ASEE'S VIRTUAL CONFERENCE
At Home with Engineering Education
JUNE 22 - 26, 2020 #ASEEVC
Paper ID #30260

Evaluation: A Teacher Professional Development Program Using Wireless Communications and NGSS to Enhance STEM Teaching & Learning

Mr. Panagiotis Skrimponis, NYU Tandon School of Engineering

Panagiotis is a Ph.D. student in Electrical and Computer Engineering at New York University, and a member of NYU Wireless, advised by Professor Sundeep Rangan. He previously earned his Diploma and MSc in Electrical and Computer Engineering from University of Thessaly in 2015 and 2018 respectively. From 2013-2018 he worked at Center for Research and Technology Hellas, Swiss Federal Institute of Lausanne, and New York University as a research assistant. His research interests include designing specialized hardware to accelerate applications on advanced FPGA platforms, developing network and communication algorithms on modern USRP/SDR platforms and prototyping ultra-low power nodes for IoT applications. Currently his main focus is on power consumption and performance optimizations for mmWave and THz communications. As part of the 'COSMOS educational team', he designs exciting and interactive problem-based STEM learning experiences for K–12 students and teachers. The team organized a teacher professional development program, using wireless communications and NGSS to create hands-on engineering lessons and promote STEM. He was part of one of the ten winning teams in Verizon's '5G EdTech Challenge', contributing in the development of several educational virtual reality applications.

Dr. Nikos Makris, University of Thessaly

Nikos Makris is a Research Engineer working for University of Thessaly, Greece. He received his B. Eng. in 2011, his M. Sc. degree in Computer Science and Communications in 2013 and his PhD in Electrical and Computer Engineering in 2019 from the same department. Since 2011, he has been participating in several collaborative research projects with University of Thessaly. During the summers of 2018 and 2019, he was a visiting scientist in New York University (NYU) working in the outreach activities of the COSMOS project. His research interests include experimentally driven research with several radio access technologies (WiFi, WiMAX, LTE, 5G-NR), conducted under real environment settings, the disaggregation of base station units, Multi-access Edge Computing and NFV orchestration using open source platforms.

Dr. Karen Cheng, Columbia Engineering

Dr. Karen Cheng is an Outreach Program Specialist at Columbia University School of Engineering and Applied Science. A former research scientist turned high school math teacher, she recently completed her Ph.D. in mathematics and STEM teacher education, with research interests in the development of professional motivation and self-efficacy among K-12 STEM teachers in the framework of out-of-school enrichment programs. With the wireless communications research experience for teachers, she coordinated logistics during the summer and provided day-to-day curriculum development and implementation support for teacher participants throughout the year. Having extensive experience in working with both rural and urban education settings, her current responsibilities at Columbia's School of Engineering include building partnerships between educational institutions, industry partners, and community schools in an effort to create greater access to high-quality STEM education opportunities for all.

Dr. Jonatan Ostrometzky, Electrical Engineering, Columbia University

Jonatan Ostrometzky received his B.Sc. degree (Magna Cum Laude) in Electrical Engineering from Tel-Aviv University, Israel, in 2009. He received his M.Sc. degree in Electrical Engineering (through the Accelerated Master Program), and his Ph.D. from Tel-Aviv University in 2012 and 2017, respectively. He was a postdoctoral research scientist at Columbia University (supervised by Prof. Gil Zussman) between 2018 and 2020, where he led WiMNet lab's NSF-BSF project in the area of wireless networks robustness via weather-sensitive predictive management, and has performed research in the area of power grid resilience and worked on the COSMOS project. In particular, Jonathan focused on the COSMOS program for middle and high school teachers. Currently, Jonatan is a faculty member at the Faculty of Engineering, Tel-Aviv University.

Prof. Zoran Kostic, Electrical Engineering, Columbia University

Zoran Kostic completed his Ph.D. in Electrical Engineering at the University of Rochester and his Dipl. Ing. degree at the University of Novi Sad. He spent most of his career in industry where he worked in research, product development and in leadership positions.

Zoran's expertise spans mobile data systems, wireless communications, signal processing, multimedia, system-on-chip development and applications of parallel computing. His present research addresses Internet of Things systems and physical data analytics, smart cities, and applications of deep learning in autonomous vehicle navigation, medicine and health. His work comprises a mix of research, system architecture and software/hardware development, which resulted in a notable publication record, three dozen patents, and critical contributions to successful products. He has experience in Intellectual Property consulting.

Dr. Kostic is an active member of the IEEE, and he has served as an associate editor of the IEEE Transactions on Communications and IEEE Communications Letters.

Prof. Gil Zussman, Electrical Engineering, Columbia University

Gil Zussman received the Ph.D. degree in Electrical Engineering from the Technion in 2004. Between 2004 and 2007 he was a Postdoctoral Associate in MIT. Since 2007 he has been with Columbia University where he is a Professor of Electrical Engineering and Computer Science (affiliated faculty), and member of the Data Science Institute. He is a co-recipient of 7 paper awards including the ACM SIGMETRICS'06 Best Paper Award, the 2011 IEEE Communications Society Award for Advances in Communication, and the ACM CoNEXT'16 Best Paper Award. He received the Fulbright Fellowship, the DTRA Young Investigator Award, two Marie Curie Fellowships, and the NSF CAREER Award. He was a member of a team that won first place in the 2009 Vodafone Foundation Wireless Innovation Project competition and is currently the Columbia PI of the NSF PAWR COSMOS project.

Prof. Thanasis Korakis, NEW YORK UNIVERSITY

Thanasis Korakis received the B.S. and M.S. degrees in informatics and telecommunications from the University of Athens, Greece, in 1994 and 1997, respectively, and the Ph.D. degree in computer and communication engineering from the University of Thessaly, Greece, in 2005. He is a Research Assistant Professor with the ECE Department, NYU Tandon School of Engineering, NY, USA. He is also with the New York State Center for Advanced Technology in Telecommunications, NYU Tandon School of Engineering. In 2004, he was a Visiting Researcher with the CSE Department, University of California at Riverside, Riverside, CA, USA. He holds five patents. His research interests include access layer protocols, cooperative networks, directional antennas, quality of service provisioning, and network management.

Dr. Sheila Borges Rajguru, Rutgers - The State University of New Jersey

Sheila Borges Rajguru, a K-16+ educator and researcher, obtained a PhD degree from Teachers College, Columbia University in STEM education. Trained as a biomedical scientist at Rutgers University and NYU she leverages both fields of study —education and STEM— to build and maintain collaborations between institutions of higher education, K-12 schools, community leaders, and corporations in order to conduct multi and interdisciplinary work. Other areas of work include: collaborating with engineers and scientists to enhance STEM education, mentorship of early-career researchers, and identifying systems of inequities in order to come up with solutions for social change. Furthermore, Dr. Borges is co-chair of the Northeastern Association for Science Teacher Education (NE-ASTE) and currently works at Rutgers, The State University of New Jersey to enhance the grant portfolio of the School of Social Work.

Evaluation: A Teacher Professional Development Program Using Wireless Communications and NGSS to Enhance STEM Teaching & Learning

1. Introduction

The global economy is changing vis-à-vis technological advances. In order to keep with the needs of industry and the latest innovations, *all* students should have quality access to science, technology, engineering, and mathematics (STEM) precollege coursework in order to bridge the digital and equity divide. Higher education is critical in preparing the next generation of STEM professionals. However, when precollege students are unprepared to tackle the rigor and/or are alienated from STEM due to poor K–12 experiences, this lack of preparedness affects innovation. Therefore, supporting teachers through research experiences and collaborating with them to create authentic, hands-on lessons could have positive effects in STEM teaching and learning.

