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An Adaptive Educational Web Application for Engineering Students

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ABSTRACT Motivated by the success of student-centered language-learning tools and data-driven platforms commonly found in popular commercial and entertainment platforms, we present a new adaptive educational web platform for engineering students. The presented adaptive education platform (ADEPT) focuses on personalizing learning in large college classes by enabling proactive and continuous student engagement. In this paper, we present the principles, implementation strategies, and initial results obtained by working with an early version of ADEPT in a required sophomore-level circuits course at Purdue University. Initial results underline the potential of this web tool to identify the challenging concepts for students as well as prepare instructors to modify the way concepts are presented to the students. In addition, ADEPT helps to reveal the student engagement habits and studying patterns that may not be easily identifiable through other means, such as self-reporting.

INDEX TERMS Electrical engineering education, application software, electronic learning, online learning, adaptive learning, computer aided instruction, educational technology.

I. INTRODUCTION

Learning environments have increasingly been impacted by technology, from online course offerings and entire degrees, to the incorporation of tools to assist in some aspect of the learning, such as homework systems, educational games, and student response systems. The use of technology has facilitated the ability to adapt instruction to meet the unique learning needs of individual students. In addition to their ability to be adaptive, these computer-based learning approaches can increase the student engagement with the material, which has been shown to have a strong positive effect on student learning [1]–[3].

Since the 1980s, adaptive systems have been developed to allow personalization of learning environments [4], with generally positive benefits on learning [5]–[7]. More recent systems continue to demonstrate positive benefits, such as those developed for teaching fluids in a chemical engineering course [8], and digital logic design [9]. Some systems have utilized games to further engage the learners [10], [11].

One strategy that can improve student engagement and motivation within these systems is gamification [12], [13], which is ‘‘the use of game design elements in non-game contexts’’ [14, p. 9] to engage participants and encourage desired behaviors. This differs from game-based learning which is typically self-contained, with a definitive start and end that can be characterized by a ‘‘win state’’ [15]. For an example of game-based learning see Wang *et al.* [16].

Although the term gamification is relatively new, the underlying learning practices of the most effective gamification platforms – retrieval practice and spaced retrieval – have been utilized to facilitate learning and studied for over a hundred years [15]. Despite the fact that the benefits of ‘‘retrieval practice, which requires learners to recall information rather than simply reread or relisten to it’’ [17, p. 184] on learning and retention have been known for decades and have been demonstrated across very diverse students and subject material, the technique is underutilized in learning systems [17], [18]. Furthermore, research on spaced retrieval by Carpenter, Cepeda, Rohrer, Kang and Pashler found that ‘‘studying information across two or more sessions that are separated (i.e., spaced apart or distributed) in time often produces better learning than spending the same amount of time studying the material in a single session.’’ [19, p. 370] Based on their findings, they recommend spaced re-exposure to promote long-term retention of the material by incorporating concepts taught earlier in the semester into reviews, homework assignments, and exams and quizzes.

These studies have shown that computer-based adaptive learning approaches offer successful, practical, engaging, and effective solutions to meet the unique learning needs of large groups of students from diverse educational and cultural backgrounds. One example of a recent adaptive learning framework with those features is Duolingo, the most successful free language-learning platform with over 100 million registered users. However, few adaptive educational tools exist today for traditional electrical engineering classes. This is unlike the corporate world where adaptive individualized data-driven selling strategies currently dominate the market (e.g. Amazon and Netflix). On the other hand, even higher-education curricula that do not heavily rely on lecture-based learning but have rather embraced blended teaching techniques, rarely include adaptive learning approaches. Nevertheless, adaptive learning approaches personalize learning to individual students with the potential to result in significant benefits, including:

- Personalized learning with individualized learning goals, paths, and assessments.
- Proactive and continuous student engagement.
- Creation of self-motivated life-long learners.
- Improved mastery of the covered material since students can adapt their studies and focus on the areas with the greatest needs.
- Improved student retention with continuous support being available when needed the most.

