Teaching Signal Processing Applications using an Android Echolocation App

Mahesh K. Banavar, Seema Rivera, Blaine Ayotte, Kevin Mack, Dana Barry, Andreas Spanias, Chinmay Sahu, Tianqi Yang

Abstract

An Android application that realizes an audible version of echolocation has been implemented. Bundled within the app are videos, notes, problems, and discussion questions, thus creating an “eModule”. The eModule contains material that is relevant to several educational levels including K-12 and undergraduate engineering. By using the echolocation features of the app, at the K-12 level, teachers are able to introduce labs, and science and engineering practices into their lesson plans. By using data collection and interpretation, undergraduate students can be exposed to various concepts in signals and systems, digital signal processing, and machine learning. Assessment instruments for the evaluation of the Reflections app, as well as the bundled content, have been developed. Pre/post assessment data and results of survey instruments have been collected and analyzed in an effort to assess the impact of the tool on student learning at the undergraduate level, as well as impacts on K-12 teacher interest in introducing science and engineering practices in their lesson plans.

Index Terms

Android, Signal Processing, Mobile Education, Machine Learning, DSP, Autocorrelation

I. INTRODUCTION

Studies show that students prefer using technology in order to learn new topics [5], [6]. One study, in particular, showed that technology not only helped students gain increased knowledge, but also contributed to developing a more positive attitude towards STEM content [7]. As mobile technology has grown, so has its use in teaching and learning [8], [9]. Additionally, it has been found that students learn better when learning using mobile devices when compared to no computers, or even using desktop computers [10]. Teaching via mobile applications (apps) is therefore a rising trend, which allows for the learning experiences of diverse populations of students to be customized, thus promoting inclusion [11], [12].

However, in [13], the authors investigated US college freshmen and found that these students are not all technology aware. However, it should not be assumed that these groups of students are all similarly skilled in their ability to use technology [14]. In school-age students, technology experiences in school tend to be different or disconnected from their technology experiences out of school. However, there is a critical need for including technology in classrooms (see Figure 1 and background literature discussing the effectiveness of immersive learning, project-based learning, and online learning in Section II).

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Parts of this work have appeared in [1]–[4].

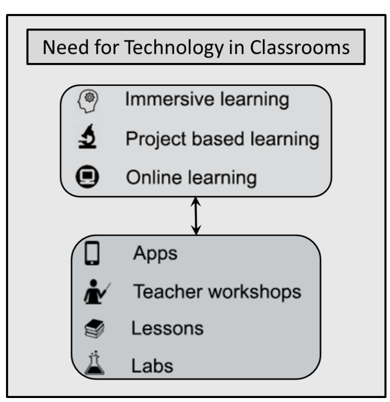


Fig. 1: Need for technology in classrooms.

Smartphones and tablets usually have large memory, high processing power and several on-board sensors [15], leading to the development of a variety of apps that can augment classroom education. In the systems area of electrical engineering, these include mobile versions of established desktop programs [16]–[20]. In our work, we develop apps, hold teacher workshops, and combine lessons and labs into eModules. In this paper, we show the effectiveness of our approach through the Reflections Android app at the K-12 and undergraduate levels for teaching concepts as varied as fundamental concepts in mathematics and physics to advanced concepts in signal processing and machine learning.

In this paper, we present the Reflections app, an example of an eModule in STEM education [21]. The Reflections app is an Android implementation of echolocation, and consists of notes, videos, quizzes, and demonstrations [22]. These components are discussed further in Section IV.

We investigate the effectiveness of this app as a teaching tool. At the undergraduate level, we further investigate how comfortable students are with using the app. At the K-12 level, we investigate the comfort-level of teachers in using the app and technology in their classrooms.

The contributions of our work are:

- We introduce the Android-based Reflections app. The app combines lecture notes, video content, exercises, and discussion questions, with hands-on activities that implement echolocation.
- We introduce the concept of an eModule, which can be used to incorporate lab activities into regular class activities.
- We demonstrate the effectiveness of the app as a teaching tool. The app and our approach were assessed via workshops held for students and K-12 teachers. The feedback from the users has been positive, with results indicating that the app improves student engagement and student learning.

The rest of this paper is organized as follows. Section III describes the concept of echolocation and provides a description of the app, and how the app can be used for ranging. The main components of the eModule, including notes, videos, and quizzes, are described in Section IV. The educational utility eModules generally, and the Reflections app in particular, at K-12 and undergraduate levels is demonstrated in Section V. We describe workshops conducted and assessment results obtained from those workshops. Finally, in Section VI, concluding remarks and future directions are presented.

II. Need for Mobile Apps in Education

International comparisons show that less than 1/3 of our 8th graders are proficient in math and science [23]. This achievement gap not only restricts our students from going into STEM or STEM-related professions but also robs our country of homegrown talent and perspectives. Much of the current literature supports mobile learning in the classroom as it has positive correlations with student engagement and is shown to be an effective use of technology [24]–[26]. The use of mobile apps in K-12 education has started to increase. However, many times, the apps are developed to cover content instead of scientific practice or investigation. This limits the function of these apps to an extension of existing classroom teaching. In order to be effective, the pedagogical portion of teaching must be incorporated into technology to maximize the learning potential for students.

While this may be beneficial, many teachers can only survey available technology by reading reviews. Instead, a more empowering and advantageous method is to directly involve the teachers in developing technology for their classrooms and lesson plans [27]. While the teachers know their class and curriculum best, many do not have experience with advanced science and engineering practices, programming, or coding.