To address this challenge, we developed a teacher professional development (PD) program and a toolkit consisting of a hardware and software system to engage STEM teachers in learning about wireless technology through various hands-on activities and collaborative research. The PD program and the toolkit directly relate to the Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment (COSMOS) testbed [1, 2] that is being deployed in West Harlem (New York City) and to the NSF ERFI NewLAW project which focuses on wireless communication. The PD program took place in Summers 2018 and 2019 within the frameworks of Research Experience for Teachers (RET) and Research Experience and Mentoring (REM) programs. Throughout the PD program, researchers and educational experts assisted teachers in co-creating lessons aligned to the K–12 *Next Generation Science Standards (NGSS)* [3]. Each standard, called Performance Expectations (PE), incorporates 'three-dimensional learning' through: Crosscutting Concepts (CCCs), Disciplinary Core Ideas (DCIs), and Science and Engineering Practices (SEPs). This teacher PD consists of a six-week long summer program, which introduces ten participants, who teach in an urban setting, to authentic wireless technology engineering experiences, as well as ongoing support for the teachers throughout the academic year. In particular, the rationale for this program and the potential benefits for participating teachers arise from two main themes: both a theoretical perspective and an empirical, practice-focused perspective.

1.1. Theoretical perspective: From a theoretical lens, self-efficacy and leadership are greatly sparked through the opportunity for teachers to participate in an innovative professional development opportunity that empowers them to fully create unique STEM lessons through a wireless technology framework. By creating a problem- and inquiry-based environment for both teaching and learning, this type of co-constructed, collaborative learning directly creates exciting opportunities for both students and teachers alike to become empowered in their investments of learning. Teaching through this constructivist lens requires that teachers understand the interconnectedness of cognitive learning, content learning, and collaborative learning [4, 5]. By being active members of a community of invested researchers and devoted teachers, teachers that engage in such a professional development program can shift their levels of participation, becoming a master teacher and leader in such a community of practice [6 – 8].

As seen in the K–12 STEM Master Teachers conceptual framework from Hite and Milbourne [6], teachers shift their boundaries of identity between varying levels of expertise as they engage in professional development and other teaching, learning, and leadership experiences. By progressing through intensive summer professional development, teachers have the opportunity to undergo such a transformation in professional identity from being simply engaged participants to becoming expert, master teachers within their cohorts. It is the ongoing hope of such programs that these cohort teachers undertake such a transformation in self-efficacy such that they eventually become leaders within their schools such that they share and disseminate the valuable knowledge gained from their experiences in the program. This growth of self-efficacy and leadership among participating teachers that engage in such constructivist learning communities also has significant potential implications for student achievement and students' transfer of knowledge through such relatable, real-world contexts [9 – 11].

1.2. Empirical perspective: The valuable immersive experience gained through participating in such ongoing professional development programs also lends directly to practice within teachers' day-to-day classrooms. Through the development of hands-on and problem-based curricula, there are many opportunities for cross-disciplinary connections in each lesson, creating meaningful applications of context to STEM standards and topics. In order to do so successfully, the role of the teacher within the classroom shifts from being a traditional lecturer and 'sage on the stage' to that of being a facilitator 'guide on the side' during such learning experiences [12 – 15].

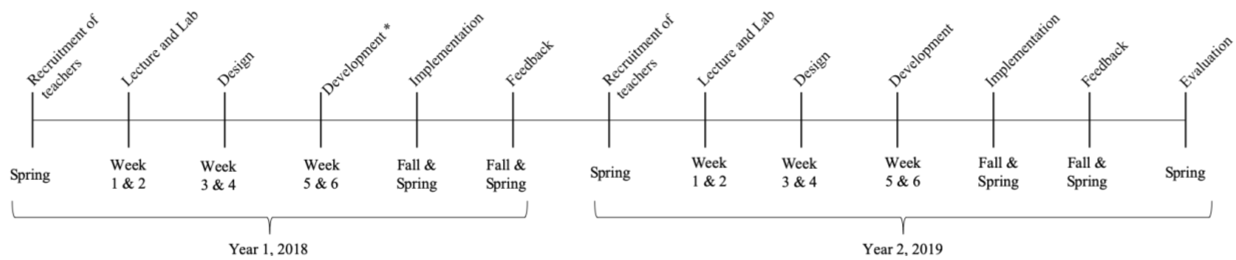

Figure 1: Teacher PD program phases timeline. *Phase when the 'COSMOS Educational Toolkit' was created.

Based on the above, a teacher PD was developed towards assisting teachers in developing NGSS course materials based on wireless networking concepts. The fundamental research question that this paper tries to address is *"How could engineers and educators collaborate to create a wireless communications teacher PD program in order to develop NGSS lessons with STEM teachers?"*. Towards strengthening the aforementioned pedagogical shift, an accompanying 'COSMOS Education Toolkit' [16] (described in detail in Section 3) has been developed, that allows to naturally integrate a real-world application of context within STEM subject areas while also demonstrating the importance of engineering and technology on communities and stakeholders [17 – 18].

2. Program Overview

The program aims to introduce new ways of teaching STEM concepts assisted through experimental research driven educational labs based on wireless technology. Every summer the project team invites over 400 local middle and high school teachers from New York City to apply for the program. Each year, 10 teachers are selected from a pool of applicants. A selection committee comprising of faculty, educational experts and experienced graduate students was created to review qualified participants. The selection is based on evaluating the application materials, which consist of a biographical note and resume, a personal essay which clearly states the motivation in the participation of the program, support and approval by the school principal, and recommendation letters. The details and the demographics of the participants are shown in Table A.1 and Table A.2 in Appendix – A.

The program is divided in five conceptual phases: (i) lecture and lab phase: the participants are introduced in fundamental and some advanced concepts in wireless communications and networking; (ii) design phase: the participants inspired by the first phase are called to research on potential educational NGSS STEM lessons with a hands-on wireless labs (activities) using components of the 'COSMOS Educational Toolkit'; (iii) development phase: the teachers co-develop with the researchers their best ideas on how to use the wireless labs for NGSS-aligned STEM lessons; (iv) implementation phase: teachers and students use the developed lessons in the class during the school year; (v) feedback phase: teachers provide feedback in order to improve the NGSS STEM lessons and develop new ones. Figure 1 illustrates the teacher PD program phases and timeline.

Figure 2: Participants attend an instructor-led lesson using the 'COSMOS Educational Toolkit' to perform the wireless activity associated with this lecture during the 'lecture and lab phase' of the program (left). Participants conduct independent research using sensors (right).

2.1. Lecture and lab phase: The first phase of the PD program, involves lectures and lab research experiments on wireless technology. The teachers are also guided through several orientation classes that introduces them to the research methodology. The lectures and the labs are separated in three major subsections: (i) wireless communications; (ii) computer networks; (iii) future trends and research facilities. These subsections have been carefully designed to aligned with their learning objectives of STEM teachers. The detailed description of the wireless technology lessons and labs are shown in Table B.1 in Appendix – B.

2.1.1. Wireless communications: The first section sets the foundations for the teachers, where they learn about the basics and more advanced details on the propagation of electromagnetic waves, interference and noise in a communication system, and digital signal processing techniques involved in communications. Some of the labs that are involved in this section are: (i) 'Ambient waves': the participants are called to use the 'COSMOS Educational Toolkit' and the lab equipment to detect ambient waves (i.e., radio FM stations, AM stations, aircraft messages); (ii) 'Signal Visualization': they explore different ways of visualizing information (i.e., time, frequency, dB-scale); (iii) 'Interference': explore the effect of interference in a communication system.

2.1.2. Computer networks: The second section builds upon the first and emphasizes on how the computer networks operate. In detail, the participants measure the performance of different communication medium (i.e., copper, fiber, satellite). They learn: (i) how internet service providers (ISP) collaborate in order to share available resources, (ii) about algorithms involved in communications (i.e., Dijkstra algorithm for network discovery), and understand the importance of encryption and authentication mechanisms that allow us to securely exchange information over the internet.

Figure 3: Participants and research team visiting the ORBIT wireless testbed at Rutgers/WINLAB [19] to present their findings. The pictures are from summer 2018 (left), and 2019 (right).

2.1.3. Future trends and research facilities: The third section is an overview of the future trends in wireless communications, and an introduction to the research methodology. The teachers learn about the internet-of-things (IoT) and smart-objects, by using the equipment to collect and analyze the data from nearby sensors nodes. Then, they are introduced to the research facilities, so-called wireless research testbed, and the advanced technologies that it includes (i.e., multiple-input-multiple-out (MIMO), full-duplex, millimeter-wave (mmWave), communication systems, and edge cloud computing). By the end of this phase, the teachers will understand how to perform experiments using an advanced research testbed with the toolkit.