The main purpose of this paper is to demonstrate how such a system could be implemented for large classes in a typical Electrical Engineering curriculum. Specifically, we assume the learning scenario found in many colleges with 100+ students. This scenario becomes even more challenging when students come from a wide variety of educational and cultural backgrounds. Such a scenario presents a real challenge for providing individualized student attention and feedback. The use of a well-crafted adaptive learning system is expected to aid in providing students with individualized learning opportunities.

II. MAIN CONCEPTS AND CHALLENGES

Recognizing the aforementioned benefits, it is the goal of this effort to develop and start assessing the effectiveness of an innovative adaptive tool called Life-Long Learning Adaptive Education Platform or simply ADEPT for short. ADEPT is a student-centric tool in the sense that it tracks the performance of each individual student and will tailor its content to the perceived needs of the student. We are currently focused on developing and evaluating ADEPT for a basic linear circuits theory course at Purdue University (ECE 20100: Linear Circuits Analysis I). This class covers the basic analysis techniques and theorems of linear resistive dc circuits, first and second order circuits (RC/RL and RLC circuits), and ac circuits including phasors and fundamentals of frequency-domain analysis. It is a required class for students majoring in Electrical, Computer, Mechanical, Industrial and Nuclear Engineering. As a result, this class impacts over 1,000 students per year from five major engineering disciplines. Similar courses also exist in Civil, Aeronautics and Astronautics, and Biomedical engineering.

While in our initial phase we are primarily focused on developing the ADEPT aspects pertinent to ECE 20100 homework and quizzes, we plan to eventually expand it to all educational materials including lecture notes, textbook and videos. Consequently, ADEPT is expected to capture the main attributes of adaptive learning for a basic circuits course. We should emphasize though that, despite the fact that ADEPT is currently focused on a basic linear circuits course, we are actually developing it as a generic platform (as discussed in Section III) that can easily encompass materials from other courses by just adding technical content. Hence we envision ADEPT as a generic adaptive education platform and not simply a course-specific tool. As such, ADEPT's main features will include:

- **Adaptivity to student needs:** Every student's performance will be monitored in real-time so that the most appropriate level of information and assessment are presented at any given time. Consequently, reaching diverse student needs will become effective and efficient.
- **Fast curriculum re-design:** Conventional curricula are hard to change because information is often organized around semester-long courses rather than concepts themselves. Creating new courses or replacing existing ones is time consuming and inefficient particularly for large required classes. ADEPT, on the other hand, will organize information and assessment around concepts. Each concept will be taught and evaluated on an adaptive-basis based on concept maps. A course can very quickly group the appropriate set of concepts leading to a modern and adaptive curriculum. This will lead to concept-centered easy-to-adapt courses.
- **Proactive and continuous engagement of students:** Unlike conventional approaches that include few high-stakes exams throughout the semester, ADEPT employs low-stakes exercises that encourage daily training by creating a unique self-motivating environment for every student.
- **Mobility and convenient real-time access:** Students and instructors will be able to access ADEPT regardless of their computing platform or software preferences.
- **Game-like and fun motivating features:** Fast-paced experiences and fun rewards will, over time, build interest and self-motivation. These will be critical to retain students and ensure their success and timely completion.

Furthermore, we are developing ADEPT with the potential to satisfy common requirements and needs of students, faculty, and university administration. Specifically,

- From the student point of view, ADEPT will focus on ensuring that every student has an equal chance to succeed regardless of his/her background, prior influences, and learning style. Additionally, it creates a unique self-motivating environment for every student so he/she keeps making progress on a daily basis.

- From the instructor point of view, ADEPT will aid in presenting concepts in the optimal order and with the appropriate focus individualized for each student. In addition, it will be invaluable in identifying students' weaknesses in real time so that solutions can be provided as needed.
- From the Schools/Departments/Colleges point of view, ADEPT will enable fast and efficient curriculum redesign. It will therefore enable university administration to respond to the continuously-changing students' needs.

ADEPT is currently under active development and assessment. As a result, the remainder of this paper discusses its main implementation features as well as some preliminary results that highlight them.

