Public Review for

COSMOS Educational Toolkit: Using Experimental Wireless Networking to Enhance Middle/High School STEM Education

Panagiotis Skrimponis, Nikos Makris, Sheila Borges Rajguru, Karen Cheng, Jonatan Ostrometzky, Emily Ford, Zoran Kostic, Gil Zussman, Thanasis Korakis

One of the greatest challenges faced by our community lies in improving the diversity of students in our educational programs. Despite the fact that computer networking, and computer science in general, is one of the most exciting and impactful fields in existence it also continues to suffer from reduced enrolments from certain groups such as minorities and women.

This paper takes this challenge head on by proposing and evaluating a learning infrastructure built atop a research testbed called COSMOS. The authors build a new learning platform atop COSMOS, which comprised an educational program, and a collection of hardware and software components that could be used for instructional purposes. The platform provides instruction in a number of exciting technologies, exposing students to how wireless works (using open-source radio technologies), IoT, and much more. While the system is thoughtfully designed and is clearly a contribution on its own, the authors were not content to stop there, and conducted an extensive evaluation of their work, providing education for nearly eighty teachers, who will go on to teach many students. Their efforts clearly demonstrated the benefits of their approaches, and more practically, touched the lives of many hundreds if not thousands of students from underprivileged and minority communities. It is also worth noting the platform has been released (`https://www.cosmos-lab.org/cosmos-education-toolkit/`) for others to use and build upon.

After reading the paper, one can hope that the authors will continue to extend their work, for example by using it to teach other sorts of technologies, or provide additional support for teaching at lower grade levels. As they gain further experience with their deployments the authors may also help our community by telling us "lessons learned" - are there K-12 institutions or teachers that prefer not to use this toolkit? Why not? Such lessons may help us to further improve the state of K-12 education and in assisting other researchers in this area to design techniques that realize largest possible impact in the K-12 community.

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ABSTRACT

This paper focuses on the K–12 educational activities of COSMOS – Cloud enhanced Open Software defined MObile wireless testbed for city-Scale deployment. The COSMOS wireless reasearch testbed is being deployed in West Harlem (New York City) as part of the NSF Platforms for Advanced Wireless Research (PAWR) program. COSMOS' approach for K–12 education is twofold: (i) create an innovative and concrete set of methods/tools that allow teaching STEM subjects using live experiments related to wireless networks/IoT/cloud, and (ii) enhance the professional development (PD) of K–12 teachers and collaborate with them to create hands-on educational material for the students. The COSMOS team has already conducted successful pilot summer programs for middle and high school STEM teachers, where the team worked with the teachers and jointly developed innovative real-world experiments that were organized as automated and repeatable math, science, and computer science labs to be used in the classroom. The labs run on the COSMOS Educational Toolkit, a hardware and software system that offers a large variety of pre-orchestrated K–12 educational labs. The software executes and manages the experiments in the same operational philosophy as the COSMOS testbed. Specifically, since it is designed for use by non-technical middle and high school teachers/students, it adds easy-to-use enhancements to the experiments' execution and the results visualization. The labs are also supported by Next Generation Science Standards (NGSS)-compliant teacher/student material. This paper describes the teachers' PD program, the NGSS lessons created and the hardware and software system developed to support the initiative. Additionally, it provides an evaluation of the PD approach as well as the expected impact to K–12 STEM education. Current limitations and future work are also included as part of the discussion section.

CCS CONCEPTS

• **Mathematics of computing**; • **Social and professional topics** → **K-12 education**; • **Computer systems organization** → **Sensor networks**; • **Networks** → **Network architectures**; **Network experimentation**; • **Hardware** → **Wireless devices**;

KEYWORDS

Computer Networks, Wireless Networks and Communications, Software-Defined Radios, Outreach, K–12 Education, NGSS Curriculum, Laboratory Experience, Professional Development, STEM.

1 INTRODUCTION

Students in dense urban environments come from diverse racial, ethnic, and socioeconomic backgrounds. Therefore, curricula must take into consideration the urban space in which they reside and connect it to science, engineering content and practices that use the tenets of inquiry-based teaching and learning. Science, technology, engineering, and math (STEM) education research in situated learning has found that students are able to learn effectively when they are actively involved in real-world research problems. Therefore, students should be guided in authentic, hands-on experiences to construct their own knowledge by conducting actual science work. When students are engaged in building positive and trusting social capital, their achievements improve [2].

