Preliminary Results on an Interactive Learning Tool for Early Algebra Education

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***Abstract*—Interactive learning tools allow students to explore STEM concepts deeply, improving educational outcomes. Interactive tools that use cloud computing resources can (1) explore computationally intensive concepts and (2) seamlessly link concepts to graphical representations. When these goals conflict, good design, and implementation principles are needed to (1) preserve interactive response times and (2) uphold curriculum goals. For this paper, we present an interactive cloud-based learning tool that allows students to *interactively* explore algebraic formulas, their corresponding graphs (including axes) and generating data. Our tool is designed with both curriculum and interactive systems support in mind and it integrates with existing classroom management platforms. Our implementation employs a careful division of work between client-side browsers and cloud servers to provide *instant* response times that are within human perception limits. We achieve these design goals by (1) client-side programming for interactive components, (2) sending student activity data to servers at different rates for different sharing types, and (3) align student's data with Moodle's (a popular open source classroom management system) schema. Twenty Math teachers were trained to teach Algebra to students using our interactive service. Over eighty percent of teachers trained with our system adopted it. Now, our system is deployed in 5 schools, 30 classrooms, and 1400 students.**

I. Introduction

Traditional learning systems divorce STEM concepts from their applications in the real world. They teach STEM concepts and applications separately. For example, Linear Algebra in Mathematics is not taught alongside Ohm's law in Science which is an application of Algebra. This hinders the students' ability to understand the importance and application of STEM leading to poor student outcomes. Seymour and Hewitt's surveyed students who switched from STEM majors to non-STEM majors in college. Their results indicate that insufficient high school preparation is one of the major reasons students switch from STEM to non-STEM majors [1]. This finding is backed by Lichtenstein's findings that students leave STEM majors due to poor teaching in their pre-engineering courses [2].In addition to STEM, an ACM report states that by 2020, one of every two jobs in the STEM field will be computing [3]. This aligns with the recent inclusion of "Computational Thinking" as a core scientific practice by Next Generation Science Standards [4]. Hence it is important to situate learning effectively through the use of computers and technology and develop technological tools that provide teachers and students the opportunity to enhance their teaching and learning experience. There is an urge for an enhanced K-12 curriculum that explores STEM and Computational Thinking in a tightly coupled and interactive manner.

We proposed an Engineering driven Algebra curriculum for middle and high schoolers to facilitate a better understanding of Algebra and highlights its importance in STEM [5]. This curriculum stimulates learning Algebra by conducting engineering experiments and graphing the data collected. Further, an interactive graphical representation of this data is used to illustrate what data means in the Algebraic and Geometric worlds. We materialized the curriculum into Algebra lessons and developed a system to support the interactive graphical functions demanded by our curriculum. For example, Our first chapter is a Linear Algebra that teaches Linear Algebra through a scientific experiment Ohm's law. Ohm's law is an application of Linear Algebra where Voltage is the independent (x), Current is the dependent (y) and Slope is a function of Resistance. Our curriculum guides students to set up Ohm's apparatus and measure current and voltage as x and y coordinates. This data will then be entered into our system which can graph the data and display the corresponding linear equation $(y = m * x <=> I = \frac{1}{R} * V)$. Students are able to interactively manipulate the graph to explore the effect of slope and intercept on a line.

We deployed our system in 5 schools for 1400 students and our system is being used to teach Algebra in these schools. Our curriculum, system design, challenges and approaches are discussed in the rest of this paper.

II. Curriculum Design

A linear equation in algebra is of the form $y = m * x + c$, where m is the slope and c is the y-intercept of the line. This linear equation can also be represented as a line in a graph by plotting points obtained by giving different values for x and calculating the corresponding values of y. Also given a set of collinear points, the equation of their line can be formed using Two-Point form. Thus, a linear equation can be represented in three paradigms, 1) as a linear equation, 2) as a line in a graph and 3) as a set of (x,y) coordinates points.

