct/incorrect answers, progress tracking). The App's design prioritizes usability: ensuring that students can navigate between sections with minimal effort, providing access to important features, and maintaining a focus on solving Circuit Analysis problems without unnecessary distractions.

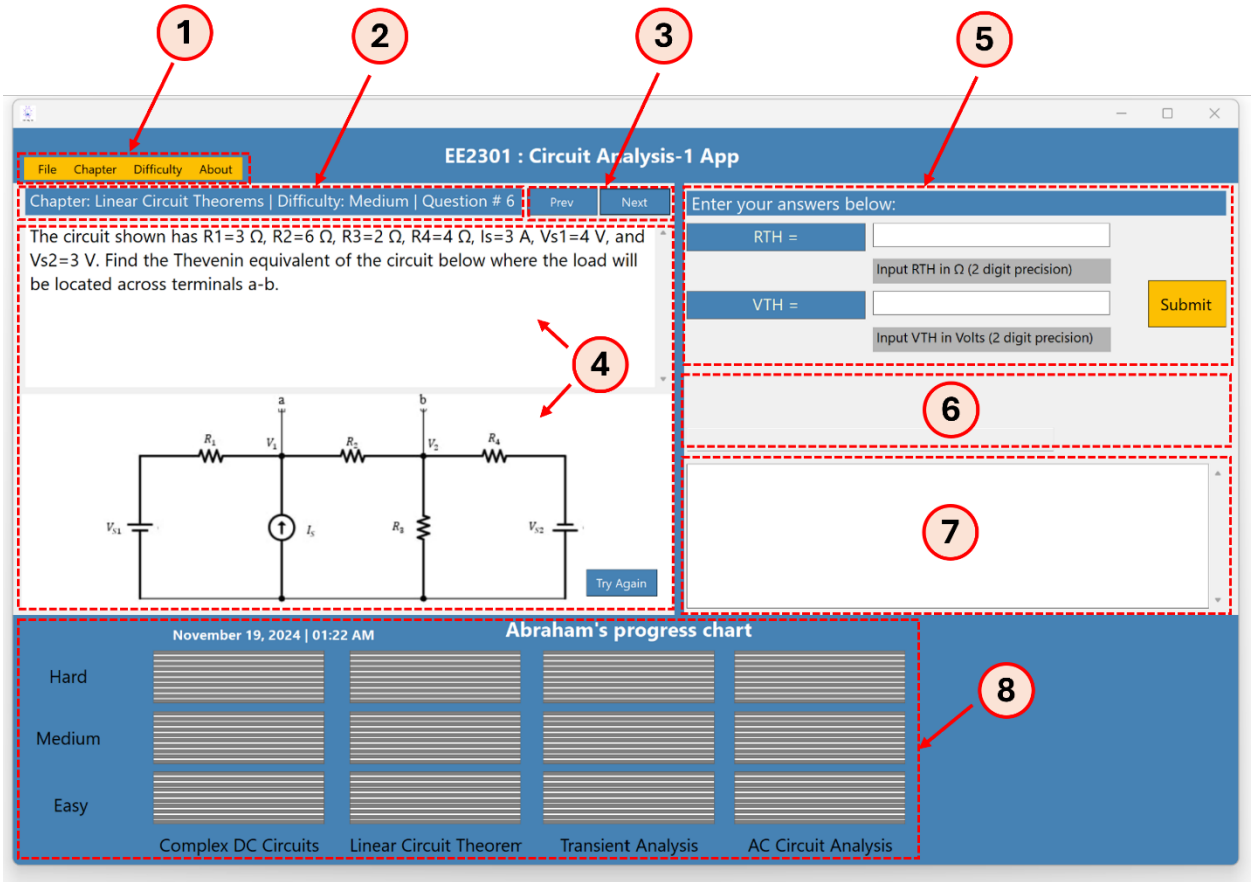

Figure 1. Main window of the App's Graphical User Interface (GUI).

A key feature of the App is the auto-generation of questions by randomization of certain selected component values in a circuit problem which ensures a continuous supply of varied practice questions. The other important feature of the App is the instant feedback. Students receive immediate feedback upon answering, allowing them to gauge their understanding and correct mistakes. The App's GUI provides the required tools and information for students to practice and track their progress easily. The interface consists of several key sections, each of which plays a distinct role in helping students interact as described below:

1) *The Main Navigation Bar:* Located at the top of the screen, the navigation bar (in orange color) enables users to change chapters, difficulty levels, and certain settings. This simple menu minimizes students' learning curve to use the App so that they are not overwhelmed by too many options.

2) *Question Information Display Bar:* Located right below the main navigation bar, the question information display bar displays the currently selected chapter/topic area, difficulty level, and question number within that tier of difficulty, which helps students understand the scope of the problem they are tackling. This region is for display only and therefore it is not clickable. The circuit is dynamically generated based on the current question variant, with varying parameters (such as resistor values or voltage source values). The actual question is generated based on a 'base' question for a given chapter and difficulty tier as described in the previous section.