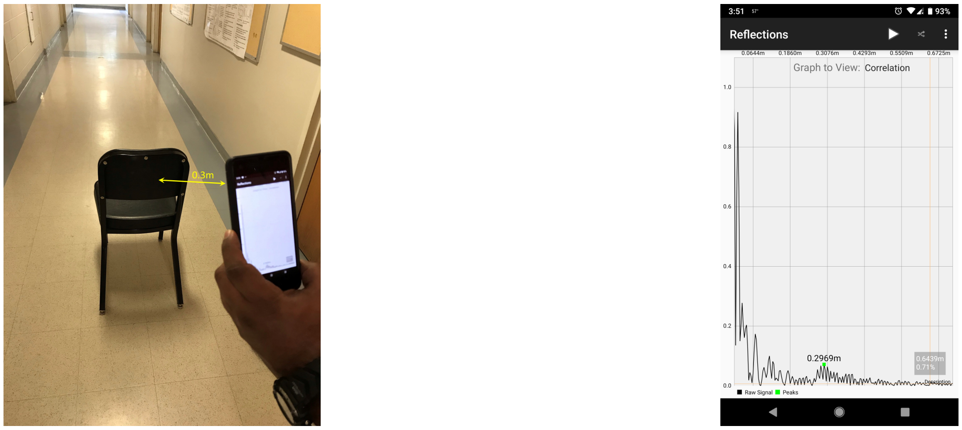
One solution to increase access to more students is via the use of technology and using immersive and innovative teaching methods [28]–[31] (see Figure 1). Studies have also shown that using handheld mobile devices in science can help promote scientific skills such as a graphing, interpreting data, making observations, and simulating data collection in the field. Students who are able to use these skills on their own are more engaged in their learning [32]. Students who are engaged in learning by simulation also showed a better understanding of content and their learning gains were positively impacted [33]–[35].

Based on the need for mobile apps for education, we present in this paper, our work based on the Android-based Reflections app, which integrates lecture notes, video content, exercises, and hands-on activities. These components combined together form an eModule, which can be used to incorporate lab activities into regular class activities. The effectiveness of the app as a teaching tool was assessed via workshops held for students and K-12 teachers. The feedback from the users has been positive, with results indicating that the app improves student engagement and student learning.

III. The Reflections App

"Reflections" is an Android app that utilizes audio signals in order to perform ranging and echolocation. Several copies of an audible signal generated in the Reflections app return after striking objects in the environment. The round-trip time for the signal to travel to an object and reflect back is measured [36] and used to estimate distances to the objects the copies were reflected from. See Figure 2 for an illustration of the app being used to detect objects, and a plot of the cross-correlation return shown in the app.

In this section, the concept of echolocation is introduced, followed by a description of how echolocation is implemented in the Reflections app.



(a) The speaker and microphone of the cell phone are pointed towards an object 0.3m away.

(b) Graph shows the return, an object detected at approximately 0.2969m.

Fig. 2: The “Reflections” app being used to estimate the distance to a chair.

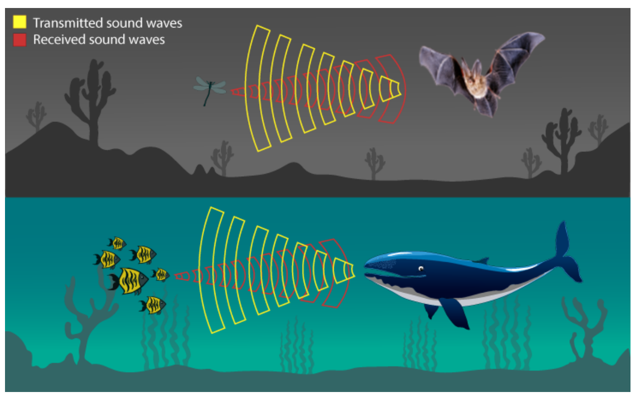


Fig. 3: Graphical representation of echolocation.

A. Echolocation

In echolocation, a sound signal is generated and transmitted. The sound signal reflects off objects in the operating environment and returns, and the round-trip time taken is used to estimate the distance to these objects (see Figure 3). Echolocation is used for ranging by a wide variety of animals including bats and dolphins.

In what follows, a simple mathematical model of echolocation is presented. Let the transmitted signal be given by $x(t)$. After reflection and propagation, the received signal, $y(t)$, can be modeled as a scaled and noisy version of the transmitted signal, $x(t)$, *i.e.*,

$$y(t) = \alpha x(t - t_0) + n(t), \tag{1}$$

where the scaling factor, α, is modeled as a random variable whose distribution is dependent on the environment [36], the additive noise, $n(t)$, is modeled as a Gaussian random variable, independent of α, and the time delay, t_0, is the round-trip time of the signal.

At the receiver, the correlation between the transmitted signal and the received signal is calculated as

$$r_{xy}(\tau) = \int_{-\infty}^{\infty} x(t)y(t+\tau)dt. \tag{2}$$

The cross-correlation signal, $r_{xy}(\tau)$, has a peak at $\tau = t_0$, indicating that the round-trip time to the object is t_0. The distance to the object can then be calculated as

$$\hat{d} = \frac{ct_0}{2}, \tag{3}$$

where c is the velocity of propagation of sound.

B. Using the Reflections app

The Reflections app implements echolocation on an Android platform. Using a dialog (see Figure 4), a user-defined signal is configured and generated. Users can configure different signal characteristics such as signal types, signal lengths, signal