III. IMPLEMENTATION CONCEPT AND DETAILS

The ADEPT software application is built using a three-tiered client-server architecture. The client runs a presentation tier, the front-end, in a web browser. The server consists of an application tier, and a data storage tier referred to respectively as the middleware, and the back-end. This is a common arrangement for what is frequently called a web application or web app.

The front-end follows the mobile first design approach which aims to create the same ease of use on tablets and smartphones as is frequently experienced by desktop users. By making extensive use of Bootstrap and jQuery, a responsive user interface is achieved across a wide variety of browsers and devices. Middleware implements the model-view-controller design pattern using the Ruby on Rails web application framework. This robust framework includes comprehensive integrated testing and an active community maintaining a vast collection of domain specific solutions known as 'gems' that aid in rapid development and deployment of web applications. PostgreSQL was chosen for the back-end database because it is well supported by the middleware framework and, like the other tools chosen, has favorable licensing terms. The complete software stack is hosted on Linux servers using Amazon Web Services which provide high availability, scalability and security. An overview of the ADEPT's architecture and software stack are illustrated in Fig. 1.

In terms of end-user convenience, the web app design has three significant advantages over the use of a native application. First, web standards enable the client to be designed such that it is device and operating system agnostic. This allows the user flexibility in their choice of hardware and software used to access the application. Second, the ubiquity of web browsers enables end users to access the application with no download or installation required. Finally, centralized software updates ensure that end users are always accessing the latest version of the software.

For our purposes, the drawbacks of the web app design include the requirement of an internet connection, and less precise control over the presentation. The first drawback is mitigated by the increasing availability of free or low-cost wireless hotspots throughout campuses and everyday meeting places. The second drawback manifest mainly as the long standing difficulties of presenting mathematical expressions in a web browser. This is addressed in the current implementation of ADEPT through the use of a LaTeX to HTML converter called HEVEA. This converter is used to generate HTML equivalents of mathematical expressions written in LaTeX. While many such expressions can be properly displayed in HTML via HEVEA, some intrinsic limitations have been encountered in production use. A more robust approach to this issue is planned for future versions of the application.

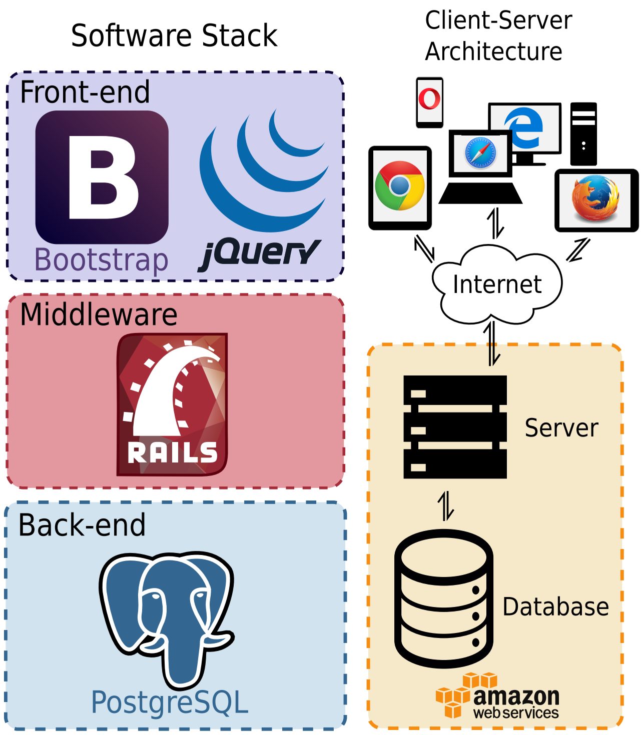

FIGURE 1. ADEPT's web application architecture and software stack.