3) *Problem Navigation:* This consists of two buttons – 'Next' and 'Previous' which allows the user to navigate different questions within the same chapter and difficulty tier.

4) *Problem Display Area:* On the left-hand side of the App window, it displays the question statement and the associated circuit diagram (if any). It allows students to visually see the circuit they are working with. The App uses simple graphical representations of resistors, inductors, capacitors, voltage sources, current sources, and switches. The question text is concise and includes clear instructions (e.g., "Find the equivalent resistance of the given circuit" or "Apply mesh analysis to solve for currents" etc.). The 'Try Again' button within this area allows to refresh and generate another question based on the same circuit diagram, but with different (variable) component values.

5) *Answer Input Section:* On the right-hand side of the App GUI window, students are provided with spaces (text input boxes) to enter their calculated answers for the given problem. The interface is programmed to accept only numerical answers. If a question asks for multiple answers to calculate, then additional answer input fields are created accordingly. For example, the question shown in Figure 1 asks for two answers – Thevenin Resistance (R_{TH}), and the Thevenin Voltage (V_{TH}). For this question, the answer input section provided two text input boxes. If a question asks for only one answer to calculate, then this region dynamically changes to display only one input text box. Below each input text box, specific instructions are given on how to enter the answers. The instruction is concise and provides valuable guidance to the students on what unit the answers should be expressed in and to what degree of precision they need to input their numbers. This is critical as the App only allows a 2% deviation from the actual precision answer to judge and score if an entered answer is correct or not. The Submit button (in orange color) allows students to confirm their answer after all answers are entered and triggers the immediate feedback system.

6) *Immediate Feedback Section:* Upon submitting the answers for a given question, the App's internal solution calculation algorithm/codes are activated which provide instant feedback. The immediate feedback system informs students whether their answers are right or wrong using a message and a visual cue consisting of a green checkmark for correct and red cross for incorrect. This immediate response helps students know the assessment of the submitted answer without delay, and it is crucial for helping students to correct mistakes, understand their thought process, and improve problem-solving skills.

7) *Error Display Area:* In case of an incorrect answer, the App might highlight the error and may be able to provide suggestions or hints on how to fix it (e.g., "Please check your calculation and final answer units. You may have entered the answer in wrong units"). This helps students reflect on their mistakes and learn the correct approach. This functionality is currently limited to wrong units when the algorithm detects entered numbers with wrong decimal points.

8) *Progress Chart Area:* One of the most valuable features of the App is the real-time progress tracker, which provides visual feedback on the student's performance over time. This section is located at the bottom of the main App window. Each grey colored horizontal bar under each chapter and difficulty tier represent a corresponding question. As a student completes a question successfully, the corresponding bar turns green. If a student attempts a question, but got the answer wrong, then the corresponding bar turns red. This chart shows the number of questions a student has successfully completed within each difficulty level (easy, medium, hard) for each chapter. For example, a student might see a graph indicating they've completed

5 easy, 3 medium, and 2 hard questions in a specific topic (e.g., Nodal and Mesh Analysis). The progress chart and status information for each question are saved with the App and remains saved even when the App is closed. When the App is opened next time, students can see the progress chart when they closed it last time and where they currently stand. This color-coded visual progress indicator scheme helps students understand their overall progress within a particular chapter or difficulty level and serves as a motivational tool to continue practicing.

Methodology:

App Implementation: A pilot run of the App was carried out during the fall 2024 semester in two sections of an introductory circuit analysis course (EE 2301). The App was freely distributed to students, and they were encouraged to use it to practice in preparation for the final exam. In Fall 2024, four out of five chapters – chapter # (ii), (iii), (iv) and (v) were integrated into the App which were available to students.
Participating students were offered extra credit points based on the rubric given in Table I below.

Table I: Extra-credit Requirements for Participants in this Study

Extra Credit Level	Minimum Requirements	Extra Credit Points
Level 1	6 Easy, 4 Medium, 2 Hard Questions	2 points
Level 2	10 Easy, 7 Medium, 3 Hard Questions	3 points
Level 3	14 Easy, 10 Medium, 6 Hard Questions	4.5 points

Students were allowed at least two weeks to interact with the app before collecting their feedback. Students were asked to complete a 5-minute online survey after using the App. To receive extra credit points, students needed to submit a screenshot of their Progress Chart from the App's main window showing the questions they completed successfully and also submit the screenshot of the survey completion confirmation through the learning management system.