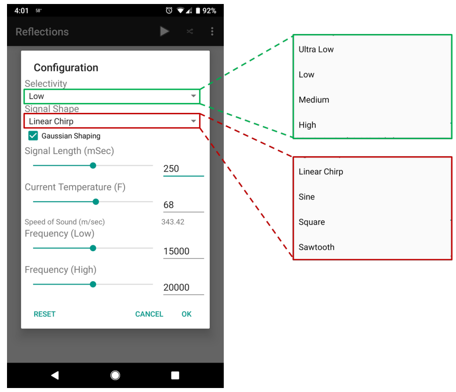
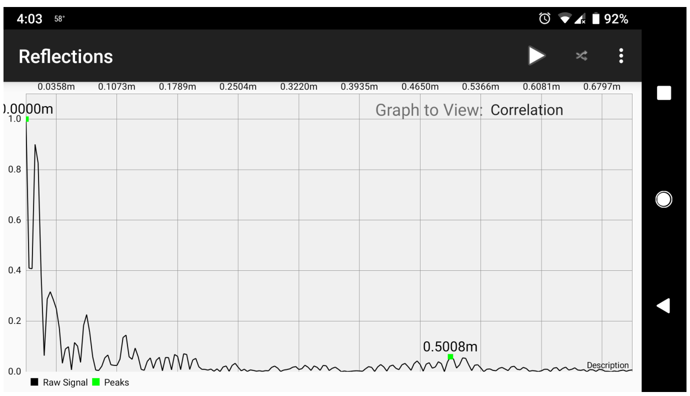
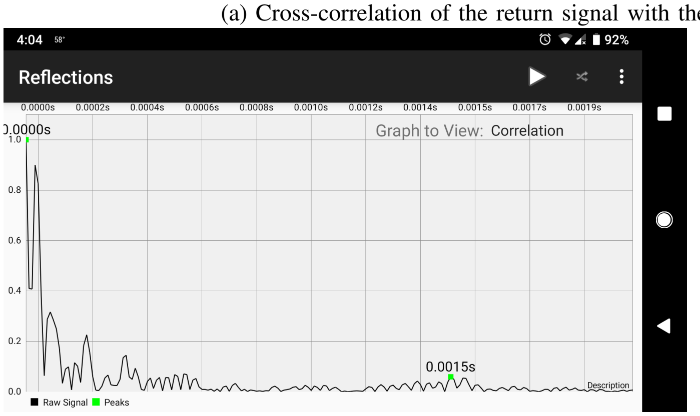


Fig. 4: Configuration window in the Reflections app (left) showing parameters that can be adjusted by users; options to select signal shapes (right).



(a) Cross-correlation of the return signal with the distance to the detected object shown.



(b) Cross-correlation of the return signal with one-way propagation time (half of the round-trip time) shown.

Fig. 5: An object was present at approximately half a meter from the Android device. The cross correlation between the transmitted and received signal is shown. Notice the peak corresponding to the distance.

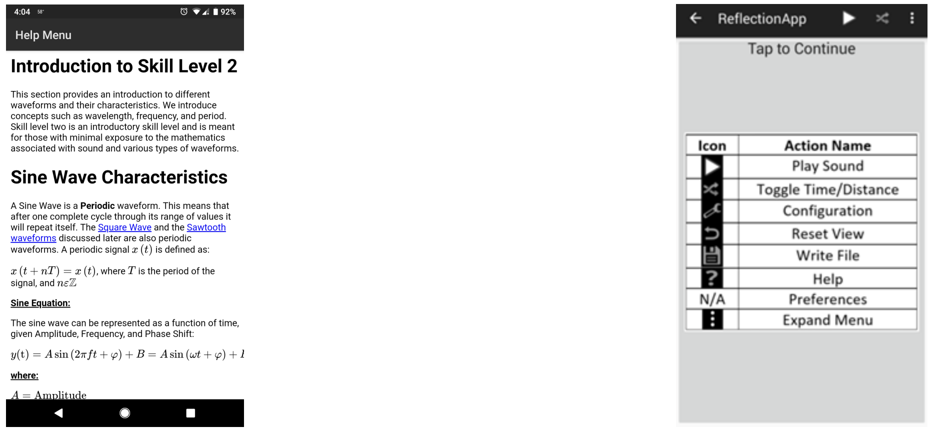
shaping, and where applicable, start and end frequencies. The selectivity of the peak detection algorithm can also be selected from this interface.

This generated signal is then transmitted from the speaker of the Android device as audio, and several copies return after striking objects in the environment. Using the original signals and the returns, the cross-correlation in (2) is calculated. However, since the data is discrete and has a finite number of samples, the correlation is performed using a summation rather than an integral as follows:

$$\hat{r}_{xy}(m) = \sum_{n} \hat{x}(n)\hat{y}(n+m), \tag{4}$$

where $\hat{x}(n)$ and $\hat{y}(n)$ are discretized versions of the transmitted and received signals, $x(t)$ and $y(t)$, respectively.

To allow fast computation of the cross-correlation, the fast Fourier transform (FFT) is utilized [22], [36]. Round-trip time and distance to the objects can be estimated using (3) and (4).



(a) An example of the notes embedded in the app. (b) The features of the app are shown in a quick start guide.

Fig. 6: A quick start guide and notes are available to users of the Reflection app.

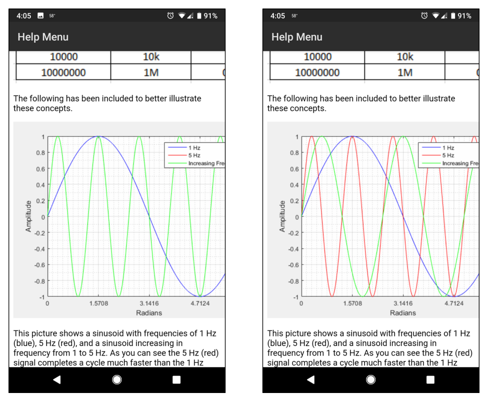


Fig. 7: Videos are embedded in the Reflections app in two ways. Some help students learn content by relating them to popular topics. Others videos like those above provide demonstrations of the features of the Reflections app. The figures above show two frames from a video illustrating sinusoids and the concept of frequency.

These distance estimates are presented to the user as a plot on a cross-correlation graph. By pushing the interleaved arrows button, one-way travel times of the signal are shown on the cross-correlation plot. All the peaks in the cross-correlation of the return signal are identified and marked on the cross-correlation plot using a peak-detection algorithm. These peaks can be labeled either with the round-trip time in seconds, or the distance in meters to the object causing the reflection. An example of the resulting plot with a distance estimate is shown in Figure 5, where an object is detected half a meter from the smartphone. The distance measurements are shown in Figure 5a, and the cross-correlation plot is labelled with one-way trip times in Figure 5b.