In addition to mathematical expressions, many of the exercises presented to users of ADEPT incorporate technical figures. The generation and presentation of these figures is accomplished via the automation of a somewhat elaborate toolchain illustrated in Fig. 2. The figures are coded directly in a web browser using the PIC drawing language and a set of m4 macros that aid in drawing circuits [20]. Each figure's code is then preprocessed by the m4 macro processor to produce pure PIC output which is compiled by dpic into a Ti*k*Z-PGF file. This file is subsequently included into a LaTeX wrapper file and processed by LaTeX to produce a DVI file. Finally, the DVI file is converted into an SVG by the dvisvgm program, and that SVG is presented to users via their web browser.

While this figure generation process may seem unnecessarily convoluted, it offers several compelling advantages.

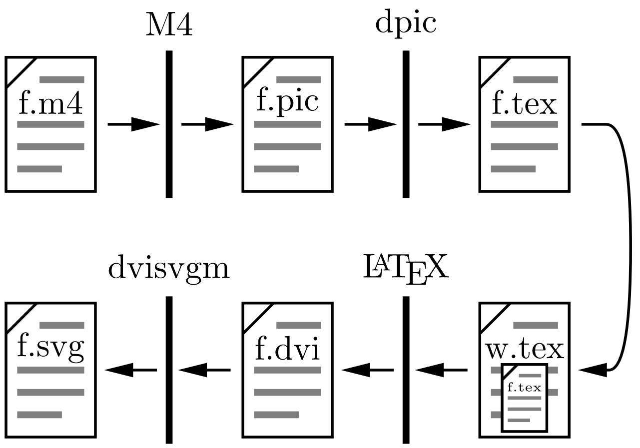

FIGURE 2. **Figure generation toolchain.**

The first being that the Ti*k*Z-PGF form of the figure may be easily included in LaTeX documents to generate PDFs of, for example, quizzes and exams. Secondly, the vector nature of all of these formats allows the figure's quality to be independent of resolution, and for all of the conversions used throughout the process to be lossless in terms of the quality of the final presented image. Thirdly, the text-based nature of these formats make programmatic generation or manipulation of the figures a possibility we plan to pursue in future work.

Flexibility regarding future enhancements was an important design consideration leading to the chosen architecture and software stack. If, for example, new display technologies such as 3D, virtual and augmented reality, or something unforeseen, completely change the presentation tier, the software in the front-end layer may need substantial modification. However, by separating the concerns of each software layer, the middle-ware and back-end are unlikely to be affected by such changes. Similarly, the middle-ware or back-end database, can be changed or upgraded independently of the other software layers.

Although initially developed with content for a circuit analysis course, other than the m4 macros used to aid in drawing circuit diagrams, nothing in the design of ADEPT is limited to use in electrical engineering instruction. In fact, our approach to figure generation makes all of the diverse and high quality symbology designed for use in LaTeX documents available for use in ADEPT as well. While this should aid in the development of content for additional courses, these additions will require structural changes to ADEPT's back-end database schema which presently only supports a single course. The Rails framework provides a database schema migration system for managing such changes in a convenient and testable manor.

Many other planned features, such as gamification elements including point systems, achievements, and progress indicators, as well as an adaptively spaced retrieval practice system will involve changes in each layer of the applications software stack. The comprehensive tools included in Rails for unit, functional, and integration testing help to verify the proper functioning of each aspect of the application. This accelerates the development cycle and allows for deployment of new features with increased confidence.

IV. PRELIMINARY RESULTS

Two sections of Purdue University ECE 20100: Linear Circuit Analysis I have been given access to the ADEPT application. The first section took the course during the regular 16 week Spring semester of 2016. This cohort consisted of 115 students of which 62 attempted at least one ADEPT exercise. The second section took the course during a condensed 8 week Summer semester in 2016. This cohort consisted of 88 students of which 32 attempted at least one ADEPT exercise. Other than having access to the ADEPT application, both cohorts were provided a conventional curriculum and no portion of the student's grade was determined by their participation or performance within the ADEPT application. Each user was provided with an account allowing them to access the application, but the application's user data was kept internally anonymous, such that, no personally identifiable information was stored within the application's database.