Student Survey Design: To evaluate the effectiveness and user experience of the App, a set of survey questions were designed and administered to the students participating in the Fall 2024 Circuit Analysis course. The survey aimed to collect both quantitative and qualitative data to assess the impact of the App on student learning, engagement, and problem-solving skills as well as to assess the App user experience. The survey included Likert scale-based questions and open-ended, free-response questions. This mixed-method approach was chosen to gather objective, measurable data as well as subjective insights into the students' experiences with the App.

Likert Scale Questions: The Likert scale questions were designed to assess students' perceptions of various aspects of the App, including its effectiveness in supporting learning, impact on engagement and motivation, usability, and overall satisfaction. These questions required students to rate their level of agreement on a 5-point scale, with options ranging from "Strongly Disagree" (1) to "Strongly Agree" (5). The responses to these questions were quantitatively analyzed to identify patterns and trends in student perceptions as discussed in the next section.

Free-Response Questions: To capture more in-depth insights, the survey also included multiple open-ended questions. These questions provided students with an opportunity to express their

thoughts, suggestions, and any challenges they encountered while using the App. The free-response questions were aimed to gather qualitative data on the students' experiences and provide insights into potential areas for improvement in the App's design or functionality. The following table lists all the questions in different categories.

Table II: Summary of Survey Questions and Areas of Assessment

Targeted Assessment	Survey Question	Type of Question
Effectiveness in Learning Circuit Analysis	The circuit analysis question application (the "App") helped me with rigorous practice of circuit analysis problems.	Likert
	The App helped me understand circuit analysis concepts better.	Likert
	I believe the App helped to improve my problem-solving skills in circuit analysis.	Likert
	I found the tiered difficulty levels (easy, medium, hard) to be helpful to improve my skills by gradually increasing the complexity of the problems.	Likert
Impacts on Engagement and Motivation	The App motivated me to practice more circuit analysis problems.	Likert
	The App helped me identify my strengths and weaknesses in circuit analysis.	Likert
User Experience and Usability	I found the App's interface was easy to navigate.	Likert
	The directions provided within the App were clear & helpful.	Likert
	I encountered technical issues while using the App.	Likert
	The instant feedback provided by the App was helpful in understanding my errors.	Likert
Overall Satisfaction	I would recommend this App to other students studying circuit analysis.	Likert
User Experience	What were the most effective features of the App in your opinion?	Open-ended
	Did you encounter any challenges or limitations while using the application? If yes, then please explain.	Open-ended
Suggestions for Improvement	Do you have any suggestions or recommendations to improve the App to better meet your needs as a student?	Open-ended

Results and Discussions:

Survey Administration: The survey was distributed to students near the end of the Fall 2024 semester, after they used the App for at least two weeks. Students were given sufficient time to complete the survey to ensure they could reflect on their entire experience with the App. The data collected from the Likert scale questions have been analyzed using descriptive statistics (mean and

standard deviation) to assess the overall effectiveness and satisfaction with the App. This allowed us to identify general trends in student perceptions and to assess whether the App met its intended goals. The responses to the open-ended questions were analyzed using thematic analysis. This approach involves reading through the responses, identifying recurring themes or patterns, and categorizing these themes to better understand student experiences. Thematic analysis provided deeper insights into how the App was perceived by students, including its strengths and areas for improvement. This research study was approved by KSU's Institutional Review Board (IRB).

Data Analysis and Results: The following bar graphs illustrate the generally positive response of students to using the App as assessed by the Likert scale questions. For the four questions that assessed the effectiveness of the App in facilitating learning circuit analysis theories, we observe that the percentage of students who responded "Somewhat Agree" or "Strongly Agree" ranged from 97.5% to 61.6% (Fig. 1). The two questions assessing the impact of the App on student engagement and motivation resulted in 66.6% and 84.7% of students responding, "Somewhat Agree" or "Strongly Agree" (Fig. 2). Respondent percentages for students who rated "Somewhat Agree" or "Strongly Agree" for the four questions used to assess User Experience and Usability ranged from 66.6% to 22.2% (Fig. 3). The low of 22.2% was observed from student responses to the question "The instant feedback provided by the App was helpful in understanding my errors." It should also be noted the 66.6% of students responded rated "Somewhat Agree" or "Strongly Agree" when asked about encountering technical issues with the App. The main cause for this was the presence of a bug in this first version of the App which resulted in displaying erroneous answers for two questions. Overall, 62.9% of students answered "Somewhat Agree" or "Strongly Agree" when asked if they would recommend the App to other circuit analysis students (Fig. 4).