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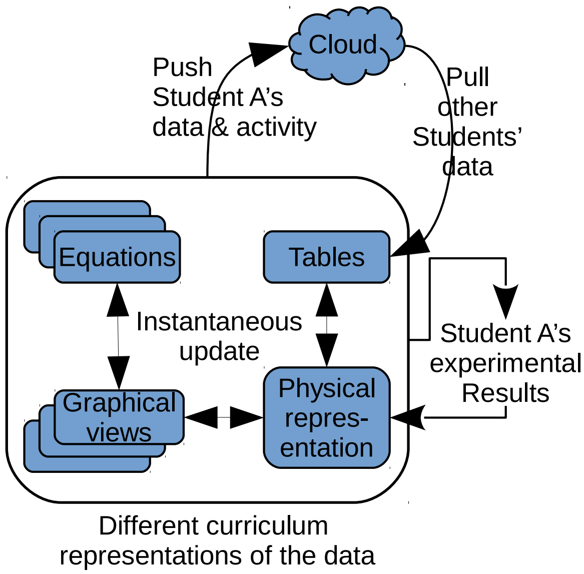

Fig. 1. Curriculum overview

An increase or decrease in the slope of the line, rotates the line in anti-clockwise and clockwise directions respectively in the graph. Similarly changes in the y-intercept, shifts the line in an up-down manner in the graph. It is important that students understand the connections between equation, graph and coordinate point paradigms for effective STEM understanding. Our system presents data points, graphs and equations in the same viewport and also allows users to interact with the graph, observe the effect of changing slope and y-intercept in the graph. Our curriculum teaches Linear Algebra exploring two of its application in STEM alongside namely, Ohm's law and a Velocity measurement experiment.

A. *Ohm's Law Experiment*

Ohm's law can be represented as $I = \frac{1}{R} * V$. In Algebra, this equation can be modeled as $y = m * x + 0$, where y is the Current, $m = \frac{1}{R}$ is the slope, x is the Voltage and the y-intercept (c) is 0. Initially with directions from the teacher, students set up Ohm's circuit. Ohm's circuit is a closed circuit formed on a bread board consisting of a voltmeter to measure the input voltage, an ammeter to measure the current and a resistor. In the first phase of this experiment students use a known resistor and different batteries (different voltages) to measure corresponding values of current in the circuit. Each battery and the corresponding current forms an x-y coordinate point. Students enter these x-y coordinate points into our system which presents them an interactive linear graph and displays the points and a linear equation below the graph canvas. Once students gain familiarity with Ohm's law and our system, Phase-2 poses them a small Algebraic quiz. Students are given an unknown resistor and using different batteries like before they will measure corresponding current and find the slope and determine the resistance (Inverse of slope is the resistance).

III. System Design

We developed an interactive system as shown in Figure 2 that supports data input and the interactive graphical functions discussed in our curriculum design. Our system is a web application supported by a cloud server that can be accessed from a web browser on any device. Students can sign-up online to use our system. During sign-up process, students will select school, teacher, and grade and based on these mandatory selections they are enrolled in corresponding sections. Once students sign-up, they can log in with their chosen username and password. After logging in, they can access any course materials that their teachers have published or use the link provided to access graphing portal.

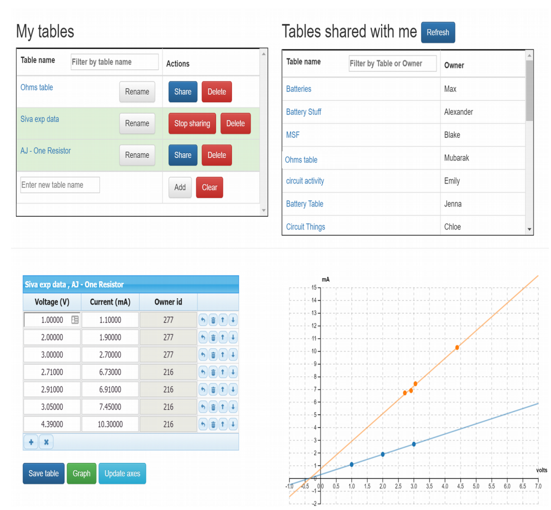

Fig. 2. Our interactive tool

The graphing portal is divided into four sections: the top left is the 'My Tables' section, top right is the 'Shared Tables' section, bottom left is the 'Data Input' section and bottom right is the 'Graph and Equation' section. My Tables section allows students to create new tables, rename existing tables or delete tables. There are also options to share/unshare tables. Sharing a table exposes it to other students in the same class. Since all these data are stored in the cloud, students can later log in from anywhere from any device and access stored tables. The Shared Tables section displays all tables shared by students in the same. These tables can be imported into My Tables. The Data Input part allows students to type in their experimental data and save them as new tables. This section is also used to view/update the data of existing tables under My Tables section. This tabular data is the Physical representation of scientific experiments. Multiple tables in My Tables section can be selected simultaneously and can be combined together. This tabular data can be graphed onto the Graph part using the Graph button.

