Mobile apps for Incorporating Science and Engineering Practices in K-12 STEM Labs

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***Abstract*— The central focus of this work-in-progress is to investigate the following: (1) What do the lesson plans created by teachers reveal about their understanding of science and engineering practices? (2) Will including programming exercises in all lesson plans improve STEM skills in general, and coding skills in particular? And (3) Will integrating science and engineering practices in high school lesson plans improve student retention in STEM and STEM-related areas?**

To answer these questions, we develop project-based lessons and mobile app-based laboratories that incorporate science and engineering practices. Additionally, with these apps, we: a) enable and motivate students to learn STEM topics by immersing themselves in interactive apps, b) include lesson content and electronic labs delivered using the latest mobile technology and platforms, and c) provide teacher training to better improve content delivery. We will design innovative Science, Technology, Engineering and Math (STEM) lesson plans and immersive labs, to create a transformative educational experience for high school students. The lessons and labs will be deployed with the help of mobile applications (apps) that will use multi-sensory and multimodal inputs and outputs to interact with students, and be designed to align with the newly adopted 2017 New York State Science Learning Standards.

Keywords—apps; STEM; high schools; Next Generation Science Standards; Science and engineering practices

I. INTRODUCTION

A consistent message from school science and math supervisors is that students do not have basic skills in science and math such as representation, modeling, analysis, and interpretation of data [1-3]. Further, inadequate integration of biology, math, chemistry, and physics concepts leads students to view each discipline as separate silos, with few multidisciplinary applications such as engineering applications [4]. The science and math skills students lack in high school only distance them further from exploring fields like engineering, a field that is highly interconnected to both math and science.

Traditional teaching modes in high schools rely on classes and traditional laboratories to transfer key knowledge to students. While this is effective for some students, most students rely on non-traditional and multimodal methods to learn. Furthermore, since many K-12 educators do not have a background in science and engineering, traditional methods do not motivate most students to continue in STEM-related majors in college. The use of mobile apps has caught the attention of educators as it can be a facilitator for learning [5,19,20]. While this may be beneficial, many teachers can survey apps only by reading reviews. Instead, a more empowering and advantageous way teachers can use mobile apps is when they are involved in the development and customization of the app [6]. The classroom teacher knows her/his class and curriculum best; however, many teachers and educators do not have experience with programming or coding. And the amount of time and effort needed to learn these skills makes it unrealistic for teachers to develop their own apps. While there are some simple app builders [7], the teachers' time is already stretched with many growing responsibilities.

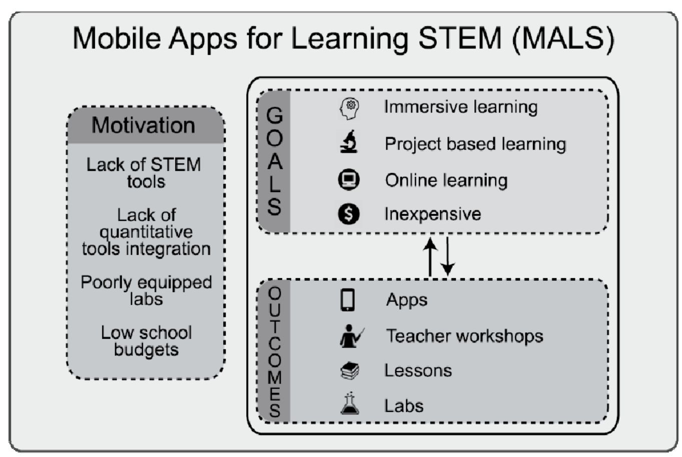


Figure 1. The MALS concept. Motivated by the lack of freely available tools for quantitative and lab work, the vision is to design and develop a framework of lessons and labs that can be implemented on mobile devices.

The focus of our work is to investigate teacher handling of science and engineering practices, by looking at lesson plans and exercises, and evaluating the impact of science and engineering practices on student retention. To do this, we design and develop project-based lessons and immersive mobile app-based laboratories that: a) enable and motivate students to learn STEM topics by immersing themselves in interactive apps, b) include lesson content and electronic labs delivered using the latest mobile technology and platforms, and c) provide teacher training to better improve content delivery. We call this combined approach as "Mobile Apps for Learning STEM" or MALS (see Figure 1).

The main objective of this work-in-progress is to investigate the following: (1) What do the lesson plans created by teachers reveal about their understanding of science and engineering practices? (2) Will including programming exercises in all lesson plans improve STEM skills in general, and coding skills in particular? And (3) Will integrating science and engineering practices in high school lesson plans improve student retention in STEM and STEM-related areas? In this paper, we describe our work with teachers to (a) design apps and lesson plans that integrate science and engineering practices; (b) to include a computing task in each lesson plan; and (c) introduce science and engineering practices to students.