Both sections employed the same set of exercises which consisted of 674 multiple choice questions. Each exercise was designed to focus in on one area of the concept inventory developed for the course, and together, the whole set of exercises provide complete concept coverage. Examples of concept derived exercises are shown in Fig. 3.

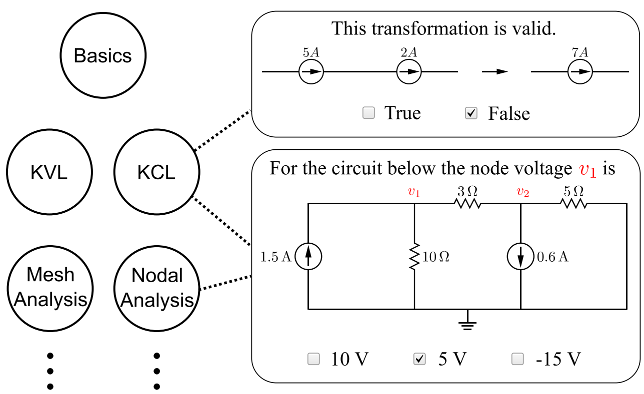

FIGURE 3. **Examples of concept derived exercises.**

These exercises were presented to users in a linear fashion corresponding to the syllabus. Once the user submits their choice for their current exercise, they are presented with feedback indicating whether or not they made the correct choice, and if not, what the correct choice was. They may then continue on to the next exercise. In an effort to reduce frustrations due to the nascent nature of ADEPT, users were also provided with the option to skip any exercises they chose. Upon skipping an exercise, the user was immediately presented with the next exercise. A screenshot of ADEPT's mobile interface showing an active exercise can be seen in Fig. 4.

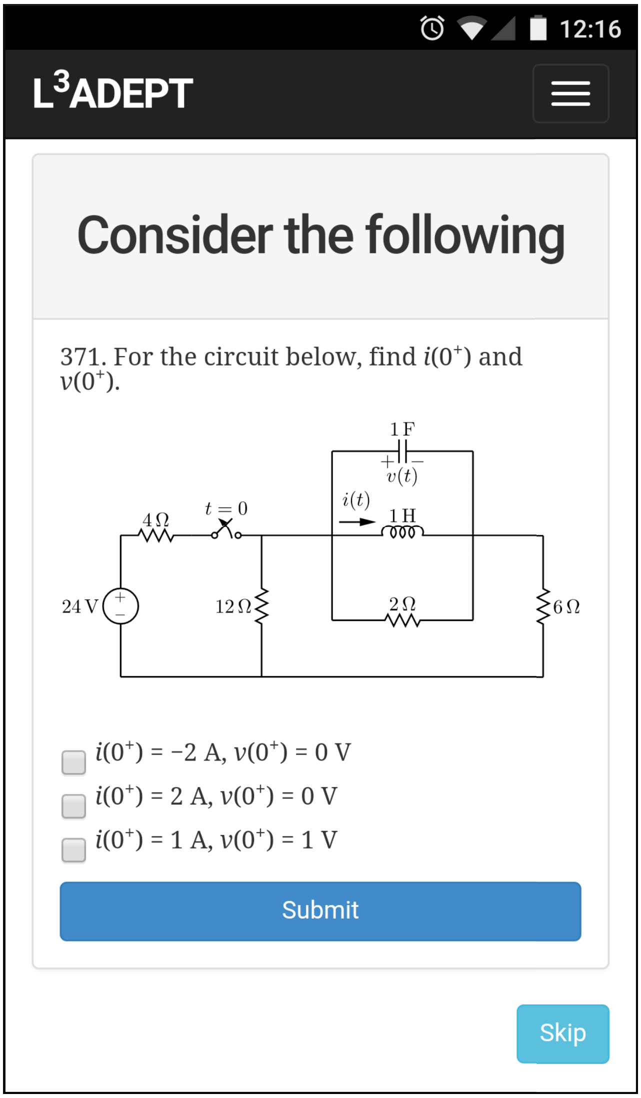

FIGURE 4. Mobile screenshot of the ADEPT exercise interface.