2.2. Design phase: During the two-week second phase of the program, the teachers conduct independent research on the potential of the wireless labs using the 'COSMOS Educational Toolkit', presenting their ideas to other teachers and the research team to receive feedback and suggestions. The teachers also receive PD sessions about the importance of the NGSS in education and how to develop three-dimensional lesson plans. During the independent research, the participants inspired by the lessons and the wireless hands-on activities of the first phase investigate ways to create meaningful and exciting STEM lessons for the students. Besides independent research, the teachers have brainstorming sessions with teachers of the same field, to collaborate and exchange innovative ideas. In addition, teachers are invited to visit ORBIT testbed at Rutgers/WINLAB to present their findings and receive feedback from the consortium (see Figure 3). The outcomes of this phase are the development of NGSS-aligned lesson plans that bridge the gap between wireless technology research and core STEM-subject area concepts. To address and succeed with this challenge, the teachers require a deep understanding of the concepts they learned during the first phase, as well as they need to be experts in their field.

Figure 4: Teachers present their developed NGSS lesson plans at Silicon Harlem.

2.3. Development phase: During the two-week implementation phase, teachers are separated in two different wireless technology labs (testbed) located at either NYU Tandon School of Engineering, and at the Dept. of Electrical Engineering and the Data Science Institute in Columbia University. Alongside with the research team, they co-develop the most concrete ideas generated in the previous phase that can better utilize the capabilities of the 'COSMOS Educational Toolkit' and the testbed within their classrooms. Teachers can present the developed NGSS-aligned lessons with an associated hands-on wireless activity using the 'COSMOS Educational Toolkit' to Silicon Harlem, which is a social venture located in Harlem [20] and receive constructive feedback before taking them back to their schools to implement with their students (See Figure 4). In Table 1 there is a summary of the developed lessons from the participants over the summers of 2018 and 2019.

2.4. Implementation phase: Over the following academic year, the developed lesson plans and the 'COSMOS Education Toolkit' are evaluated in the schools by teachers who were part of the program as well as their students. The teachers continue to receive support to execute the lessons and the wireless lab activities, express any concerns or new ideas they might have, update the developed lesson plans, and create even more new engineering-based labs.

Table 1: Distinct developed lessons in Phase II for each subject

Subject Area	2018	2019	Total
Mathematics	8	15	23
Science	11	22	33
Computer Science	6	4	10
Interdisciplinary (Math, Computer Science)	1	5	6
Interdisciplinary (Math, Science)	2	1	3
Interdisciplinary (Science, Computer Science)	4	0	4
Total	32	47	79

2.5. Feedback phase: After the end of the third phase of the program, the program team collected constructive feedback by the teachers who used the 'COSMOS Educational Toolkit' in their classrooms regarding the effectiveness of the developed lesson plans, impacts on student achievement and conceptual understanding, as well as engagement in STEM. Based on the results, the team incorporate the feedback to strengthen the impact and plan the future directions of the program.

3. COSMOS Educational Toolkit

Through the PD program and the development of the 'COSMOS Educational Toolkit', the COSMOS research testbed is transformed into an innovative learning platform for K–12 urban students that would help bridge the digital divide and provide significant educational benefits for the local community. All italicized wireless communications technical terminology is found in Appendix – C.

3.1. COSMOS research testbed: The COSMOS testbed [1, 2] is part of the NSF Platforms for Advanced Wireless Research (PAWR) program led by Rutgers University, Columbia University, and NYU in partnership with New York City (NYC), City College of New York (CCNY), IBM, University of Arizona, and Silicon Harlem. The COSMOS testbed is based on dedicated wireless-capable components, programmable hardware, and open-source software. The testbed's architecture has a focus on *ultra-high bandwidth* and *low latency* wireless communication, which makes it very relevant for *edge and cloud computing* applications [21]. These technologies will be integrated with innovative smart city applications that will be implemented and evaluated through real-world experiments. A key feature of the research platform is the integration of fully programmable, high-performance *software-defined radio (SDR) nodes* with state-of-the-art wireless technologies (e.g., *mmWave phased arrays*). Furthermore, the research platform aims to enable experimentation with heterogeneous wireless technologies towards delivering high performance with *low-latency network connections for end-users*, suitable for a plethora of different applications.

The wireless research testbed is being deployed in West Harlem (New York City) covering a 1 sq. mile dense urban area, in partnership with the New York City and the local community. The location of the testbed was selected due to its proximity to university campuses, K–12 schools, where students can be opt-in users, concentration of city assets, and the existence of an engaged community of educators. The center of the deployment area includes ~20 public housing buildings and 9 public schools, managed by the city.

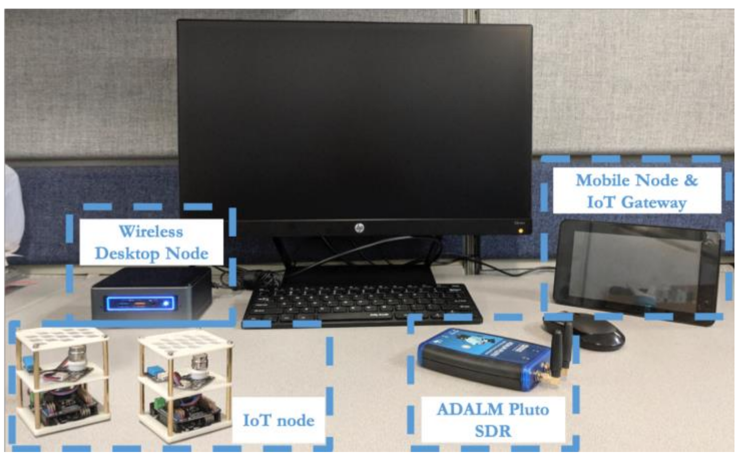

Figure 5: Hardware components of the 'COSMOS Educational Toolkit'

3.2. Hardware system: The hardware setup of the 'COSMOS Educational Toolkit' is inspired by the testbed's nodes. It consists of various off-the-shelf components, which, in combination with dedicated software, allows the teachers to execute a vast number of real-world experiments. The hardware setup can be observed in Figure 5. The major components of the toolkit can be summarized as follows:

- Software defined radio: A small device that can be programmed to transmit/receive any wireless signal, within the device supported frequency range. One of the selected devices, is the ADALM Pluto SDR [22], a transmitter/receiver module that helps students develop a foundation in of real-world communications. The other module used in the toolkit is the RTL-SDR [23] units, due to their excellent reception capabilities, and their extreme low-cost which allows supporting more students.

- Processing units: The Intel NUC [24] is an ideal solution, since it is a small form factor computer, with both enough processing capabilities to drive the SDR units, and support for connecting a standard computer peripheral (e.g., computer screen, keyboard and mouse).
- IoT nodes: These are small sensors that are controlled by an on-board microcontroller, with various wireless interfaces (i.e., XBEE, Wi-Fi, and Bluetooth). These sensors have several sensing capabilities such as air and soil temperature, humidity, light luminosity and color, carbon dioxide (CO_2) levels, dust (PM1.0, PM2.5, and PM10), noise sensor, and accelerometer.
- Mobile node: A device based on the open-source Raspberry-Pi [25] platform. The Raspberry-Pi is a low-power programmable computer, which can be powered by batteries. Thus, it provides mobility to the SDR-based experiments, and acts as an IoT gateway for outdoor (or more generally, scenarios in which access to an electric-outlet is non-existing) experiments.