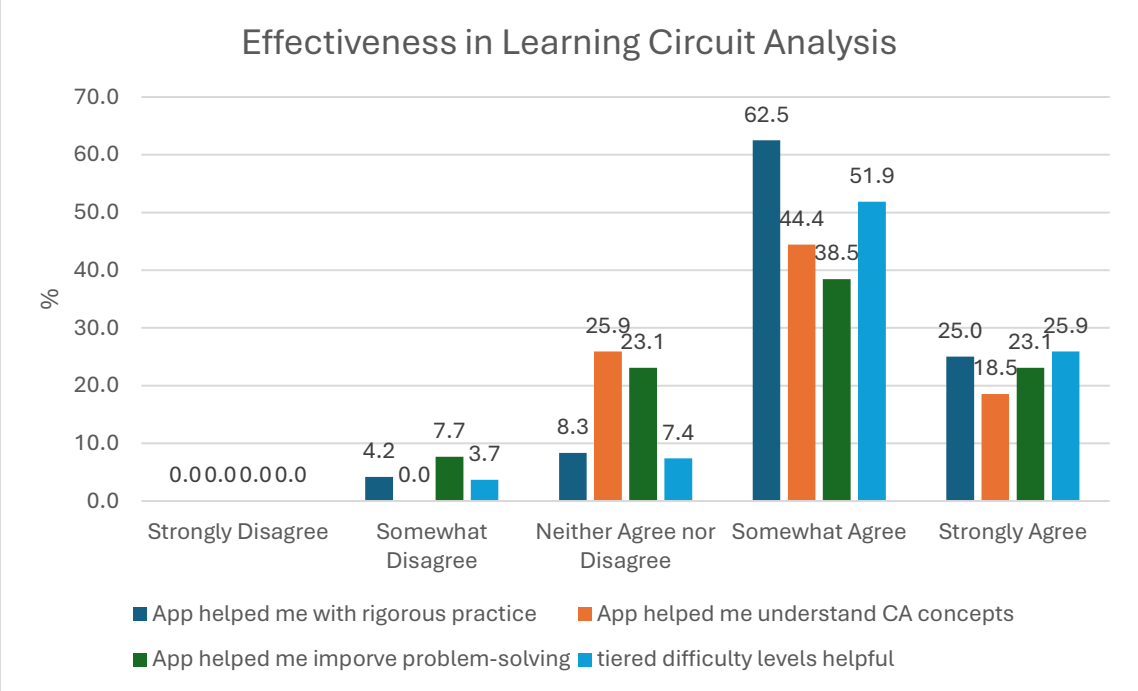

Figure 2. Student responses to Likert scale questions assessing the effectiveness of the App in facilitating learning of Circuit Analysis.

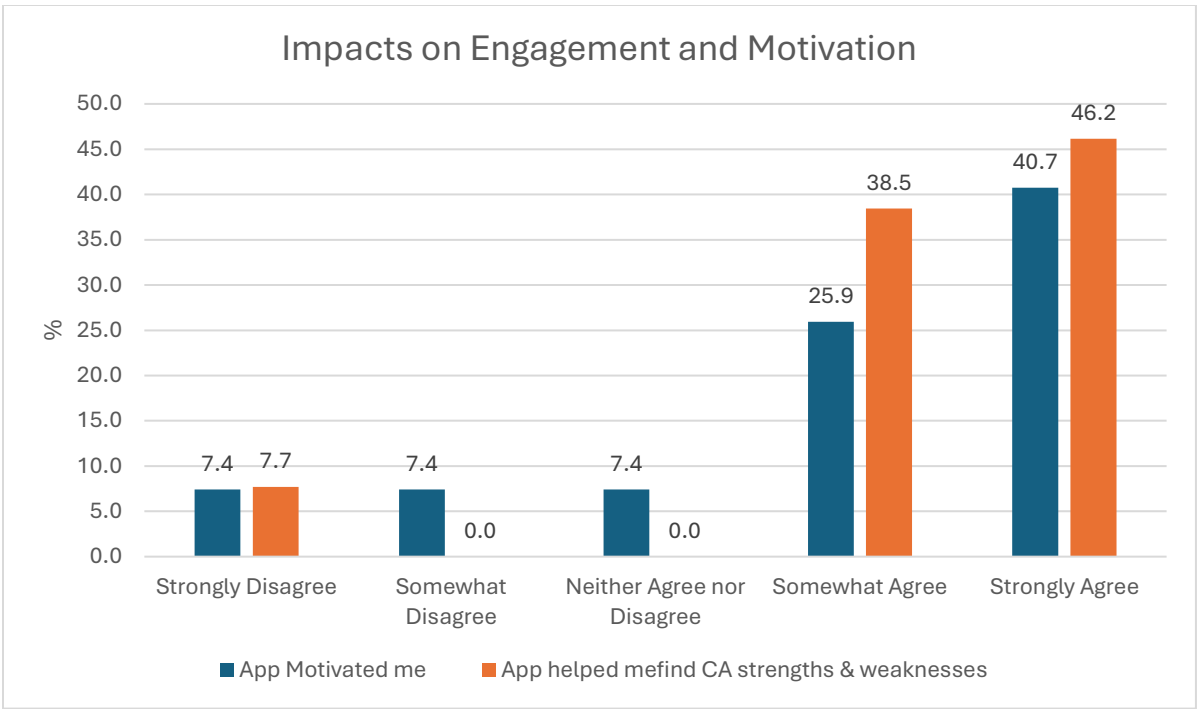

Figure 3. Student responses to Likert scale questions assessing the impact of the App on engagement and motivation.