K–12 STEM educational researchers and policymakers suggest that in order to enhance STEM education *for all*, including culturally and linguistically diverse students, hands-on engineering teacher professional development (PD) programs, including meaningful activities for students, need to be developed. They usually introduce curricula that focus on project-based learning (PBL) [3], engage in culturally relevant pedagogy [4–6] and explicitly connect school science to the students' community science concerns [7, 8].

To cope with this challenge, we focus on transforming the COSMOS testbed [9, 10] into an innovative learning platform for K–12 students that would help bridge the digital and equity divide providing significant educational benefits for the local community. We designed a PD program and the COSMOS Education Toolkit [11, 12], consisting of a hardware and software system to engage students in STEM. The PD program consists of three phases: (i) a two-week structured learning phase, during which ten teachers attend lectures about wireless technology and perform various hands-on experiments related to wireless communications; (ii) a four-week research phase, during which the teachers collaborate in two different research labs in order to co-create lessons aligned with the K–12 Next Generation Science Standards (NGSS) [13]; (iii) school-year

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Table 1: Details of a science NGSS-plus-5E Lesson created by teachers during Phase 2

Lesson Name: Design of a wireless communication system		
Topic: Design thinking		
Grade/Grade Band: 9^{th} - 12^{th}		
Lesson Description: Students learn about different wireless technologies (WiFi at 2.4 GHz and 5 GHz, FM from 80 MHz to 200 MHz, and XBee at 915 MHz). The students are asked to answer *'How reliable is your wireless signal if obstacles block the transmission?'* by observing the power level of the received signals for different wireless technologies, and obstacles.		
Performance Expectation(s): 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 HS-ETS1-2 and HS-ETS1-3: Constructing Explanations and Designing Solutions	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
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 are divided in small groups based on a different wireless technology. They explore the effects of obstacles (e.g., 4" dry wall, 8" cinderblock wall,metal cabinet, and wooden box) and interference (e.g., microwave, wireless jammer) on the signal strength values (dBm). Students research on the most applicable communication technology based on the environment.		
5E Model **Engage:** Students discuss the effects of the environment on the wireless communications. Students try to answer the following question 'Can we use the wireless headphones underwater inside a pool?'. **Explore:** Students use the educational toolkit to explore the effect of blockages for different wireless communication technologies. **Explain:** Students present their findings on the obstacles that affected the most each wireless technology. **Elaborate:** Students perform literature research to explain why the obstacles does not affect the same every wireless technology. **Evaluate:** Students based on their findings will try to answer again the same question about swimmers and music. Students evaluate the wireless technologies based on the application and the environment.		

phase in which we provide support for the teachers/students over the academic year for executing the experiments and implementing new engineering-based labs.

The remainder of this paper is organized as follows. Section 2 provides the educational framework and the learning model. Section 3 demonstrates lessons developed by the teachers during the PD program. Section 4 presents in detail the educational toolkit. Section 5 shows evaluation results of the program. Section 6 presents current limitations and future work. Section 7 concludes the paper.

2 BACKGROUND

The NGSS are national science standards that have been formally adopted in the United States schools. Each standard is called Performance Expectation (PE), and is made up of 3 dimensions: (i) Disciplinary Core Ideas (DCIs): the science concepts within each of the four science disciplines [14], (ii) Cross Cutting Concepts (CCCs): the common concepts connecting all four science disciplines, and (iii) Science and Engineering Practices (SEPs): the practices that scientists and engineers enact. All 3 are necessary in order to meet one PE. The NGSS is explicit about the importance of engineering in K–12 STEM education and issues of diversity and equity. The NGSS is paramount to the future of STEM, highlighting engineering and technology education.

To teach students effectively, their prior knowledge should be assessed, science misconceptions should be identified and undergo conceptual change–replaced with the correct scientific conceptualization [15]. STEM educators use the 5E Lesson Model, which takes students through a learning progression by enacting in hands-on activities. The 5E's are: Engage, Explore, Explain, Elaborate, and Evaluate [16]. Using the 5E model teachers engage students in a question that is usually a common misconception. As the student goes through the journey of all the 5E's, the science concept becomes clear [16].

PBL is another important model that can be applied in classes in order to enhance the student learning. PBL utilizes projects in order to enhance student learning that comes from constructivist theory [17, 18]. There are five categories that PBL should satisfy [19]. Projects must (i) be central to the curriculum, (ii) include questions that 'drive' students to the concepts and principles of STEM, (iii) engage participants in constructive investigation, (iv) be student-driven, and (v) authentic research. STEM education research in situated learning has found that students are able to learn effectively when they are actively part of real-world research problems [10]. It is known that when educators engage students in building positive and trusting relationships, and giving them authentic hands-on STEM experiences, student achievements improve [7].