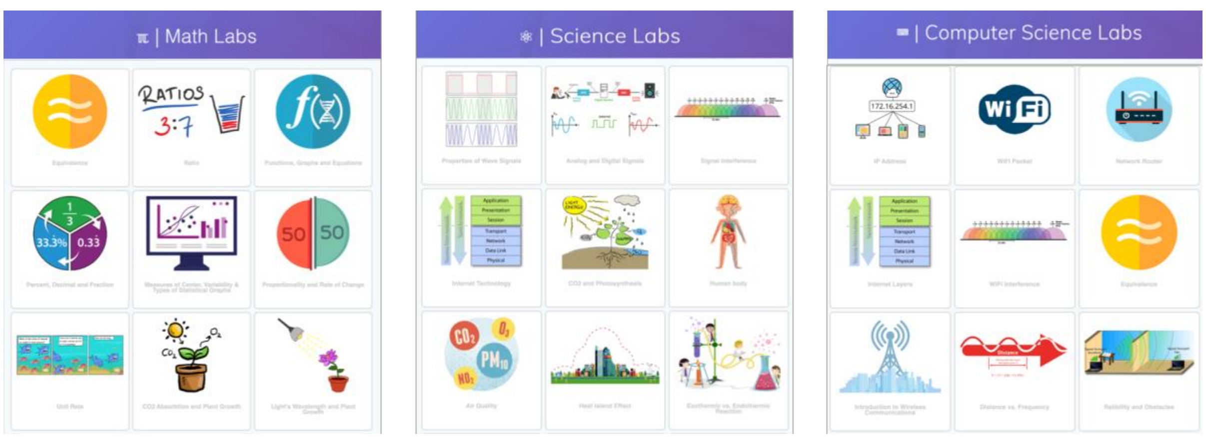

Figure 6: Examples of math, science and computer science NGSS-lesson webpages.

3.3. Software system: The software system has been designed around a web-based graphical interface enhanced with an easy to use philosophy on the execution and management of the lab activities. The students access the graphical interface to navigate and select a lesson, execute the lab activity, and collect the measurements with a similar philosophy as the wireless research testbed. The software system is divided into the following components:

- Web front-end interface: The front-end graphical interface is developed using standard web-developing tools (e.g., HTML, CSS, and Javascript). The front-end interface is communications with a back-end server
- Web back-end server: The server is based on the popular python programming language and is responsible to manage the experiments and collect IoT measurements.
- GNU radio: An open-source software suite, that provides the necessary signal processing blocks to implement software radios [26] and is used in combination with the web front-end interface.
- IoT management: The measurements are collected by the server, stored in a database (influxdB [27]), and then analyzed and presented to the users using a visualization tool (Chronograf [28]).

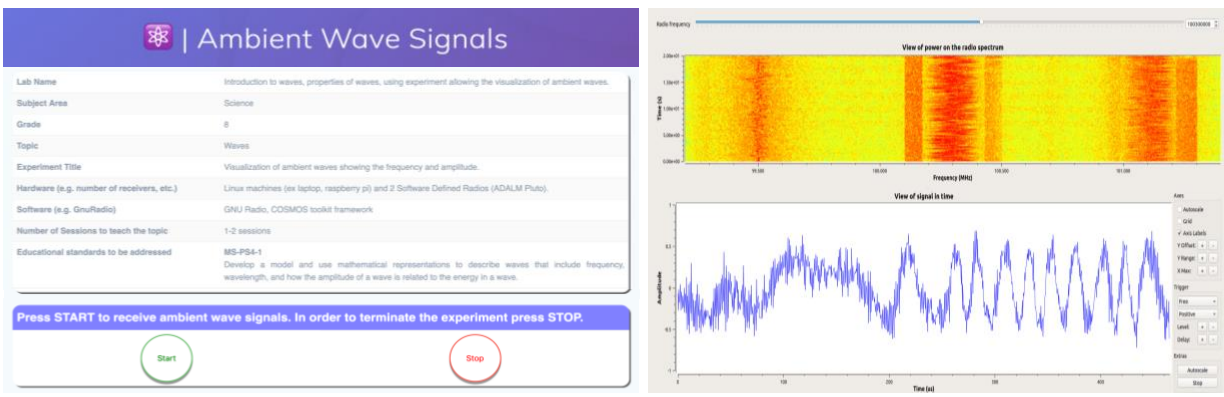

Figure 7: Example of a science lesson web page with a detailed experiment description (top-left), the easy-to-use interface (bottom-left) with the GNU Radio visualization (right).

4. NGSS Lesson Development

The modules that were created in this PD program follow the NGSS lessons standards in order to support teachers in their science conceptualization. We address the STEM, K-12 digital and equity divide by using the testbed as an experimental educational platform and engaging underserved students in real-world engineering activities. In the following subsections, we provide indicative examples of the developed NGSS lessons organized by subject.

4.1. Mathematics – analyzing variables involved in aircraft flights: Through this curriculum, students explore applications of the Pythagorean theorem, rate, ratio and proportionality through a real-world application. The students use the education toolkit in order to capture ambient waves (i.e., AM/FM, aircraft messages). Students will study the different airplane routes of the two different/same airports and find out the percentages and trends of the flights for a specific period of time. Students also use a web-interface for live visualization of the aircrafts flying above their classroom. Then, they use a table that stores the flight number, altitude, latitude, longitude and speed to measure the angle of elevation and depression of a given airplane at the current location and compute the distance for the line of sight or use a triangulation technique and use the Pythagorean theorem to find the missing side. They can have a project extension by group through creating their own investigation and analyzing trends of other airlines. They also demonstrate their ability to use variables for representing quantities and apply them in solving mathematical problems. The NGSS lesson plan can be reviewed in Table D.1 in Appendix – D.

4.2. Engineering – wireless communication system: This curriculum allows students to explore the methodology involved in the design of a wireless communication system, by examining how a signal propagation is related to different types of obstacles present between a transmitter and receiver. Through real-world applications of experiments involving wireless devices, students are able to visualize the mathematical representations of different wave properties as well as design and solve real-world engineering problems. Through the experiment, students will be guided to change the properties of the transmitted signal and set up different types of transmitters and receivers to record power levels (in dBm). The students then will place various obstacles of different material between transmitters and receivers to analyze changes in signal strength. Through the collection and analysis of real-world measurements, students explore the interdependence of science and technology, as well as understanding of qualitative and quantitative data. They also demonstrate their ability to use computer simulations to model proposed solutions to real-world problems. The developed curriculum aligns with the NGSS Science Learning Standards for Engineering Design. The developed NGSS lesson plan can be observed in Table D.2 in Appendix – D.

4.3. Life science – the life cycle of a plant: Through this curriculum, students explore the parameters involved in the plant life cycle and affect the growth by using the 'COSMOS Educational Toolkit' for sensor data collection and visualization. Through real-world applications of experiments involving wireless devices and sensors, students are able to visualize the representations of dynamic variables that affect the sustainability of life, as well as explore relationships between environmental factors and seed germination. Through the multi-weeklong experiment, students set up different seeds for growth, establishing germination conditions and growth parameters for data collection. The students then measure different variables, such as temperature (C or F), humidity (%), CO_2 (ppm), and light intensity (lux) on a daily basis. Students explore the processes of scientific inquiry and experimental design, as well as understanding how to analyze qualitative and quantitative data. They also demonstrate their ability to use wireless sensor probes to measure different variables affecting plant and cellular growth. The developed curriculum aligns with the NGSS Life Science standards on modeling systems and transfer of energy. The developed NGSS lesson plan can be observed in Table D.3 in Appendix – D.

4.4. Computer science – evolution of technology: In this curriculum, students learn about the evolution of technology by exploring the five main types of internet connections (fiber optics, cable, DSL, wireless, satellite) and wireless data transmission. Through real-world experimentation involving wireless devices, students compare different communication medium by collecting data on internet transmission speed. Through the experiment, students measure and calculate factors such as amount of data transmitted (MB), transmission time (sec), and transmission rate (MB/sec). Students use the toolkit to execute the experiment by emulating a selected technology, observe and record the time for electronic data transmission using different methods of internet connections and calculate the data transmission speeds for each. Through the collection and analysis of real-world measurements, students are able to describe the differences between the five main types of internet connections as well as calculate the data transmission speeds for each based on self- collected data. The developed curriculum aligns with the NGSS on wave applications for technology. The developed NGSS lesson plan can be observed in Table D.4 in Appendix – D.

5. Evaluation Results

The developed PD program was evaluated during the 2019 year by an external evaluator, who examined whether the objectives of the program were achieved. The evaluator collected data from 2019 participants throughout the program, using online surveys as well as in-person interviews.

5.1. Program data: A pre-survey was administered at the beginning of the summer program, during the intensive lecture series, and hands-on wireless activities. The pre-survey included Likert-scale measures of the lecture content. From the 2019 responses, 100 percent of participants strongly agreed or agreed that this lecture series was interesting and informative. However, 80 percent also strongly agreed or agreed that the content shared contained more information than they could absorb within the two-week timeframe. This pre-survey also examines other questions that asked for participant feedback regarding the technical lecture component. The evaluator also visited the location of the program to conduct interviews with program personnel, mentors, and teacher participants.