The Graph section is shown in Figure 3. Graph section has a graph canvas with labeled axes and horizontal and

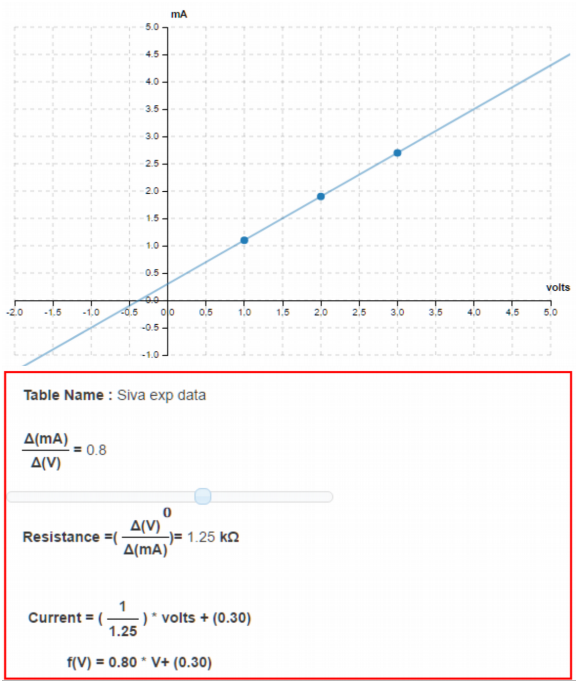

Fig. 3. Interactive graph and sliders

Curriculum Requirements	Number of clicks in	
	Excel	Our system
Input n points	2n	2n
Graph points to a line	6	1
View equation of line	3	0
Change slope	-	1
Change intercept	-	1
Update point and update graph	0	0
Add a new line to existing graph	12	1
Delete an existing line from graph	3	1
Update 1 extreme axis	4	2
Update all 4 axis	9	6

Fig. 4. Number of interactions required in Excel vs Our system

vertical guidelines. Data points from physical representation are plotted on the graph, joined by the line of linear regression. When multiple tables are selected, all points and lines appear in the same graph in different colors one for each source table. The axes rescale automatically based on the input points but can also be updated manually using the update axes button. The Graph section also displays the equations of regression lines and provide a set of sliders for interactive manipulation of data. There are two sliders for every table selected, a slope slider and an intercept slider that can be changed to update the graph and equations instantaneously. Our system also saves the states of students work, so they can resume learning without starting over when they log in again.

Following paragraphs discuss the key design principles our system is built on and how these design principles solve the issues in building any interactive system.

A. *Curriculum and System Co - Design*

While other tools like Microsoft Excel may offer visualization features, they are not built for these curriculum demands. For example, a key curriculum requirement is updating the graph parameters like slope is not supported by Excel. We realized this necessity to co-design a tool with our curriculum to excel in performing the curriculum requirements. Our tool is based client visualization where our web client uses D3.js (Data-Driven Documents) to achieve the visualization functions and support interactive graphing.With client visualization there is necessity to contact server for every graph update and thus there is no network latency involved in processing these updates. We provide interactive response times for graphing less than 10 milliseconds.

Our co-designed system achieves the interactive graphical functions demanded by the curriculum in minimal interactions at minimal response times. Figure 4 shows a comparison of the number of user interactions in Microsoft Excel and our system for each curriculum requirement. It is evident that our system outperforms Excel in almost all requirements. The core curriculum requirement to be able to manipulate the graph by changing the slope and intercept of lines is not supported by Excel. Our system allows students to manipulate graphs by changing the slope and intercept using a set of sliders. Another curriculum requirement is the ability to simultaneously graph different tables to visually observe the effect of different slopes. While it takes more than ten interactions in Excel to add a new data series, our system achieves it in a single click.

B. *Data transfer between Client and Server*

All data transfer between the client and server are ajax requests (Asynchronous Javascript and XML). Ajax requests enable our system to seamlessly exchange data with server, without clients having to reload an entire page. All our features discussed before like creating tables, retrieving tables, accessing other students tables, graphing or updating graph can be done from the same page without having to refresh the page. Ajax programming and client visualization helped us to create a single page application reducing redundant page loads. Our system also collects students' mouse movements and keystrokes for analyzing and understanding students learning behavior. We batch user interactions with the web page at the client and send them via ajax requests to the server every 140 seconds. The interval 140 seconds was empirically determined to give better performance.