A cursor to provide details on points of interest on the cross-correlation signal has been implemented. Other features include pan and zoom.

IV. Components of an eModule

The Reflections app contains several modules that distinguish it from other demonstration apps. Here, the companion tools embedded in the Android eModule app to assist in STEM education are described.

A. Supporting Notes, Exercises, and Quizzes

One of the main components of the eModule is the embedded notes that can be accessed on the app itself or from the companion website [21]. These notes provide educational content suitable for several educational levels (see 6 for an example). Practice problems are provided, along with quizzes at each skill level. Each quiz, upon completion, gives the user the correct answers, as well as explanations for all answers. The quiz interface points to appropriate locations in the notes for further study.

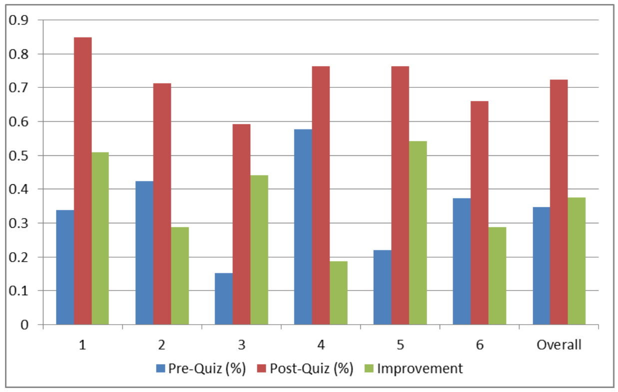


Fig. 8: Results of the pre-quiz and post-quiz. Overall, students are able to answer >72% of the questions correctly after the workshop activities, compared to only 34% before the activities.

B. Companion Videos

In order to better demonstrate concepts to students, videos are used. The videos are embedded in the app, and are also available on YouTube and the companion website [21]. The videos serve two purposes:

(a) **Description of concepts** including publicly available videos and lecture videos that complement the app.
(b) **Demonstrations** of how the app can be used for teaching specific lessons, and serve as an aid to teachers to help guide their lesson plans (see Figure 7).

V. Use in Classrooms

The Reflections app can be used in classrooms at multiple levels. In what follows, we describe its use in undergraduate classrooms for both signal processing and machine learning applications. We also discuss possible uses in middle school and high school classes.

A. At the Undergraduate Level

Workshops were conducted in a junior-level signals and systems class, and in a senior level signal processing class to evaluate the effectiveness of the app in demonstrating concepts in signal processing. These workshops were scheduled to be ninety minutes each. This time included administering a pre-quiz, providing the students a brief overview of the activities, time for hands-on activities, and the post-quiz. Overall, the students had over an hour for the hands-on activities, and found that to be sufficient to carry out all workshop activities.

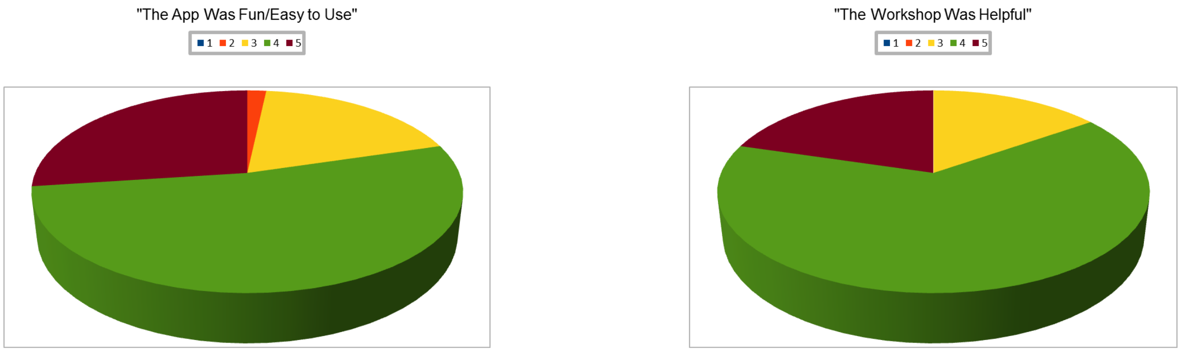
1) Demonstrating Signal Processing Concepts: A workshop was conducted at Clarkson University's junior-level Systems and Signal Processing class. The total number of students who participated in the workshops was 67. The benefits of using the app for teaching concepts was measured using pre/post quizzes. Specific concepts covered were:

1) Autocorrelation;
2) Round-trip time;
3) Distance Estimate;
4) Correlation;
5) Symmetry of the autocorrelation; and
6) Noise effects.

After the pre-quiz, a short lecture was presented to the students describing how to use the app. Students were then asked to perform a series of hands-on activities. These allowed the students to, in sequence, familiarize themselves with the app, verify the effectiveness of ranging using the app, and connect the steps in echolocation to abstract concepts covered in class prior to that point. Additionally, students also experimented with changing signal types, signal duration, signal shapes, and other signal parameters.

After the hands-on exercises, in order to assess the effectiveness of the workshop and the Reflections app, a post-quiz was administered to the students. Finally, as survey was given in order to obtain student experience with the app.

By looking at the results, it is clear that (see Figure 8) students are able to learn concepts including what signals help with better correlation results; the role of correlation in ranging; and several other areas of interest, such as the effect of noise on signal processing algorithms. A statistical analysis was performed on the results. Using a two sample t-test [37], we obtained a p-value of 6.1×10^{-5}, indicating that the null hypothesis was rejected, and confirming the alternate hypothesis that students did show improvement. Furthermore, as shown in Figure 9, most students agreed that "The app was fun to use"; "The exercises were helpful"; and "The workshop was helpful".



(a) How students responded to the statement "The app was fun/easy to use".

(b) How students felt about the statement: "The workshop was helpful".

Fig. 9: Student were asked about the ease of use of the app and helpfulness of the workshop to learn concepts. Their responses were recorded on a 1-5 scale with 1 being the lowest and 5 the highest.