A post-survey was administered at the conclusion of the summer program, with follow-up on questions similar to those from the pre-survey, as well as additional questions specific to design and implementation phases from the PD program. This post-survey also assesses teachers' overall experiences of the program, as well as their self-evaluation of products delivered from participating in the program. Examples of questions asked include: (i) whether or not the teachers feel that the wireless research content is translatable; (ii) whether or not the teachers feel that it provides a relevant real-world context for application of STEM content for their students. Questions regarding classroom implementation and viability for integration were also posed to the participants. For instance, 60 percent of the participating teachers indicated that they felt the level of technical support was sufficient, meaning assistance with integration of the 'COSMOS Educational Toolkit' to the curriculum being developed. This was an important metric to capture, as the objective was centered on learning about different technical components of the toolkit and how to leverage the kit for curricular content. However, a couple of teachers also indicated they would prefer a greater amount of help during this phase, and another indicated a preference for working more on their own, indicating some variation in preferences. Participant teachers' responses also highlighted that the physical divide of participants based on the geographical location across the two campuses also established challenges in providing adequate support as well as collaboration between all participating teachers.

As the program is not limited to just the six-week summer research experience, post-program evaluation of the proposed PD program includes various opportunities to follow-up with teacher participants throughout the ongoing program. Teachers present their summer program developments (curriculum and self-evaluated professional growth and efficacy) at the Research Presentation at the end of the six-week summer workshop, attend and participate in various program stakeholder meetings throughout the academic year, and also host classroom visits and observations during implementation of the toolkit lessons/activities during the academic year.

5.2 Evaluation findings: Between the 2018 pilot year and the 2019 cohort, a total of 79 teacher-created lessons integrated wireless technologies and STEM curricula. There was an increase in overall number of lessons created, from 32 lessons in 2018 to 47 in 2019, even though the same number of participants attended each year. The evaluator noted that it is possible that there is a difference between these numbers due to the fact that many of the 2018 lessons were created by groups of two to three teachers, whereas only two of the lessons in 2019 were created by more than one teacher.

The following are overarching themes found from the 2019 evaluation of the summer PD program. These themes were formed through recurring responses from participating teachers' survey responses as well as interviews with the evaluator. The themes include thoughts and feedback regarding the following: (i) program logistics; (ii) curriculum development; (iii) classroom implementation.

5.2.1. Program logistics: Overall, teachers were very grateful for the opportunity to learn about wireless technology, particularly in an environment in which they can collaborate and work with a diverse group of teachers and researchers. They were also very grateful for the technical support received throughout the program and the chance to create lessons that incorporate the 'COSMOS Educational Toolkit'.

Initially, several teachers stated that the lecture and lab phase (weeks 1-2) of the program could have been shorter, rather than full-day activities because there was a lot of material to absorb. In addition, teachers also noted that they especially enjoyed the lecture topics that coincided directly with lab experiments, as this gave them a sense of how-to best design lessons for their own students by being able to actively take on a learner's perspective. These comments were made immediately after the first 2-weeks of the PD program. At the end of the PD program teachers reflected and stated that the rigorous lecture and lab phase supported their conceptualization of wireless communications in order to best create lessons in the design phase (weeks 3-4).

5.2.2. Curriculum development: During the creation of curricula, teachers noted that there is a need for help in translating the high-level content learned during Phase 1 to lessons that fit directly with existing STEM curricula and standards and can be understood by their students. Some of the challenges shared by teachers included being able to isolate a singular topic from their existing STEM curricula that would be applicable for wireless technologies and potential activities for their courses.

5.2.3. Classroom implementation: Teachers provided some feedback regarding their confidence-levels for implementing the developed lesson plans and lab experiments in their classrooms. They also predict the excitement of the students for being exposed to hands-on activities. In Table 2 we can observe some of the questions that the evaluator asked the teachers, using a 5-point scale (with 5 being the highest, 'very confident') about their expectations for support in their schools.

Several of the teachers also voiced that they believed their students would be most eager to encounter and utilize the wireless technology toolkits during experiments due to the hands-on and interactive nature of the activities. They also highlighted the value of having the technology to provide an additional representation and visualization of STEM concepts for their students

Table 2: Confidence level for support in teaching lessons.

Questions	Value (5 = highest)
Getting my students access to computers	4.22
Finding time to complete the labs/lessons	4.00
Getting access to technical support with toolkits	3.89
Getting my students access to a sufficient number of computers	3.22
Having sufficient support at the school if I run into difficulties	2.67

5.2.4. Evaluation summary: Based on the 2019 program evaluation, there are significant implications provided by the evaluator in regard to suggested changes for improvement based off of program participants' responses to support cognition and learning to best promote enriching and meaningful professional development for participating teachers in the program. As many of the program participants noted in their feedback surveys and interviews that there was too much information to absorb in the first part of the program, the evaluator suggested two aspects of cognition and learning that can potentially create great positive impacts on the participating teacher learners, including 'anchored instruction' and 'active learning' [29, 30]. Anchored instruction will allow for teachers to better share the levels of their prior knowledge and posit real conditions and constraints that they face in their classrooms into consideration when learning about wireless technology and later on developing curricula. Active learning can also be tied into the Phase 1 component of the program, such as many of the teachers' feedback suggestions that advocated for ways to make the learning more active and collaborative during the lecture component.

6. Conclusions and Future Work

This paper describes a teacher PD summer program that aims to enhance K-12 teaching and learning by integrating wireless communications into the STEM curriculum in an urban school district that serves low-income, minority students. The outcomes of this program are the following: (i) The participants gained in-depth knowledge of wireless communications; (ii) development of the ‘COSMOS Educational Toolkit’ – a hardware and software system that provides the necessary infrastructure for STEM lessons. The software is enhanced with an easy-to-use philosophy on the execution and management of the experiments since it was designed for K–12 teachers and students; (iii) the development of the NGSS-aligned lucrative engineering lessons. Through follow-up sessions over the academic year, teachers received support for executing the engineering labs and implementing new NGSS-based lessons to their students. Future work includes: i) Analyzing data of K-12 students’ learning outcomes; and ii) supporting teachers to provide their own teacher PD programs in their school districts utilizing the ‘COSMOS Educational Toolkit’ and NGSS lessons in order to scale up the PD.

Acknowledgements

This work was supported in part by REM supplement to NSF award EFMA-1641100 (NewLAW EFRI), RET supplements to NSF awards ECCS-1547406, CNS-1650685, CNS-1650669, CNS-1702952, CNS-1527750, ECCS-1547332, CNS-1513110, CNS-1730043, CNS-1329939, OAC-1541069, the Columbia Data Science Institute, AT&T foundation, and NSF award CNS-1827923 (PAWR COSMOS).

We thank the following for their numerous important contributions to the PD program: Emily Ford (Engineering Outreach, Columbia); Ben Esner (NYU Center for K12 STEM Education); Clayton Banks, Bruce Lincoln (Silicon Harlem); Victoria Mason-Ailey, Phoebe-Sade Arnold (Government and Community affairs, Columbia); Susan Lowes (Teachers College, Columbia); Robin White (AT&T Foundation); Tracy Van Brakle (AT&T); Sharon Sputz (Data Science Institute, Columbia); Joshua Breitbart (New York City Mayor’s Office of the CTO); Harish Krishnaswamy (EE, Columbia); Shivendra Panwar, Sundeep Rangan (ECE, NYU); Ivan Seskar, Dipankar Raychaudhuri (WINLAB, Rutgers)

We thank the teachers who participated in the program during the summers of 2018 and 2019 for their contributions to the development of the COSMOS Educational Toolkit.

We thank the anonymous reviewers for their insightful comments.