The rest of this paper is organized as follows. In Section II, we provide a description of our previous work, an Android app designed and developed for undergraduate STEM education. We go on to describe our current work, including the design of lesson plans that incorporate science and engineering practices from the Next Generation Science Standards (NGSS). In Section III, we describe our assessment and evaluation plan. Finally, in Section IV, we provide concluding remarks, as well as future directions for our work.

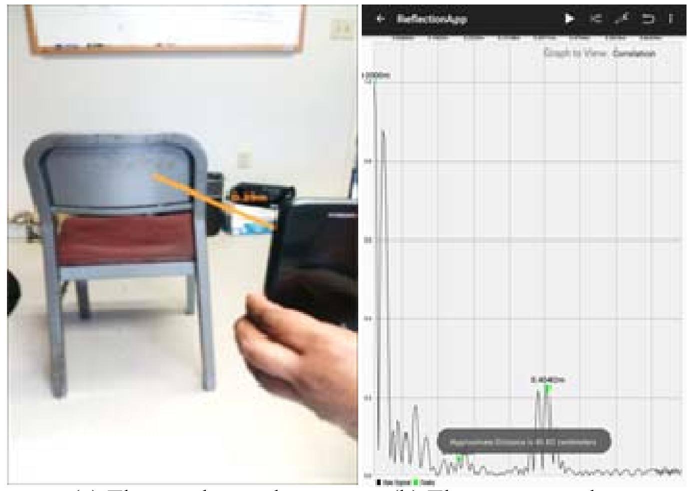
II. Research and Design Development

A. Previous Work

An example of technology that can be used to support this work in progress is an Android app being used for undergraduate STEM education. The Android app called "Reflections" [8-11] has been designed and developed for STEM education, and consists of four components: (1) an Android demonstration of echolocation; (2) a set of notes describing the functionality of the app, the basics of echolocation, and its application to advanced systems such as RADAR, LIDAR, and SONAR; (3) quizzes to test the concepts introduced by the demonstration and the notes; and (4) companion videos. The app is, therefore, a holistic teaching and learning app that can be used across various grade levels including K-12, undergraduate, and graduate education.

The app provides students a means to determine distances to objects while allowing them the ability to manipulate signal envelopes, signal shapes, signal types, and frequency constraints. A signal is generated and transmitted through the speaker of the Android device. The signal travels through the environment, strikes objects, and reflects back towards the device. The sent and received signals are then used to calculate the round-trip time [12], from which a distance estimate is calculated (see Figure 2 for example operation).

The app was used in an undergraduate Signals and Systems class at our University. The app was used to demonstrate the concepts of autocorrelation, time-of-flight, and noise effects. In order to assess the learning of the material, pre- and post- quizzes were given to the students. The results from the pre- and post-quizzes, as well as the improvement for each question, are displayed in Figure 3. Students were also asked questions about the app usability and how they perceived the usefulness of the workshop to teach them concepts in signals and systems. More than 80% of the students agreed that "The app was fun to use"; "The exercises were helpful"; and "The workshop was helpful".



(a) The speaker and microphone of the phone are pointed towards an object 0.39m away.

(b) The output on the app shows the return, and an object detected at approximately 0.4m.

Figure 2. Android app for echolocation being used to estimate the distance to a chair. The experiment is shown on the left, where the app is used to estimate the distance to an object (chair). The output of the app is shown on the right, with the peak indicating the distance estimate.

B. Current Work

The prior mobile app work with undergraduate students was a success and therefore it is being used to also make positive changes in secondary STEM education. Engineering is an important component of STEM which stands for science, technology, engineering, and mathematics. Like many secondary STEM curricula in the United States, the NYS science and math curricula cover more breadth than depth of science and math concepts. This challenges science and math teachers who may want to better align their lessons with Next Generation Science Standards (NGSS) that include engineering design principles, but are concerned about having enough time to cover all the necessary material for the Regents exams. Engineering is an important component of STEM but often gets neglected, especially at the K-12 level.

The overarching objective of our work is to support the creation and impact of STEM learning through the use of mobile apps by examining how these apps enable STEM teachers to understand and develop STEM concepts and engineering practices to be used with their secondary students. We use a grounded theory approach to create theory from the collected data [13]. Grounded theory can complement other research methods, such as case studies, and provides flexibility when collecting and analyzing data.