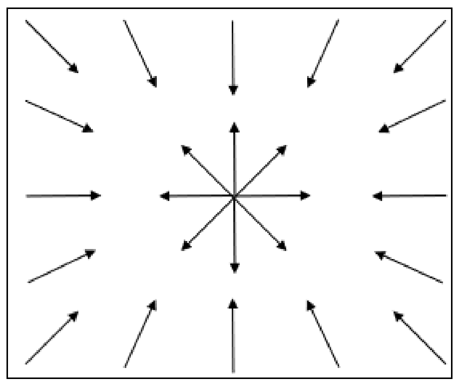


Fig. 10: Room classification using the Reflections app is used as a machine learning application. Several readings are taken in each room. Some readings are taken from the center of the room pointing out and others are taken pointing to the center of the room from the edges of the room.

2) Demonstrating Machine Learning Concepts: With the increasing impact of machine learning and artificial intelligence (AI) on society [38], and the increased awareness of these topics among students [39], there is a growing need to teach these concepts at the undergraduate level. However, the methods used to teach these concepts need to be appropriate to the level of understanding of the students.

To accomplish this task, we use one of the applications of the Reflections app, which is learn how to make the best use of a given space [40] by characterizing its acoustic properties. Since the Reflections app reacts to the objects in the environment, the app is ideally suited for the space characterization task.

Audio cross-correlation data obtained from the app can be fed into a machine learning algorithm that then determines the best use of the space. Concepts that can be reinforced include machine learning in signal processing, feature identification and extraction, and decision making in artificial intelligence (AI).

A workshop was conducted at Clarkson University. Students from two-classes participated: a senior-level Digital Signal Processing class and a senior-level Signal Processing and Applications course at Clarkson University, specifically designed for students not in the Electrical Engineering major [41]. Students in this course included a mix of Computer Engineering majors, Software Engineering majors, and Mechanical Engineering majors. The total number of students who participated in the workshops was 32.

A pre-quiz covering the basics of machine learning was administered, followed by a brief introduction to concepts, as well as hands-on activities. The hands-on activities included room classification using data collected from the Reflections app.

Audio signals from the Reflections app were transmitted into the center of a room, as well as from the center of a room as shown in Figure 10. The acoustical profiles of each room were estimated using the Reflections app and collecting cross-correlation data from different points in the room.

With this data, students were given two tasks: feature selection and classification. For classification, students were introduced to several algorithms including support vector machines (SVM), k-nearest neighbors (kNN), and random forests. Students were

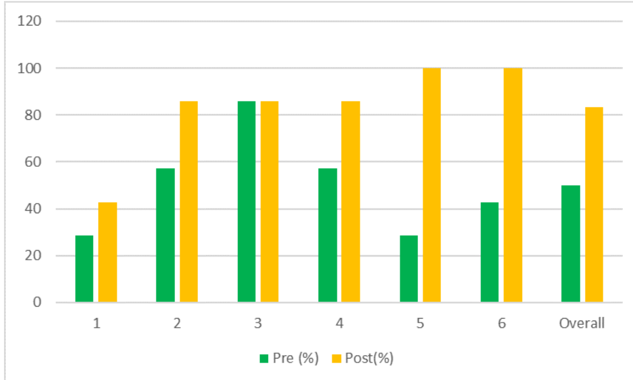


Fig. 11: Pre/post-quiz. Results have improved after the students have been exposed to machine learning concepts and hands-on activities using the Reflections app. Overall, students are able to answer >83% of the questions correctly after the activities, compared to only 50% before the activities.

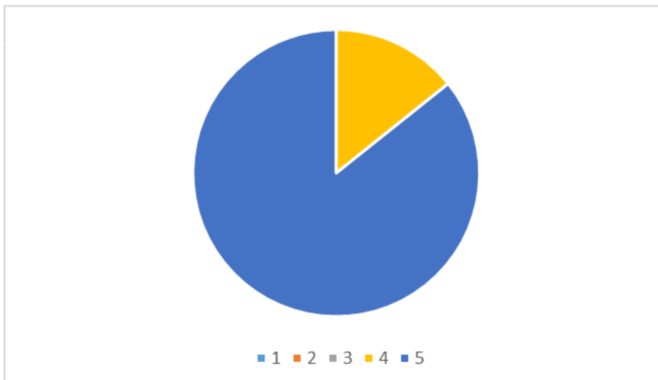


Fig. 12: Response to the question: "This workshop was helpful and informative." The response was collected on a one to five Likert-type scale with 1 indicating "Not helpful or informative at all", and 5 indicating "Very helpful and informative". All students found the hands-on activities helpful and informative.

asked to investigate two types of feature selection: intuitive features such as peak distances, the distance between peaks, etc.; and features extracted using energy methods such as principal component analysis (PCA). Using a combination of extracted features, students were asked to evaluate each classification algorithm for room classification.

In a post-quiz and survey, the students were retested on the same topics as the pre-quiz and were asked questions to determine if the students found the hands-on activities helpful in understanding machine learning concepts. Specific topics covered in each question that was asked in the pre-/post-quiz are:

1) Comparison between kNN and SVM
2) Properties of a kernel SVM classifier
3) Cross-validation
4) Supervised machine learning
5) Random forests
6) Principal component analysis (PCA)

The survey question asked was "This workshop was helpful and informative." The answer was collected using a one to five Likert-type scale, where 1 indicated "Not at all helpful", and 5 indicated "Very helpful".

The results of the pre/post quiz are shown in Figure 11, and the results of the survey question are shown in Figure 12. Students were able to show improvement in understanding of machine learning concepts as can be seen from the results of the pre/post quiz. A statistical analysis was performed on the results. Using a two sample t-test, we obtained a p-value of 0.005, rejecting the null hypothesis, and confirming the alternate hypothesis that students showed improvement. The students also found the workshop to be helpful in getting acquainted with machine learning concepts.