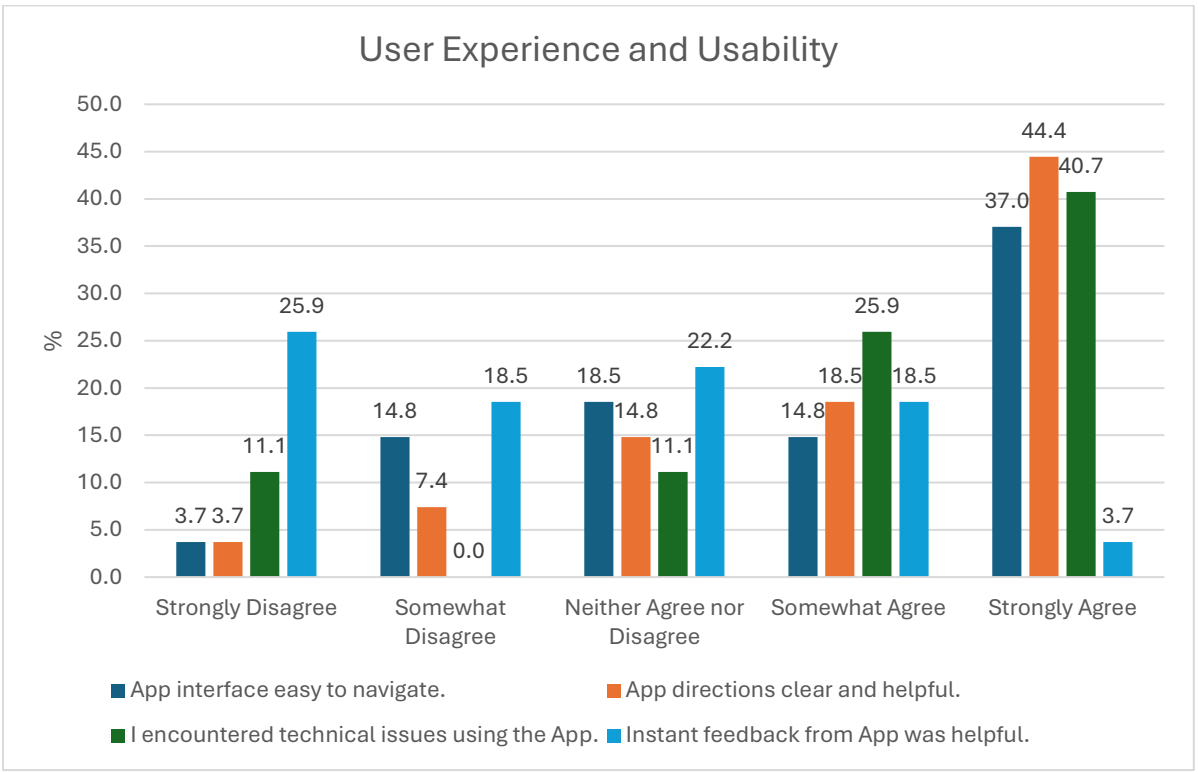

Figure 4. Student responses to Likert scale questions assessing student user experience and the App's usability.