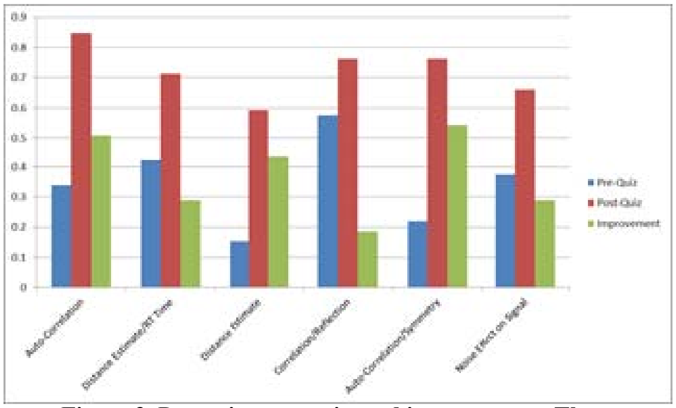


Figure 3. Pre-quiz, post-quiz, and improvement. The effectiveness of this app in undergraduate education is demonstrated through the improvement in student understanding of concepts. We plan to adapt the work to K-12.

In order to implement the lesson plans, we take a two-step approach. In the first step, we will work select teachers (currently, Mr. Dan Mattoon, Math and Computer Science, Niskayuna High School) to design lesson plans and get feedback on what apps and app content they would like to deploy with lesson plans. In the second step, we will co-lead workshops with the master teachers and work with other teachers to design lesson plans that fit their needs.

C. Example Lesson on Echolocation

In what follows, we present a complete lesson plan that covers a lesson on echolocation. This lesson uses the existing echolocation app designed by co-author Banavar, (see Section IIA), and is shown in Table I. The app is free and is available on the Google Play app store [10].

Our focus in this work is the "science and engineering practices" module of the NGSS. We are designing our lessons and apps to help teachers and students apply these engineering practices in their lessons. We address the following practices as identified by NGSS [14]: (P1) Asking Questions and Defining Problems; (P2) Developing and Using Models; (P3) Planning and Carrying out Investigations; (P4) Analyzing and Interpreting Data; (P5) Using Mathematics and Computational Thinking; (P6) Constructing Explanations and Designing Solutions; (P7) Engaging in Argument from Evidence; and (P8) Obtaining, Evaluating, and Communicating Information.

For each unit, a lesson and lab will be developed that uses a mobile app. The topics covered in this sample lesson are based on the Masters of Arts in Teaching (MAT) lesson template in the Department of Education [14]. Further lessons and labs will be developed in consultation with the master teachers as part of this project.

In the lesson description in Table I, we have:

(a) The central topic that is being studied: The topic that is the main focus of the lesson, this can help the teacher organize her/his lessons in a logical order.

Table I. Sample lesson on echolocation.

Central Topic: ***Echolocation***	NGSS Engineering Practices: P1, P3, P4, P5, P6, P7, P8
Abstract: Echolocation is used as a tool for locating objects by animals such as bats and dolphins, as well as in technology such as SONAR, seen used in submarines. In this lesson, the basics of echolocation, relationship to sound propagation, and applications are explored.	
Materials & Equipment: Mobile App, mobile device	Key Vocabulary: Echolocation, SONAR, time of flight
Lesson: 1. Sound propagation in different media 2. Use of echolocation by SONAR 3. Discussion: Will a submarine SONAR work outside water? 4. Discussion: Can times to same distance in different media be different? Will a submarine in fresh-water find objects the same way in salt water?	Lab activities: 1. Compute the time for a sound signal to travel to an object 1m away and back. 2. Stand 1m away from wall. 3. Use default app settings; point device at wall and run experiment. 4. Change sound to bat chirp and dolphin clicks and redo experiment. 5. Change distance to 2m and repeat. 6. Thought exercises: Which signals work best and why?
Behavioral objectives: Lesson: 1. Students should be able to list the modes of sound propagation in different media. 2. Students should be able to describe the use of echolocation by submarines.	Behavioral objectives: Lab: 1. Students should be able to use the app to manipulate variables to obtain data. 2. Students should be able to interpret the data and relate it to the real world. 3. Create or revise a simulation of a phenomenon or process.
Introduction and Exit for lesson: Bell Ringer—Prompt on the board (What do you think echolocation is?). Exit Ticket—Students describe echolocation and how it is used.	Evaluation strategies: Lab write up Formative assessment—teacher will walk around room and ask questions, make observations, read exit tickets, listen to answers from introduction.
Coding Exercise: Create a module that takes round-trip time as input and generates distance to object as output.	Skills covered: Science process skills, problem-solving skills, critical thinking skills, technical skills
Teacher reflection: What went well? What should I improve?	STEM Topics covered: Science (Bio, Physics), Technology, Math
Differentiation Strategies: Tactile and visual learning; groups made by mixing ability levels.	