B. At the K-12 Level

Our focus in this work is the "science and engineering practices" module of the Next Generation Science Standards (NGSS). We design our lessons to help teachers and students apply these engineering practices in their lessons. Using this technology and building them into lesson plans help us address the science and engineering practices as identified by NGSS [42].

We use the Reflections eModule app in consultation with middle school and high school teachers. We work with teachers to develop lesson plans that align with topics already being covered in class. By using the eModule, the teachers are able to seamlessly integrate science and engineering practices into their existing lesson plans.

A workshop was held at Clarkson University in December 2018, as part of the Master Teacher "Teacher to Teacher" Conference. The participants were K-12 teachers who have been selected to be Master Teachers [43] in both physical sciences and life sciences. Participating in the workshop were 12 New York State master teachers. In the workshop, a lesson plan was developed based on the Reflections app that covered multiple topics in physical and life sciences. The format of the lesson plan is based on the Masters of Arts in Teaching (MAT) lesson template developed at the Clarkson University Department of Education [44]. The lesson plan is shown in Figure 13.

Prior to the start of the workshop, the teachers were asked two questions:

(a) "How comfortable are you using technology in your classroom?" (One to five Likert-type scale)
(b) "Do you think using technology in your classroom will help increase student engagement?" (Yes or no question)

The responses to these questions are shown in Figure 14. We can conclude that while a significant portion of the participants was hesitant in using technology in their classrooms, they all believe that using technology in classrooms will improve student engagement.

At the end of the workshop, we asked the teachers the following questions:

(a) "Has this workshop improved your understanding of science and engineering practices?" (Yes or no question)
(b) "How willing are you to use technology in your classrooms?" (One to five Likert-type scale)

The responses to these questions are shown in Figure 15. It is clear from these responses that being exposed to a simple methodology to incorporate science and engineering practices into lessons, with the help of the Reflections app, allows teachers to think more positively about science and engineering practices, and to include them in their lessons.

VI. Conclusions

In this paper, we introduced the Android-based Reflections app. The app is an audio-based echolocation implementation, combined with lecture notes, video content, exercises, and discussion questions form an eModule. The app and the eModule enable lab integration and implementation of engineering methods across the educational spectrum from K-12 to undergraduate engineering. With the help of workshops, where participants were given pre/post assessments and survey questions, the effectiveness of the app as a teaching tool has been verified. We can see from the results that our approach provides information to students in a way that encourages learning, and students feel like they are participating in the activities, rather than being passive learners. Furthermore, the feedback from the users has been positive, with most users agreeing that the app improves student engagement and student learning.

A. Interdisciplinary extensions

The Reflections app has been designed as an app for implementing echolocation. As such, it has been used to teach concepts in sound propagation, waveform shapes, correlation, and machine learning. By extending the applications that the app can be used for, the number of concepts that can be covered increases as well.

For example, the echolocation app can be used to distinguish between the physical characteristics of different objects based on the signature of the reflected sound. A hard object would have a different signature, compared to a soft object. Different types of material can then be distinguished from each other using a classifier. Topics that be covered using this approach include classification, feature extraction, and signature detection.

B. Future Directions

In this paper, we presented one way of introducing machine learning content to students: via stand-alone workshops. Another approach is by integrating content into the curriculum of a course. The effectiveness of this method will be investigated by the authors in future work. As part of these assessments, we will include a control group to better highlight the effectiveness of our approach. With regard to the K-12 aspect, we will also contact the teachers from the Master Teacher workshop in order to see if they are using the science and engineering practices discussed in the workshop. We will elicit information about the methods they are using as well as the tools they are using.

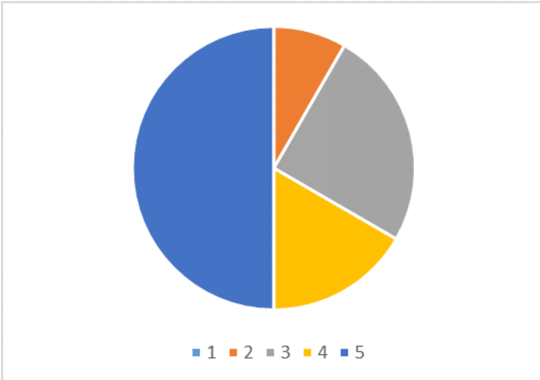
Currently, the Reflections app is a stand-alone app, and students can work together to facilitate group work. For future online classes and remote reaching applications, the users of the app need the capability to collaborate in a networked environment. One avenue of future work is to incorporate a built-in collaboration environment that enables screen-sharing, data-sharing, and a chat interface.

Possible future extensions to the project include the development of new eModules. Possible areas of interest include concepts and applications that have relevance to technology that students regularly use. Examples include localization (GPS and similar applications), speech processing (motivated by phone calls), and data communications and data protection (cybersecurity).

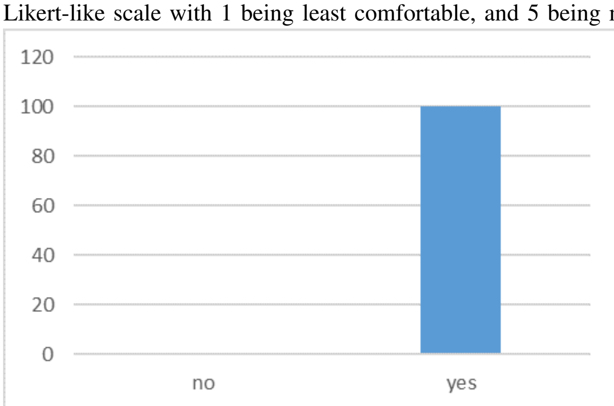
These extensions will allow this app and future eModules to reach a wider audience of educators and students.

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 a wall. 3. Use default app settings; point the device at the wall and run the experiment. 4. Change sound to bat chirp and dolphin clicks and redo the 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 the 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—the teacher will walk around the room and ask questions, make observations, read exit tickets, listen to answers from the 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.	