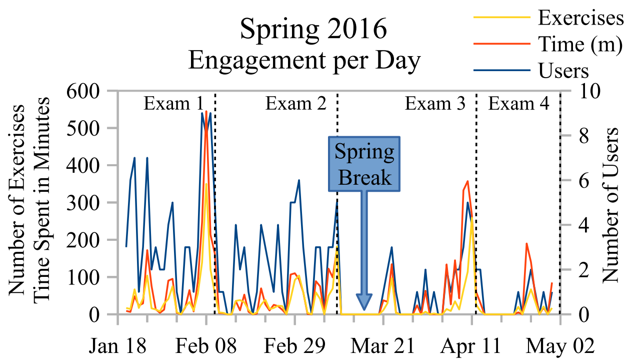

FIGURE 5. Spring cohort exercises, time spent, and users per day.

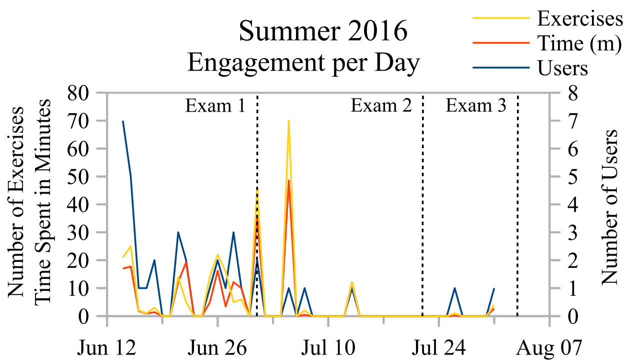

FIGURE 6. Summer cohort exercises, time spent, and users per day.

Data collected from each cohort include the date and time each exercise was presented, the interval between presentation and the users response, and the response itself. The number of exercises attempted, the estimated time spent, and the number of active users per day are shown in Figs. 5 and 6. The count of exercises attempted on a given day excludes skipped exercises. The estimated time spent was calculated as the sum of the intervals between presentation and response for each exercise attempted on that day. The count of users includes all users with at least one attempted exercise on that day.

In some cases, users have waited for extended periods of up to several days after being presented with an exercise before submitting their response. These long intervals have been excluded from the estimate of time spent because it is unlikely the user was contemplating their response during the entire interval. They also were not included in the counts of the number of users or number of exercises on that day. The cut-off for an interval to be included was set as less than 35 minutes. This excluded only 74 intervals or 2.2% from the total set of 3441 attempted exercises. In addition, no attempt was made to measure the time users spent considering the feedback they received after completing an exercise. For these reasons, we have likely underestimated the actual time spent using the application.

The trends visible in Figs. 5 and 6 illustrate users tendency to study most intensely immediately prior to an examination. Modifications to the application, including gamification features that encourage a more even distribution of practice time, will be investigated in future research.

In addition to usage and user engagement, the data collected by ADEPT also support an analysis of the course's exercises. Responses to each exercise are classified as either correct, incorrect, or skipped. In total, 5704 exercises were presented to users, with 2610, 831, and 2263 receiving responses classified as correct, incorrect, or skipped respectively. Relative response rates of each type are shown for a subset of exercises in Fig. 7. The percentage of responses in each category are shown stacked totaling 100% of the responses for each exercise. As can be seen in the figure, exercises 16 through 19 show a distinctly lower than average correct response rate. Upon further investigation, it was noted that each of these four exercises incorporated a diagonally drawn resistor as shown in Fig. 8. These exercises don't

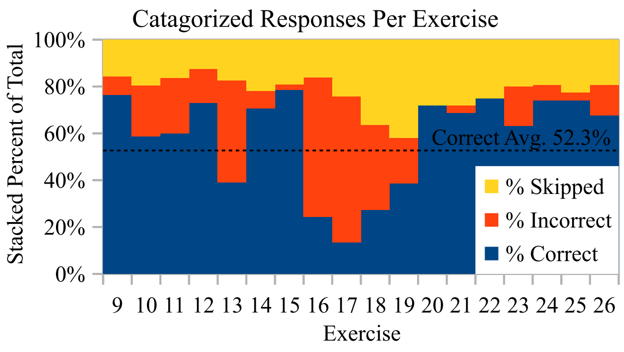

FIGURE 7. A subset of exercise response rates including a difficult concept.