References

1. COSMOS, "Cloud enhanced open software defined mobile wireless testbed for city-scale deployment," https://cosmos-lab.org/
2. D. Raychaudhuri, I. Seskar, G. Zussman, T. Korakis, D. Kilper, T. Chen, J. Kolodziejski, M. Sherman, Z. Kostic, X. Gu, H. Krishnaswamy, S. Maheshwari, P. Skrimponis, and C. Gutterman, "Challenge: COSMOS: A City-Scale Programmable Testbed for Experimentation with Advanced Wireless," *In Proc. ACM MOBICOM'20*, 2020
3. NGSS, "Next Generation Science Standards (NGSS): For States By States," *The National Academies Press*, http://www.nextgenscience.org/
4. E. D. Graaf and A. Kolmos, "Characteristics of problem-based learning," *International Journal of Engineering Education*, vol. 19, no. 5, pp. 657-662, 2003.
5. A. M. A. E. Sayary, S. A. Forawi, S, and N. Mansour, "STEM education and problem-based learning," in *The Routledge International Handbook of Research on Teaching Thinking*, ch.29, pp. 357 – 369, 2005.
6. R. Hite and J. Milbourne, "A proposed conceptual framework for K-12 STEM master teacher (STEMMaTe) development," *Education Sciences*, vol. 8, no. 4, 2008.
7. J. Lave and E. Wenger, *Situated Learning: Legitimate Peripheral Participation*, Cambridge University Press, 1991.
8. S. R. McKay, L. Millay, E. Allison, E. Byerssmall, M. C. Wittmann, M. Flores, J. Frattini, B. Kumpa, C. A. Lambert, E. A. Pandiscio, and M. K. Smith, "Investing in Teachers' Leadership Capacity: A Model from STEM Education," *Maine Policy Review*, pp. 54 – 63, 2018.
9. G. V. Caprara, C. Barbaranelli, P. Steca, and P. S. Malone, "Teachers' self-efficacy beliefs as determinants of job satisfaction and students' academic achievement: A study at the school level," *Journal of School Psychology*, vol. 44, no. 6, pp. 473 – 490, 2006.
10. D. L. Ball and F. M. Forzani, "The work of teaching and the challenge for teacher education," *Journal of Teacher Education*, vol. 60, no. 5, pp. 497 – 511, 2009.
11. M. Tschannen-Moran, and A. W. Hoy, "Teacher efficacy: Capturing an elusive construct," *Teaching and Teacher Education*, vol. 17, no. 7, 2001.
12. A. L. DeChambeau, and S. E. Ramlo, "STEM high school teachers' views of implementing PBL: An investigation using anecdote circles," *Interdisciplinary Journal of Problem-Based Learning*, vol. 11, no. 1, 2017.
13. P. A. Ertmer, and K. D. Simons, "Jumping the PBL implementation hurdle: Supporting the efforts of K-12 teachers," *Interdisciplinary Journal of Problem-based learning*, vol. 1, no. 1, 2006.
14. C. E. Hmelo-Silver, "Problem-based learning: What and how do students learn?," *Educational Psychology Review*, vol. 16, no. 3, pp. 235 – 266, 2004.
15. K. M. Meyrick, "How STEM education improves student learning," *Meridian K-12 School Computer Technologies Journal*, vol. 14, no. 1, pp. 1 – 6, 2011.
16. COSMOS, "COSMOS Education Toolkit," https://cosmos-lab.org/cosmos-toolkit/
17. M. J. Scherer and R. L. Glueckauf, "Assessing the benefits of assistive technologies for activities and participation," *Rehabilitation Psychology*, vol. 50, no. 2, pp. 132 – 141, 2005.
18. K. Yelamarthi, "RFID-Based Multidisciplinary Educational Platform to improve the engineering and technology curriculums," *Journal of STEM Education: Innovations and Research*, vol. 13, no. 5, 2012.

19. WINLAB/Rutgers, “Orbit testbed,” http://www.winlab.rutgers.edu/projects/Orbit.html
20. Silicon Harlem, “Silicon Harlem,” https://www.siliconharlem.com
21. S. Yang, E. Bailey, Z. Yang, J. Ostrometzky, G. Zussman, I. Seskar, and Z. Kostic, “COSMOS smart intersection: Edge compute and communications for bird’s eye object tracking,” *In Proc. 4th International Workshop on Smart Edge Computing and Networking (SmartEdge’20), 2020*
22. Analog Devices Inc., “ADALM-PLUTO SDR,” https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/adalm-pluto.html
23. [n.d.], “RTL-SDR,” https://www.rtl-sdr.com/about-rtl-sdr/
24. Intel Corporation, “Intel NUC,” https://www.intel.com/content/www/us/en/products/boards-kits/nuc/mini-pcs.html
25. Raspberry Pi Foundation, “Raspberry Pi,” https://www.raspberrypi.org
26. GNU Radio Foundation, “GnuRadio,” https://www.gnuradio.org
27. InfluxData Inc., “InfluxDB v2.0,” https://www.influxdata.com/products/influxdb-overview/influxdb-2-0
28. InfluxData Inc., “Chronograf,” https://www.influxdata.com/time-series-platform/chronograf/
29. National Research Council, “Exploring Opportunities for STEM Teacher Leadership: Summary of a Convocation,” *The National Academies Press*, pp. 1–78. 2014.
30. L. Desimone, “Improving Impact Studies of Teachers’ Professional Development,” *Educational Researcher*, vol. 38, no. 3, pp. 181 – 199, 2009.

Appendix – A

Table A.1: Details and demographics of participating teachers from 2018

Participant	Gender	Ethnicity	Grade level	Subject
A	F	Hispanic	6	Math
B*	F	Asian	6 – 8	Math
C	F	African-American	7 – 8	Math
D*	M	African-American	7 – 8	Science
E	M	Caucasian	12	Science
F	M	Asian	10 – 12	Science
G	F	Asian	9 – 12	Science
H	M	Caucasian	9 – 12	Computer Science
I*	M	Caucasian	9 – 12	Computer Science/ Engineering
J	M	Caucasian	8	Technology / Special Education

Table A.2: Details and demographics of participating teachers from 2019. *Note that participants B, D, I are returning teachers from the 2018 cohort.

Participant	Gender	Ethnicity	Grade level	Subject
B*	F	Asian	6 – 8	Math
K	M	Asian	6 – 8	Math
L	F	African-American	6 – 8	Math
M	F	Asian	10 – 11	Math
N	M	Caucasian	10 – 12	Math
O	F	Caucasian	7	Science
D*	M	African-American	7 – 8	Science
P	F	Asian	9 – 12	Science
Q	M	Caucasian	8 – 12	Science
I*	M	Caucasian	9 – 12	Computer Science/Engineering

Appendix – B

Table B.1: Overview of the wireless technology lessons and the lab activities used in 'lecture and lab phase' of the program.

Section 1. Wireless communications	
Lesson	**Activity**
1.1. What is a wireless signal: Introduction and learning what electromagnetic waves and their properties.	Using the lab equipment, participants capture live ambient electromagnetic signals that carry information (e.g. FM radio, aircraft messages). Following this, they observe and discuss on the properties of different waves.
1.2. How is information passed on a wave: participants are guided on the basic representations of information (e.g. binary/ASCII representation) and learn how this information is passed on a wave that travels the air.	Using the lab equipment, the participants generate a wave that carries voice, captured through a microphone, and modulate it accordingly over a signal that is transmitted over the air. Similarly, they generate binary data, depict it as a wave, and modulate it over digital signals before transmitting it over the air.
1.3. Time and frequency representation: participants learn about the different manners of observing a signal (time/frequency) and about different signal properties.	Participants use the equipment to send and receive signals using different modulation schemes. Signals are depicted in time and frequency domains, so as the participants observe in real practice the different signal properties.
1.4. Complex representation: Participants are guided through the different types of representing a signal (complex numbers) and produce constellation diagrams.	Time and frequency representation of signals.
1.5. Relationship between bandwidth and data rate: participants learn about the speed of communications between a transmitter and receiver pair and how this can be increased (e.g. by increasing the bandwidth used).	Participants use the lab equipment to transmit and receive files of different size, while tuning the channel bandwidth used. They measure the time needed for the file transmission and analyze their results.
1.6. Noise: Participants learn how noise can impact wireless transmissions. Different types of noise are introduced, and ways to mitigate their effects.	Participants use the lab equipment to adjust attenuation and send signal with different signal-to-noise ratios. They experiment with different modulation schemes and observe the effect of noise on a constellation diagram over real transmissions.
1.7. Interference: Participants learn how wireless signals may interfere with each other and are guided on best practices and methods for mitigating wireless interference in Wi-Fi equipment.	The participants observe in practice with on-site Wi-Fi networks the effects of interference in wireless transmissions. They are guided to run a spectrum challenge scenario with a Wi-Fi access point that each of the groups use and reach consensus on the frequencies that they will use to minimize interference.
1.8. The spectrum crunch: Participants learn about the current wireless spectrum crunch, and on multipe research solutions to this problem (e.g. full-duplex communications, using the mmWave bands)	Advanced wireless experiments are showcased by the instructors on full-duplex communications using research prototypes. Following this, the participants use the equipment to run a communication channel over the 60GHz mmWave band using IEEE 802.11ad, and observe the different characteristics of the signals in such