Fig. 13: Sample lesson on echolocation.



(a) Response to the question: “How comfortable are you using technology in your classroom?” The responses were recorded on a Likert-like scale with 1 being least comfortable, and 5 being most comfortable.



(b) Response to the question: “Do you think using technology in your classroom will help increase student engagement?”.

Fig. 14: While a significant portion of the participants is not comfortable with using technology in classrooms, all respondents believe that using technology in classrooms will improve student engagement.

References

[1] T. H. DePue, B. Robistow, R. Newman, K. Mack, M. K. Banavar, T. Yang, D. Barry, P. Curtis, A. Spanias, and W. Watkins, “An android app for spatial acoustic analysis as a learning tool,” in *2016 IEEE Frontiers in Education Conference (FIE)*, October 2016.

[2] B. Robistow, R. Newman, T. H. DePue, M. K. Banavar, D. Barry, P. Curtis, and A. Spanias, “Reflections: An emodule for echolocation education,” in *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, March 2017, pp. 1562–1566.

[3] M. K. Banavar, H. Gan, B. Robistow, and A. Spanias, “Signal processing and machine learning concepts using the reflections echolocation app,” in *2017 IEEE Frontiers in Education Conference (FIE)*, October 2017.

[4] S. Rivera, M. K. Banavar, and D. Barry, “Mobile apps for incorporating science and engineering practices in k-12 stem labs,” in *2018 IEEE Frontiers in Education Conference (FIE)*, October 2018.

[5] D. M. West, “Connected learning: How mobile technology can improve education,” *Center for Technology Innovation at Brookings*, 2015.

[6] E. Tekinarslan, “Reflections on effects of blogging on students’ achievement and knowledge acquisition in issues of instructional technology,” *International Journal of Instructional Technology and Distance Learning*, vol. 7, no. 11, November 2010.

[7] E. Solak and R. Cakir, “Face to face or e-learning in turkish efl context,” *Turkish Online Journal of Distance Education*, vol. 15, no. 3, pp. 37–49, July 2014.

[8] F. Khaddage, W. Müller, and K. Flintoff, “Advancing mobile learning in formal and informal settings via mobile app technology: Where to from here, and how?” *Journal of Educational Technology & Society*, vol. 19, no. 3, pp. 16–26, 2016.

[9] J. Eppard, O. Nasser, and P. Reddy, “The next generation of technology: Mobile apps in the english language classroom,” *International Journal of Emerging Technologies in Learning (iJET)*, vol. 11, no. 04, pp. 21–27, 2016.

[10] Y.-T. Sung, K.-E. Chang, and T.-C. Liu, “The effects of integrating mobile devices with teaching and learning on students’ learning performance: A meta-analysis and research synthesis,” *Computers & Education*, vol. 94, pp. 252 – 275, 2016.

[11] L. Naismith, M. Sharples, G. Vavoula, and P. Lonsdale, “Literature review in mobile technologies and learning,” *futurelab*, vol. 11, 2004.

[12] J. Roschelle, M. Sharples, and T. W. Chan, “Introduction to the special issue on wireless and mobile technologies in education,” *Journal of Computer Assisted Learning*, vol. 21, no. 3, pp. 159–161, 2005.

[13] E. Hargittai and A. Marwick, ““what can i really do?” explaining the privacy paradox with online apathy,” *International Journal of Communication*, vol. 10, no. 0, 2016.

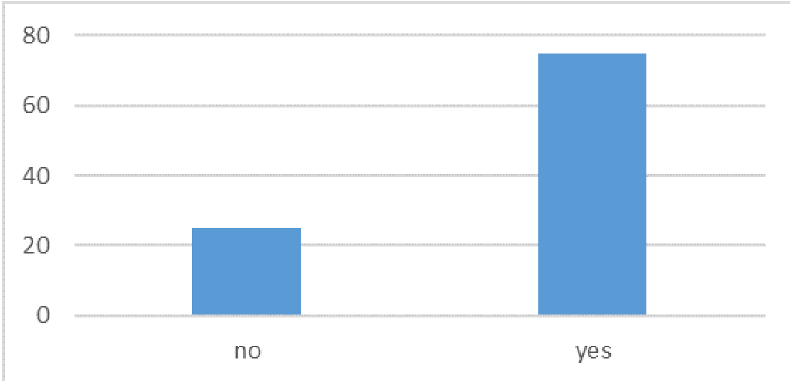
[14] P. Thompson, “The digital natives as learners: Technology use patterns and approaches to learning,” *Computers & Education*, vol. 65, pp. 12 – 33, 2013.

[15] N. D. Lane, E. Miluzzo, H. Lu, D. Peebles, T. Choudhury, and A. T. Campbell, “A survey of mobile phone sensing,” *IEEE Communications Magazine*, vol. 48, no. 9, pp. 140–150, September 2010.

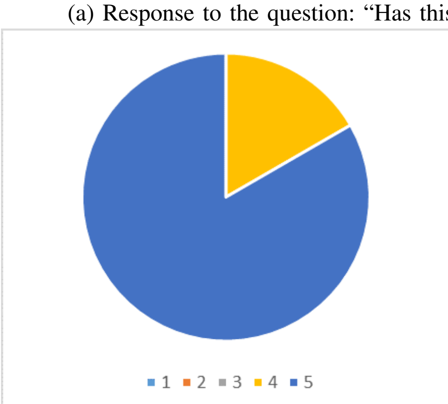
[16] National Instruments, “NI LabVIEW mobile module,” Online: http://sine.ni.com/nips/cds/view/p/lang/en/nid/12222, last Accessed March 2020.

[17] S. Ranganath, J. J. Thiagarajan, D. Rajan, M. K. Banavar, A. Spanias, J. Fan, K. Jaskie, and C. Tepedelenlioglu, “Interactive signal processing education applications for the android platform,” *Computers in Education Journal*, vol. 10, no. 2, January 2019.