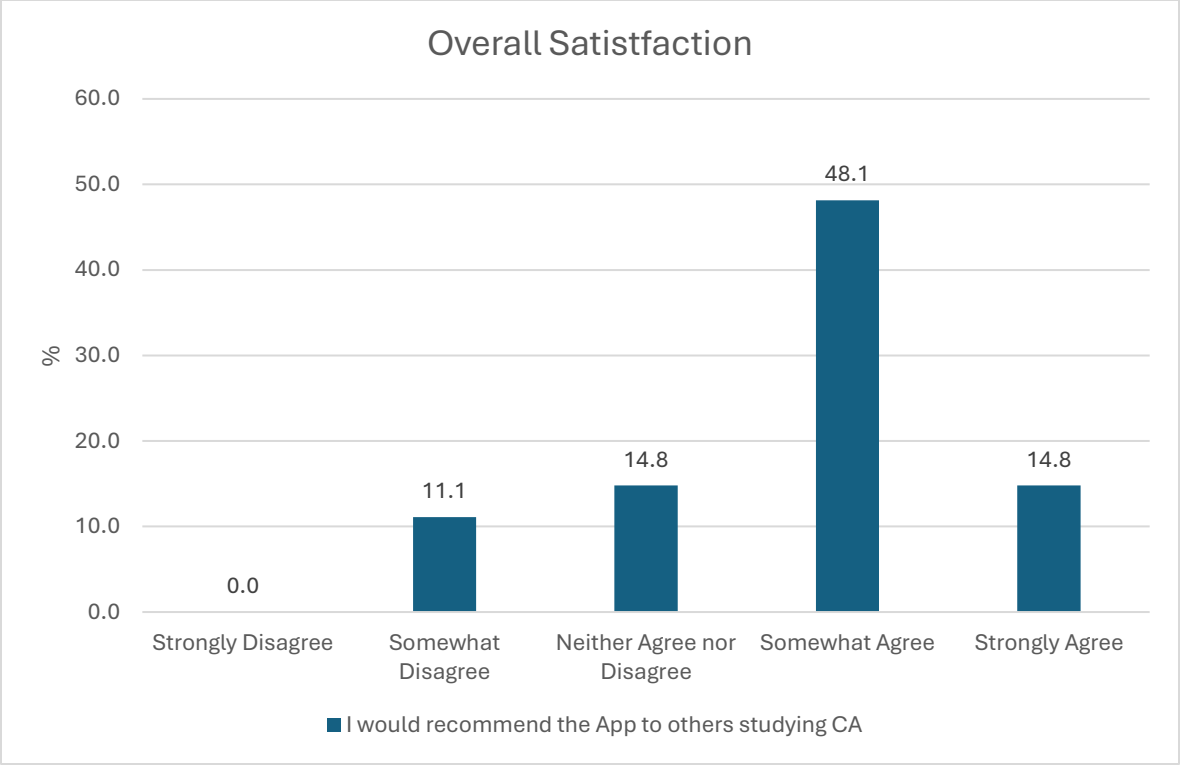

Figure 5. Student responses to Likert scale questions assessing overall student satisfaction.

The mean and standard deviation of the Likert Scale response are displayed in Table III. The mean score for most of the questions was ≈4, indicating general agreement for these questions. The single exception was the mean score for responses to the question related to the helpfulness of instant feedback, which had a mean score of 2.50 indicating student neutrality to mild disagreement to this statement.

Table III: Descriptive Statistics of Likert-Scale Questions

Targeted Assessment	Survey Question	Mean	Standard Deviation
Effectiveness in Learning Circuit Analysis	The circuit analysis question application (the "App") helped me with rigorous practice of circuit analysis problems.	4.08	0.72
	The App helped me understand circuit analysis concepts better.	3.92	0.72
	I believe the App helped to improve my problem-solving skills in circuit analysis.	3.83	0.92
	I found the tiered difficulty levels (easy, medium, hard) to be helpful to improve my skills by gradually increasing the complexity of the problems.	4.13	0.74
	The App motivated me to practice more circuit analysis problems.	3.96	1.30

Impacts on Engagement and Motivation	The App helped me identify my strengths and weaknesses in circuit analysis.	4.25	1.11
User Experience and Usability	I found the App's interface was easy to navigate.	3.75	1.29
	The directions provided within the App were clear & helpful.	4.04	1.20
	I encountered technical issues while using the App.	3.96	1.33
	The instant feedback provided by the App was helpful in understanding my errors.	2.50	1.25
Overall Satisfaction	I would recommend this App to other students studying circuit analysis.	3.75	0.90
User Experience	What were the most effective features of the App in your opinion?	4.08	0.72
	Did you encounter any challenges or limitations while using the application? If yes, then please explain.	3.92	0.72
Suggestions for Improvement	Do you have any suggestions or recommendations to improve the App to better meet your needs as a student?	3.83	0.92

The first of three open-ended questions asked students to provide their opinion of the most effective features of the App. Student responses were coded and grouped using thematic analysis, and the results are shown in Fig. 5. The bar chart indicates that students found most effective features of the App to be the organization of the problems in tiers (26.1%), the quantity of problems provided (21.7%), the variety of problems provided (21.7%), and to a lesser extent, the immediate feedback (13.0%) and the progress chart (8.7%).