	bands like penetration abilities, antenna radiation patterns, etc.
1.9. Future trends in wireless and associated challenges: The participants learn about massive IoT communications, and novel technologies such as visible light communications (VLC) and Li-Fi.	The participants use the provided equipment for running and experiment using LEDs for VLC. As a second set of labs, the participants use IoT sensors that they deploy in the classroom and adjacent rooms, collect and depict measurements from them and reach conclusions by observing their values (e.g. temperature/humidity levels, CO_2 concentration).
Section 2. Computer networks	
Lesson	**Activity**
2.1. TCP/IP model: The participants learn about the layered structure of networks, and the basic functions of each layer.	Participants use the provided equipment to generate traffic, capture and analyze packet traces for observing the different layers of the networking stack.
2.2. Structure of the Internet: The participants learn about the structure of the Internet, major Internet Service Providers (ISPs) managing the Internet backbone and contracting methods between them.	The participants generate traffic towards servers located at different countries. Using applications like traceroute, they observe the paths established through the Internet using different tiers of ISPs and CDNs
2.3. Routing: The participants delve into the networking layer of the TCP/IP model, and learn about how data is routed from one network to another.	The participants learn about Dijkstra's algorithm, and are using the board to find the optimal paths in network graphs. Subsequently, they use the wireless research testbed to setup routes between different nodes using the Dijkstra's algorithm.
2.4. Basic home network: Participants are lectured on common services found on home routers (e.g. DHCP for receiving network addresses, network address translation (NAT) for translating their addresses to Internet routable, etc.)	The participants setup the lab equipment to operate as a home Wi-Fi router and observe how NAT works. Moreover, they observe network traces for the domain name system (DNS) traffic, and how URLs are translated to network addresses.
2.5. Kinds of networks: The participants learn about the different media used for interconnecting computers (e.g. wired copper/cable, air, optical fiber) and different protocols used (e.g. cellular, Wi-Fi, xDSL, DOCSIS)	The participants in groups of two use the Wireless Educational Toolkit to emulate the different communication mediums. They compare the performance in terms of data rate (Mbps)
2.6. Network security: Participants are lectured on different aspects on (wireless) network security.	The participants use the equipment to generate messages and encrypt them using private keys. Afterwards they exchange them encrypted messages and use public keys to decrypt them.
Section 3. Future trends and research facilities	
Lesson	**Activity**
3.1. Why testbeds are important: Participants learn the value of testbeds in the research landscape.	The participants use the equipment to access the research testbed and run a prepared experiment on wireless networks. Afterwards, they use the equipment to run a simulation of the same experiment and compare their findings.
3.2. Taxonomy of testbeds: Participants learn about different types of testbeds that exist and on different experiments that they can run.	The participants use three different testbeds to run a simple networking experiment.
3.3. A,B,C testbeds: Participants learn for three different research facilities that exist in the city of the program.	The participants are guided through the processes of create accounts and reserving time on wireless research

	testbed. They learn the interfaces of useful tools that ease the experimentation process on the testbeds.
3.4. Wireless capabilities of testbeds: participants learn about the technologies that they can experiment with on A, B and C testbeds.	The participants login to the A testbed and set up a Wi-Fi network in the testbed. Subsequently, they use the same node to set up an SDR link in a testbed
3.5. Techniques for experimentation on testbeds: Participants learn easy scripting languages and how they can automate different computing processes with them.	The participants are guided into writing experiments scripts, code version control and reproducibility of experiments.
3.6. Why testbeds are important: Participants learn the value of testbeds in the research landscape.	The participants use the equipment to access the testbed and run a prepared experiment on wireless networks. Afterwards, they use the equipment to run a simulation of the same experiment and compare their findings.

Appendix – C

Table C.1: Short description of the technical wireless communication terminology used in the paper.

Terminology	Short Description
Bandwidth	Bandwidth is the quantity of data sent or received in a second, commonly measured in Mbps (megabits-per-second) or Gbps (gigabits-per-second)
Latency	In computer networking, latency is an expression of how much time it takes for a data packet to travel from one designated point to another. Usually it is measured in milli seconds (ms). The brief moments after you open a link before your web browser starts to show anything is perceived as latency.
Edge computing	Edge computing is processing that is done near the source of the data, instead of relying on data centers to do all the work. A key enabler for edge computing is the high demand for applications like virtual and augmented reality with very low latency and high bandwidth requirements.
Cloud computing	Cloud computing is the access of services (i.e., storage, databases, analytics, intelligence, processing) over the internet.
Internet-of-things (Iot)	The core idea that everyday objects can be equipped with sensing, networking and processing capabilities that will allow them to communicate with other devices or services over the internet.
Software-defined radio	A small device that can be programmed to transmit/receive any wireless signal, within the device supported frequency range.
Phased array	A phased array is defined as a multiple-antenna system that electronically alters or directs the transmission or reception of an electromagnetic beam.
mmWave	Millimeter-wave (mmWave) frequencies have attracted a lot of interest for the development of future wireless communication systems, due to the broad frequency spectrum leading to tremendous data rates.

Appendix – D

Table D.1: Details of a math NGSS-plus-5E lesson created by the teachers in Phase II.

Lesson Name: Analyzing variables involved in aircraft flights		
Topic: Pythagorean theorem, distance, law of cosines & correlation		
Grade/Grade Band: 6th - 12th		
Lesson Description: This is an introduction to waves, and their properties (i.e., amplitude, frequency, and phase). Students learn about different types of waves and explore how electromagnetic waves propagate in space. Students use technology to visualize ambient waves, listen to FM radio, AM stations, and capture aircraft messages. Students also analyze different variables involved in airplane routes and the real-world applications of the Pythagorean theorem, distance ($distance = speed \times time$), percentages, proportionality, and other advanced trigonometric concepts such as the Law of Sines/Cosines.		
Performance Expectations: MS-PS4-1, MS-PS4-2, MS-PS4-3, HS-PS4-1, HS-PS4-2, HS-PS4-3, HS-PS4-4, HS-PS4-5		
Science & Engineering Practices (SEPs)	**Disciplinary Core Ideas (DCIs)**	**Crosscutting Concepts (CCs)**
MS-PS4-1 and HS-PS4-1: Using Mathematics and Computational Thinking MS-PS4-2: Developing and Using Models MS-PS4-3: Obtaining, Evaluating, and Communicating Information HS-PS4-2: Asking Questions and Defining Problems HS-PS4-3: Engaging in Argument from Evidence HS-PS4-3: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena HS-PS4-4 and HS-PS4-5: Obtaining, Evaluating, and Communicating Information	PS4.A: Wave Properties PS4.B: Electromagnetic Radiation PS4.C: Information Technologies and Instrumentation PS3.D: Energy in Chemical Processes	MS-PS4-1: Patterns MS-PS4-2: Structure and Function MS-PS4-3: Influence of Science, Engineering, and Technology on Society and the Natural World HS-PS4-1, HS-PS4-4 and HS-PS4-5: Cause and Effect HS-PS4-3: Systems and System Models HS-PS4-2: Stability and Change HS-PS4-5: Interdependence of Science, Engineering, and Technology HS-PS4-2 and HS-PS4-5: Influence of Science, Engineering, and Technology on Society and the Natural World
Common Course State Standards (CCSS)		

ELA/Literacy: SL.8.5, RST.6-8.1, RST.6-8.2, RST.6-8.9, WHST.6-8.9, RST.9-10.8, RST.11-12.1, RST.11-12.7, RST.11-12.8, WHST.9-12.2, WHST.11-12.8 **Mathematics:** MP.2, MP.4, 6.RP.A.1, 6.RP.A.3, 7.RP.A.2, 8.F.A.3, HSA-SSE.A.1, HSA.SSE.B.3, HSA-CED.A.4
Lab activity: Students observe ambient wave signals and their properties on graphs, using the 'Wireless Educational Toolkit'. Students detect and record the FM radio and AM stations based on the strength of the signal. Students work in groups to capture and analyze data about the airplane flights they detected.
5E Model **Engage:** Students discuss about what is a wave and if they can think examples in nature. **Explore:** Students observe the properties of the ambient waves in graphical representation on their computer. **Explain:** Students brainstorm on reasons to explain the relationship of the signal strength and the existence or not of a FM station in that frequency. **Elaborate:** Students explore all the ambient waves such as FM radio stations, AM stations, and aircraft messages. **Evaluate:** Students capture and analyze actual data of ambient wave signals

Table D.2: Details of an engineering NGSS-plus-5E lesson created by the teachers.