(b) Standards from the NGSS science and engineering practices that are addressed in this lesson: This section contains the NGSS science and engineering practices that are addressed in the lesson.

(c) Abstract: This section is a brief overview of the lesson, describing the lesson, its importance, and the activities that will take place.

(d) Materials and equipment needed to complete the lesson/lab: This will help in teacher preparation. Teachers can then gather the necessary materials beforehand for the particular lesson. In some schools where resources are shared, this can help with the organization of resources.

(e) Key vocabulary: This is a list of the significant relevant vocabulary that is covered in the lesson. There is substantial literature that argues the connection between student readability and science, [16,17] therefore emphasizing key vocabulary is essential.

(f) General lesson and lab activity overview: This is a general overview of the steps that will take place in the lesson and the lab. This can help teachers plan appropriate amounts of time for the activities.

(g) Behavioral objectives for both lesson and lab: These are examples of what teachers can look for while they help groups and individual students. Clearly stating what they should be looking for can help guide their lessons.

(h) Introduction and endings to lessons: These are samples of 'bell ringers' and closures to lessons, this may help the teacher with classroom management, utilization of class time and staying connected with the lesson topic.

(i) Evaluation strategies: These are a short list of objectives that may help the teacher in how to assess students.

(j) Differentiation strategies: These strategies are essential as classrooms are filled with diverse learners. Planning ahead on how to differentiate the lesson can help the teacher in preparation for class.

(k) Skills that are addressed: This section can help teachers make the connections between the STEM fields. Skills they are using in one lesson/lab can be connected to other disciplines, making explicit the interdisciplinary nature of STEM.

(l) Teacher reflections: This is a way for teachers to reflect upon their lesson, what went well, and challenges they encountered. This will help to improve their pedagogy.

(m) STEM areas covered: Explicitly stating what STEM fields are related to the lesson can help the teacher in planning, potentially even working with other teachers in other disciplines.

III. Evaluation and Assessment

In order to study the effectiveness of our approach, we conduct assessments using several methods, specific to each of our main focus questions as stated in Section I. Preliminary assessment results will be presented at the conference.

Teacher Understanding of Science and Engineering Practice will be addressed by a) completing a content analysis of the teachers' daily lesson plans and/or unit plans, b) observing lessons and c) conducting interviews with the STEM teachers. These will occur before, during and after teacher interactions. These data will be transcribed from the lesson plans, lesson observations and qualitative interviews and will be coded to highlight key moments or segments that took place during the activities.

Programming Exercises to improve STEM Skills will be addressed via conducting a content analysis on mobile app programming lessons. A simple assessment will be created to review student skills prior to the mobile app STEM lessons and then again after the lessons occur. These data will be transcribed from the lesson observations, assessments and qualitative interviews with the students before and after the lessons.

Integrating Science and Engineering Practices to Improve Retention will be addressed in two ways. First, we track student career paths before their current course and for 3 years after the current course (or their intended major going into college). Secondly, students will be given an S-STEM survey [18], to share information about their attitudes towards science, technology, engineering, math, postsecondary pathways and career interests. This survey will be given to the students at the beginning of the school year; after the year involving the use of our proposed lesson plans; and then again, one year after their participation in the lessons. The survey will be analyzed in accordance with The Friday Institute for Educational Innovation.

IV. Conclusions and Future Work

Since the use of mobile apps (a result of applied engineering by co-author Banavar) has been successful for teaching STEM education to undergraduate college students, we designed a program to use apps with high school teachers and their students. This method introduces science and engineering practices, included in the Next Generation Science Standards (NGSS), to secondary schools. Our apps will provide creative learning experiences for pupils in science and other STEM classes. A sample lesson about echolocation was presented with its lab, various activities, and behavioral objectives for students.

Future directions of this work will involve the need to design apps and prepare the necessary units (that incorporate mobile apps) for the Living Environment Core Curriculum. In addition, teacher workshops will be prepared and carried out to instruct them on the use of the apps in their classrooms. We aim to successfully expand the use of apps to other schools; develop new lesson plans in multiple areas, each incorporating science and engineering practices; and to teach other STEM courses.

V. ACKNOWLEGEMENTS

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