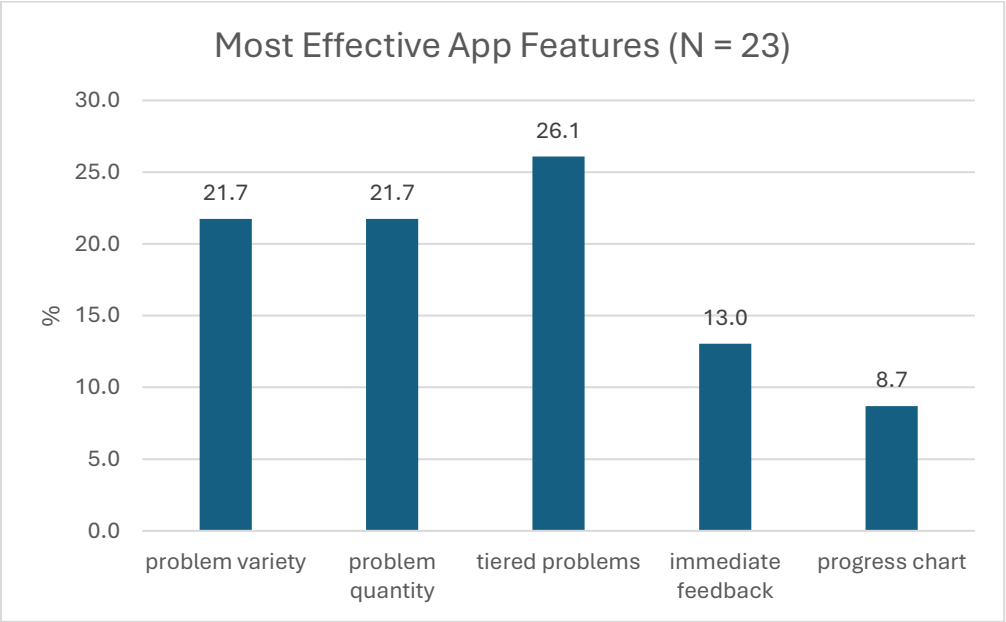

Figure 6. Bar chart of most effective App features based on student opinion.

The second open-ended question asked students about any challenges or limitations students encountered while using the App. The bar chart of Fig. 6 summarizes their responses and shows that the most frequent challenge encountered were perceived incorrect answers (50%). Additionally, some students observed loss of their progress when closing the App (18.2%) and found the progress bar difficult to read (9.1%). The remaining student responses could not be coded into a category primarily because a specific feature was not identified in the response (22.7%).

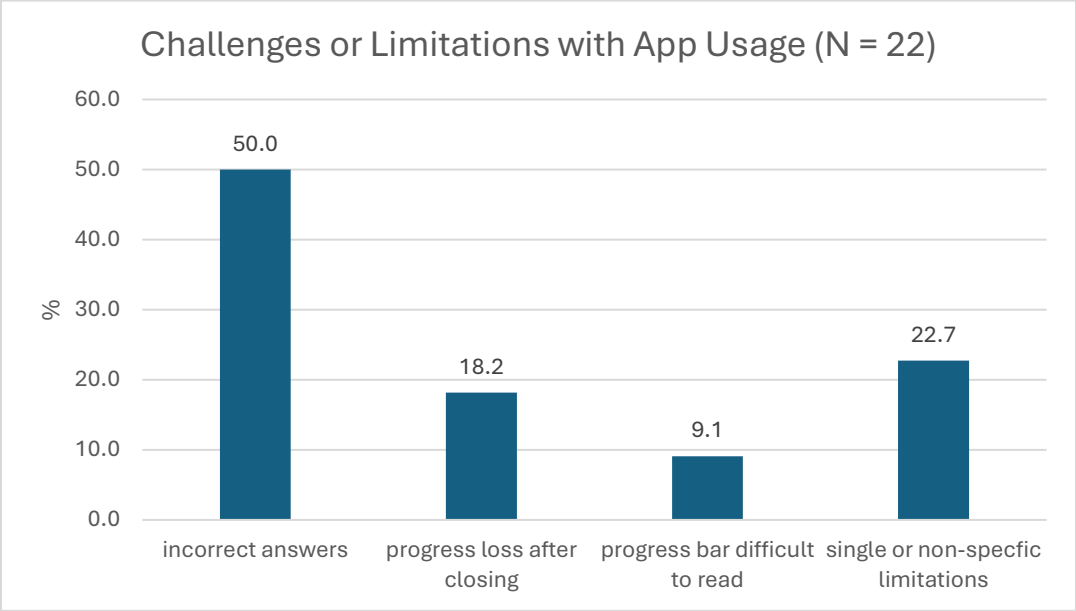

Figure 7. Bar chart of challenges or limitations encountered by students during App usage.