[18] Octave, “Octave app,” Online: https://play.google.com/store/apps/details?id=com.gnuroot.octave, last Accessed March 2020.



(a) Response to the question: “Has this workshop improved your understanding of science and engineering practices?”



(b) Response to the question: “How willing are you to use technology in your classrooms?” The responses were recorded on a Likert-like scale with 1 being least willing, and 5 being most willing.

Fig. 15: After the workshop, teachers exposed to the Reflections app and the ease with which it can be used as a tool for including science and engineering practices, are willing to use more technology in their classrooms. They also have an improved understanding of science and engineering practices.

[19] Wolfram, “Mobile and tablet apps,” Wolfram—Alpha APIs: Computational Knowledge Integration. Online: http://products.wolframalpha.com/mobile, last Accessed March 2020.
[20] Mathworks, “MATLAB Mobile,” Online: http://www.mathworks.com/products/matlab-mobile, last Accessed March 2020.
[21] CoSiNe Lab, “Reflections App,” Online: http://cosine.clarkson.edu/Reflections/index.html, last Accessed March 2020.
[22] P. Curtis, M. K. Banavar, X. Zhang, A. Spanias, and V. Weber, “Signals and systems demonstrations for undergraduates using android-based localization,” in *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, October 2014.
[23] S. Olson and D. G. Riordan, “Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. report to the president,” *Executive Office of the President*, February 2012.
[24] P.-S. D. Chen, A. D. Lambert, and K. R. Guidry, “Engaging online learners: The impact of web-based learning technology on college student engagement,” *Computers & Education*, vol. 54, no. 4, pp. 1222 – 1232, 2010.
[25] E. Khoo, G. Falloon, and N. Nguyen, “ipad mediated talk in young children’s learning and exploration of interests,” in *There and back again : charting flexible pathways in open, mobile and distance education*, N. Wright, Ed. Distance Education Association of New Zealand, 2016, pp. 163–167.
[26] M. G. Domingo and A. B. Garganté, “Exploring the use of educational technology in primary education: Teachers’ perception of mobile technology learning impacts and applications’ use in the classroom,” *Computers in Human Behavior*, vol. 56, pp. 21–28, 2016.
[27] S. Price, P. Davies, W. Farr, C. Jewitt, G. Roussos, and G. Sin, “Fostering geospatial thinking in science education through a customisable smartphone application,” *British Journal of Educational Technology*, vol. 45, no. 1, pp. 160–170, 2014.
[28] J. S. Krajcik, P. C. Blumenfeld, R. W. Marx, and E. Soloway, “A collaborative model for helping middle grade science teachers learn project-based instruction,” *The Elementary School Journal*, vol. 94, no. 5, pp. 483–497, 1994.
[29] S. J. Lynch, *Equity and Science Education Reform*. Taylor & Francis, 2000.
[30] M. M. Atwater, “Equity for black americans in precollege science,” *Science Education*, vol. 84, no. 2, pp. 154–179, 2000.
[31] L. Johnson, S. Adams, and M. Cummins, “Mobile apps: The nmc horizon report: 2012 higher education edition,” The New Media Consortium, Tech. Rep., 2012.
[32] S. J. Melcalf and R. F. Tinker, “Probeware and handhelds in elementary and middle school science,” *Journal of Science Education and Technology*, vol. 13, pp. 43–49, 2004.
[33] A. Jimoyiannis and V. Komis, “Computer simulations in physics teaching and learning: a case study on students’ understanding of trajectory motion,” *Computers & Education*, vol. 36, no. 2, pp. 183 – 204, 2001.
[34] S. A. Barab, B. Scott, S. Siyahhan, R. Goldstone, A. Ingram-Goble, S. J. Zuiker, and S. Warren, “Transformational play as a curricular scaffold: Using videogames to support science education,” *Journal of Science Education and Technology*, vol. 18, no. 4, pp. 305 – 320, 2009.
[35] Özlem Koray and A. Koray, “The effectiveness of problem-based learning supported with computer simulations on reasoning ability,” *Procedia - Social and Behavioral Sciences*, vol. 106, pp. 2746 – 2755, 2013, 4th International Conference on New Horizons in Education.
[36] A. S. Spanias, *Digital Signal Processing: An Interactive Approach*, 2nd ed. LL Press, 2014.
[37] A. J. Hayter, *Probability and Statistics for Engineers and Scientists 4th Edition*, 4th ed. Cengage Learning, 2012.

[38] U. S. Shanthamallu, A. Spanias, C. Tepedelenlioglu, and M. Stanley, "A brief survey of machine learning methods and their sensor and iot applications," in *2017 8th International Conference on Information, Intelligence, Systems Applications (IISA)*, 2017, pp. 1–8.
[39] U. S. Shanthamallu, S. Rao, A. Dixit, V. S. Narayanaswamy, J. Fan, and A. Spanias, "Introducing machine learning in undergraduate dsp classes," in *ICASSP 2019 - 2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2019, pp. 7655–7659.
[40] W. Watkins, M. K. Banavar, P. D. Curtis, and A. Spanias, "An android app for evaluating acoustic properties of library spaces," *Access YYZ Conference*, 2015.
[41] A. Spanias, P. Curtis, P. Spanias, and M. K. Banavar, "A new signal processing course for digital culture," in *2015 IEEE Frontiers in Education Conference (FIE)*, October 2015.
[42] NSTA, "Science and engineering practices," Online: https://ngss.nsta.org/PracticesFull.aspx, last Accessed March 2020.
[43] Binghamton University - SUNY, "New york state master teacher program," Online: https://www.suny.edu/masterteacher, last Accessed March 2020.
[44] Clarkson University, "Clarkson University Graduate School," Online: http://graduate.clarkson.edu/program/masters-arts-teaching/, last Accessed March 2020.

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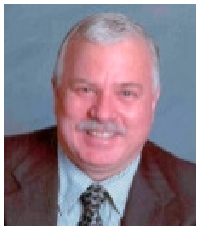

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