C. *Integration with Classroom Management Systems*

Moodle and Blackboard are very popular classroom management systems of which moodle is open sourced. Our tool is

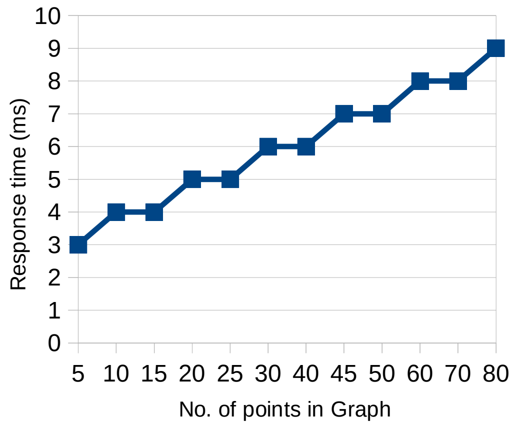

Fig. 5. Interactive response times for graph updates

built alongside moodle using many of the course management features that moodle provides. Typically classroom management systems handle students in one educational institution but we extended moodle to manage classes across multiple educational institutions (schools). We introduced another layer of abstraction on top of moodle's database which distinguishes students from different schools using a unique school-id identifier. We use moodle's secure login features for students to log in and we have tweaked moodle's course enrollment api to enroll students from different into our system. Our system supports many schools, with many teachers in each school and each teacher can handle many grades/sections in the same school. We use an attribute called class-id in addition to moodle's databases to achieve this one to many relationships. With this unique class-id, a teacher in one school can handle different sections in the same grade or different grades in same or different schools.

IV. Evaluation

We evaluated our interactive graphical client for response times and determined the variation in response times with increase in number of points in the graph. All evaluation is done using a trace from live deployment. Trace-based performance evaluation is widely used to assess response time in Internet services [6]–[8], [12]. Figure 5 shows the variation in response times for every slope/intercept update on the graph for different number of points, the client was a Chromebook provided in the school. When the graph button is clicked, the JavaScript client does a linear regression on the points in the graph and draws the regression line. Also upon every update to the graph, the new slope and intercept values from the slider are used to calculate the updated (x,y) coordinates for points and draw the new line. All updates to the graph are handled by the client without any interaction with the server. We provide response times of few milliseconds for every graph interactions without any server interaction by using the popular JavaScript visualization library D3.

V. Deployment

We piloted our system in summer 2016 with 20 teachers. During this pilot session, we trained the teachers to practice our curriculum and use our system effectively. The teachers were given an algebra quiz before and after their training with our curriculum. Quiz results show that training with our system can increase their understanding of Algebra and introduce them to Science and Engineering. We updated our curriculum with feedback from teachers after the pilot session. This updated system is deployed live and more than 80 percent of the teachers that piloted our curriculum adopted it. They use our system now to teach Algebra to their students. Currently, our system has been used by more than 1400 students from five schools in the Columbus area.

VI. Related Work

Web-based learning provides interactive response times for interfaces that cover sophisticated topics [9]. Our learning platform achieves instant response time (i.e., faster than interactive) by designing for performance and curriculum goals at the same time. This section describes related work.

Learning Platforms: EIMA (Engage, Investigate, Model, Apply) framework aims to help school teachers to incorporate model-centered scientific inquiry into science teaching practices. The inclusion of scientific modeling in schools can address the lack of STEM in schools.The approach taken in our curriculum reflects the benefits of context-based experiences with mathematics and follows EIMA [5].

Novel System Design for Interactive Response Time: SocialTrove targets search applications in social networks [10]. The data structure is co-designed with search to reduce retrieval costs. DICE [11] targets database queries, especially queries initiated from devices with high speed inputs like tablets. By co-designing the database query language with approximation techniques, they are able to achieve nearly instant response times. ApproxHadoop [8] targets data analytics over system logs. By outfitting the Hadoop platform with approximation support, they achieve interactive response times. Ubora [12], [13] targets data-intensive services, e.g., search and recommendation engines. Ubora integrates co-design at the operating system level, using network virtualization to capture workload specific details, and achieves instant response time. Compared to these works, our work implements co-design at a higher level in the software stack, but targets a novel workload (educational systems).

Educational platforms that combine concepts and applications: Educational platforms on computer systems often struggle with realism. Prior work have used virtual execution environments to reduce complexity while ensuring students experience realistic programming environments [14]–[16]. Our work targets early algebra education but borrows techniques from prior systems work in our design and implementation. Other recent work have explored other domains, including statistics, IoT and others [17], [18]

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