Lesson Name: Wireless communication system		
Topic: Design thinking		
Grade/Grade Band: 9th – 12th		
Lesson Description: Students will learn about different wireless technologies (i.e., Wi-Fi, XBEE, FM, AM). Then, the students will explore the reliability of the wireless signal based on the How reliable is your wireless signal if there are obstacles blocking the transmission? This lesson explores different how different obstacles affect the power level of the received signals, and how that looks differently for different types of wireless communications technologies.		
Performance Expectations: HS-PS4-1, HS-ETS1-1, HS-ETS1-2, HS-ETS1-3, HS-ETS1-4		
Science & Engineering Practices (SEPs)	**Disciplinary Core Ideas (DCIs)**	**Crosscutting Concepts (CCs)**
HS-PS4-1 and HS-ETS1-4: Using Mathematics and Computational Thinking HS-ETS1-1: Asking Questions and Defining Problems	PS4.A: Wave Properties ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	HS-PS1-1: Cause and Effect HS-ETS1-4: Systems and System Models HS-ETS1-1 and HS-ETS1-3: Influence of Science, Engineering, and Technology on Society and the Natural World

HS-ETS1-2 and HS-ETS1-3: Constructing Explanations and Designing Solutions		
Common Course State Standards (CCSS) **ELA/Literacy:** RST.11-12.7, RST.11-12.8, RST.11-12.9 **Mathematics:** MP.2, MP.4, HSA-SSE.A.1, HSA-SSE.B.3, HSA.CED.A.4		
Lab activity: Students will be divided in small groups based on a different wireless technology. Students will explore the effects of obstacles (i.e., 4" dry wall, 8" cinderblock wall, bucket of water, wooden box) and interference (i.e., microwave, wireless jammer) on the signal strength values (dBm). Students will research on the best communication technology based on the application and the environment (i.e., outdoor, indoor).		
5E Model **Engage:** Students will discuss the effects of the environment on the wireless communications. Students will try to answer the following question 'Can we have wireless headphones inside a pool and why?' **Explore:** Student will explore the **Explain:** Students will present their finding on the obstacles that affected the most each wireless technology. **Elaborate:** Students will do research in the literature to explain why not all the obstacles have the same effect on every wireless communication technology. **Evaluate:** Students based on their findings will try to answer again the same question about swimmers and music. Students will evaluate the wireless technologies based on the application and the environment.		

Table D.3: Details of a science NGSS-plus-5E lesson created by the teachers.

Lesson Name: The life cycle of a plant		
Topic: Photosynthesis		
Grade/Grade Band: 9th		
Lesson Description: Students study the effects of environmental factor (carbon dioxide, temperature and humidity) in the growth rate of Brassica rapa over weeks (or months). Students study the effects of red, blue, green wavelengths of light on the plant's ability to perform photosynthesis. Sensors will be used to collect at store the environmental conditions of the flower. Sensors will also be used to confirm the presence and intensity of a specific wavelength of light as well as measure photosynthetic output as reflected in a sensor measuring carbon dioxide absorption.		
Performance Expectations: HS-LS1-2, HS-LS1-5, HS-LS2-3, HS-LS2-5		
Science & Engineering Practices (SEPs)	**Disciplinary Core Ideas (DCIs)**	**Crosscutting Concepts (CCs)**

HS-LS1-2, HS-LS1-5 and HS-LS2-5: Developing and Using Models HS-LS2-3: Constructing Explanations and Designing Solutions HS-LS2-3: Scientific Knowledge is Open to Revision in Light of New Evidence	LS1.A: Structure and Function LS1.C: Organization for Matter and Energy Flow in Organisms LS2.B: Cycles of Matter and Energy Transfer in Ecosystems PS3.D: Energy in Chemical Processes	HS-LS1-2 and HS-LS2-5: Systems and System Models HS-LS1-5 and HS-LS2-3: Energy and Matter
Common Course State Standards (CCSS) **ELA/Literacy:** SL.11-12.5, RST.11-12.1, WHST.9-12.5		
Lab activity: Students use the 'Wireless Educational Toolkit' to determine which environmental factor (carbon dioxide, temperature and humidity) most influences growth rate of Brassica rapa over weeks (or months). Students will also use the sensors to study the effects of red, green, blue wavelength lights on the plant's photosynthetic ability.		
5E Model **Engage:** Students will watch a time-lapse film of a plant growing in the wild. Students will discuss phenomena of germination and growth. **Explore:** Student teams research the literature and conduct multiple discussions to determine the best possible location on school ground to nurture the germination and photosynthesis of their Brassica rapa plants. **Explain:** Students brainstorm on reasons to explain germination, photosynthesis, growth rate, data collection & formatting, analysis and reflection and finally presentation. **Elaborate:** Students explore all the ambient waves such as FM radio stations, AM stations, and aircraft messages. **Evaluate:** Students chart growth (stem length, leaf surface area) of Brassica rapa against water (precipitation), sunlight and temperature and finally determine which of these three environmental factors is the most or least influential.		

Table D.4: Details of a computer science NGSS-plus-5E lesson created by the teachers.

Lesson Name: Evolution of technology
Topic: Different types of internet connectivity
Grade/Grade Band: 8th
Lesson Description: Students will investigate how the progress of technology changed the way we communicate. Students will learn about different types of internet connection (i.e., optical, DSL, Wi-Fi, satellite) over a communication medium (i.e., copper, optical, air, space). Students will use the toolkit to measure the data rate (Mbps) to compare the different internet technologies. Students will explore everyday activities that are possible due to the evolution of technology. Finally, they will create bar graphs and they will answer reflective questions based on the activity they just completed.
Performance Expectations: MS-PS4-1, MS-PS4-2, MS-PS4-3

Science & Engineering Practices (SEPs)	Disciplinary Core Ideas (DCIs)	Crosscutting Concepts (CCs)
MS-PS4-1: Using Mathematics and Computational Thinking MS-PS4-2: Developing and Using Models MS-PS4-3: Obtaining, Evaluating, and Communicating Information	PS4.A: Wave Properties PS4.B: Electromagnetic Radiation PS4.C: Information Technologies and Instrumentation	MS-PS4-1: Patterns MS-PS4-2: Structure and Function MS-PS4-3: Influence of Science, Engineering, and Technology on Society and the Natural World

Common Course State Standards (CCSS)

ELA/Literacy: SL.8.5, RST.6-8.1, RST.6-8.2, RST.6-8.9, WHST.6-8.9

Mathematics: MP.2, MP.4, 6.RP.A.1, 6.RP.A.3, 7.RP.A.2, 8.F.A.3

Lab activity: Students will use the ‘Wireless Educational Toolkit’ in order to create a server and a client over different communication mediums. Students will transmit a file and they will measure the impact of the different internet connectivity to the data rates. Students will record their findings to present to the rest of the groups.

5E Model

Engage: Students perform independent research on the different type of internet connections.

Explore: Students will watch a short slide show that will introduce the lesson and the experiment. Students will use the toolkit to record the time it takes to transfer a specific amount of data over different internet connections.

Explain: Students will present their findings to the rest of the classroom.

Elaborate: Students will identify everyday activities that are possible due to the evolution of internet technology and will brainstorm on something that will be possible due to the next generation of internet technology.

Evaluate: Students will create charts of data rate versus data size for each internet connection.