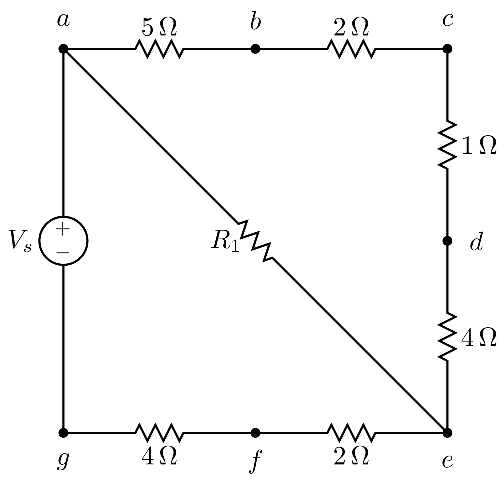

FIGURE 8. Circuit diagram with a potentially confusing diagonal resistor.

otherwise appear to be particularly difficult and we hypothesize that the user's lack of prior exposure to diagonally oriented circuit elements led to errors in their analysis.

Whether our hypothesis regarding these exercises is correct or not, the data collected by ADEPT is enabling the investigation of previously hidden trends. Beyond helping to identify potentially confusing concepts, variations in response rates across exercises may be helpful in identifying ambiguous phrasing, typographical errors, or coding errors. The aggregated response data can even be used as a means of assessing each exercise's difficulty. Quantifying the difficulty level of each exercise from the students perspective will aid in the development of adaptive features that present exercises appropriate to each student's demonstrated competency.

More results are needed in order to evaluate the effectiveness of ADEPT. In particular, comparisons against a control group will provide important insight into the effectiveness of this implementation. However, the preliminary results are encouraging, and demonstrate some of its salient features. Continued investigation promises to enhance our understanding of the learning process and to help us improve the learning environment for our users.

V. DISCUSSION AND NEXT STEPS

As mentioned in Section II, ADEPT will eventually be an environment to integrate all major learning tools including textbook, lecture notes, videos, quizzes, homework assignments, and exams. In our current approach, we plan to first optimize its adaptive features in exercises that take the place of traditional quizzes and homework assignments. Once this is accomplished and evaluated, lecture notes and videos will be introduced in a similar fashion. Furthermore, once optimized for the current focus-course, additional material will be added for other core courses.

There are certain challenges though that needs to be overcome before ADEPT becomes effective. These include:

- Integration to a traditional curriculum and wide-spread adoption: Many instructors and universities are unfamiliar with the benefits and processes of adaptive education platforms. Consequently, a special plan needs to be developed for widespread adoption. The same is true for students. Many students have not experienced such learning modes before and need to adapt to them.
- Assessment: Continuous and careful assessment of ADEPT and its features will be critical in effective evaluation as well as in aiding integration in traditional curricula.
- Broader impact: One of the main envisioned benefits of using ADEPT as an instructional platform is the ability of the students to recognize life-long learning and its benefits. Evaluating this aspect will be particularly challenging due to its long-term results and impact.

VI. CONCLUSION

Motivated by research into retrieval practice, spaced retrieval, and gamification, we have developed a flexible educational software platform named ADEPT to facilitate the application of these principles in a variety of courses. Such a system is expected to be of benefit not only to students but, also to instructors and administrators by providing real time progress data and enabling rapid curriculum redesign. ADEPT's design leverages modern web standards and well established design patterns in a concious attempt to maintain flexibility with respect to our ever changing technological environment. Early trials of ADEPT demonstrate the feasibility of the chosen architecture and data from those trials are already providing insights into student's engagement habits and to areas of the course content they may find difficult. Many new features are planned for ADEPT and its value is anticipated to grow substantially with their development.

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