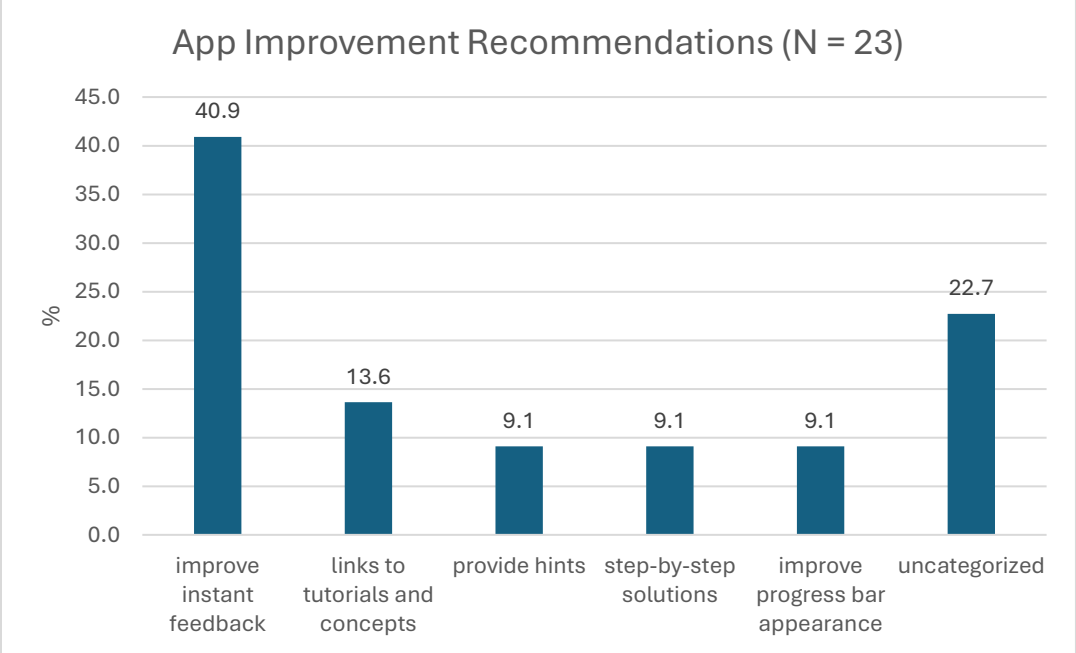

Figure 8 – Recommendations for the App improvement suggested by students.

The third open-ended question asked students to make recommendations for improving the App based on their experience with it. As shown in the bar chart of Fig. 7, 40.9% of students who responded thought the immediate feedback could be improved, with some students explicitly suggesting integrating step-by-step solutions into the feedback (9.1%). Other recommendations include providing links to tutorials and conceptual material within the App (13.2%), providing hints (9.1%) and improving the appearance of the progress bar (9.1%). The remaining student responses could not be coded into a category (22.7%).

Conclusions:

The App represents a promising tool for enhancing student engagement and learning in Circuit Analysis courses. By offering dynamic question generation, instant feedback, and real-time progress tracking, the App helps students develop critical problem-solving skills while providing instructors with valuable insights into student performance. Preliminary survey data suggests that the App may significantly improve students' mastery of circuit analysis concepts as well as increase their levels of motivation and engagement. Students particularly liked the volume and variety of problems the App provided for practice and the tiered levels of difficulty in which the questions were organized. The App is well suited to address the diverse needs of students who are at different levels of readiness due to the tiered nature of the problem set. Leaning on the theory of Vygotsky's Zone of Proximal Development (ZPD) [13], the App is more likely to align with the level of readiness that a student possesses to maximize learner growth. This in-turn positions the App to be an essential tool for broadening student participation in electrical and computer engineering programs. The overall positive rating for student satisfaction (66.6%) was despite some deficiencies in this preliminary release of the App with students primarily citing concerns erroneous answers and suggesting an improvement in the format of the instant feedback. Further analysis will be conducted in the following semester to continue assessing student perception of the usability of an improved version of the App and its impact on their learning and engagement. Additionally, we will also assess the impact of App usage on student outcomes.

Future Work:

Future work will focus on refining the App's user interface based on student feedback and expanding its features to support more advanced topics in Circuit Analysis. Additionally, the App's effectiveness will be evaluated over multiple semesters to gauge its sustained impact on student learning outcomes. Ultimately, the goal is to develop a comprehensive, interactive learning platform that can be used in engineering courses across a variety of disciplines.

While the current version of our Circuit Analysis App has shown promising results in its initial implementation, there are numerous areas for further development and enhancement to optimize its effectiveness as a practice and learning tool. The future work for this project will focus on expanding its capabilities, improving its user experience, and integrating new data analytics technologies. We have identified the bugs in the first version and have taken necessary measures to rectify them in the next version. Currently, we are working on to further expanding the base question bank. By expanding the question bank, the App can provide students with a broader range of problems to practice, reinforcing their understanding across a wider array of topics in circuit analysis and related fields. Another area of our future development focuses on integrating adaptive learning algorithms into the App. The current version of the App provides random question generation capability based on difficulty levels, but there is potential to personalize the learning

experience for each student based on their individual strengths and weaknesses. We plan to develop a future version of the App with integrated machine learning algorithms to track student performance and adapt the content dynamically. This adaptation could include personalized difficulty progression where the App could use past performance data to adjust the difficulty of questions based on the student's success rate. For example, if a student is consistently answering medium-level questions correctly, the App could automatically move them to more difficult questions in that topic area. In addition, the App can be improved to detect if a student struggles with specific topics and then provide recommendations for additional practice related to those particular topics, thus helping the student to focus on their areas of weaknesses. Further development of the App, coupled with continuous feedback from students and instructors, will help ensure that it meets the evolving needs of the learners and educators in the digital age.

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