3 NGSS LESSON DEVELOPMENT

The developed teacher PD program follows the NGSS standards and applies the 5E model for the developed K–12 lessons. We consider

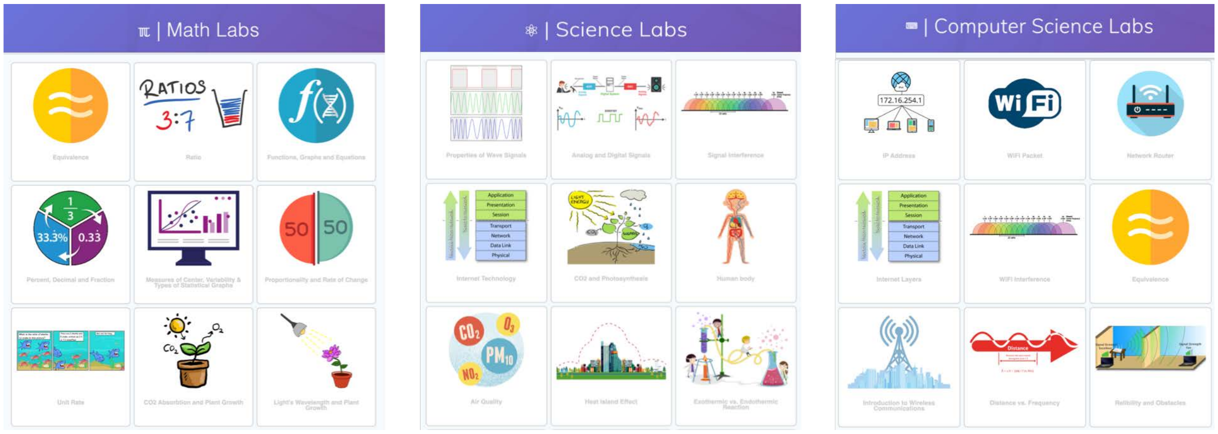

Figure 1: Examples of math, science, and computer science NGSS-lesson webpages.

the PBL model for the teacher PD program and the lessons utilizing the educational toolkit. Our goal is to create curricula that engages K–12 students, and especially under-served students in real-world engineering activities. In the following subsections, we provide indicative examples of the developed NGSS lessons[1], including the scientific concepts to be taught in each of them, the experiments involved, as well as their educational goals.

3.1 Engineering – Wireless communication system

This lesson allows students to explore different factors that affect the design of a wireless communication system. By using the toolkit, students execute several real-time experiments, using different wireless technologies (WiFi, FM, XBee) and different signal characteristics (e.g., transmission power). For each transmission, students record the received signal strength (in dBm) and compute the attenuation. The students then place various obstacles of different materials (e.g., dry wall, wooden boxes, metal cabinets) between transmitters and receivers and run the same set of experiments in order to understand the effect of different obstacles to wireless communications. 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. The developed curriculum aligns with the NGSS Science Learning Standards for Engineering Design. The NGSS lesson plan can be reviewed in Table 1.

3.2 Mathematics – Functions and probability

In this lesson, students learn about functions and probability by exploring wireless network experiments run on the toolkit and examine the relationship between different modulation schemes and noise. Students explore the mathematical functions that translate information (bits) into waves by visualizing them in real time, using the web interfaces of the toolkit. Additionally they understand the relationship between noise level and data rates by running several experiments, changing the modulation scheme/data rate and calculating the probability of error. Finally, students visualize and depict functions through multiple representations of wireless signals in frequency and time (e.g., constellation diagrams). The developed curriculum aligns with the Common Core Standards [20] for 'High School: Functions' [21].

3.3 Chemistry – Rates of reaction

This lesson allows students to explore the parameters involved in the collision theory and affect the rate of reaction, by using the toolkit to create and interface remote sensor networks for data collection and subsequent analysis and visualization. Through the experiments, students observe how factors such as temperature, pressure, and volume of a substance relate with each other. Students record data and hypothesize variables that they think contribute to changes in the rates of reaction, as measured through the wireless sensor probes. Through the lesson, students are able to describe the nature of catalysts in relation to rates of reaction, while measuring and capturing data through wireless measurement tools. The curriculum aligns with the NGSS Chemical Reactions standards [22, 23].

3.4 Mathematics – Analyzing variables involved in aircraft flights

In this lesson, students explore mathematical concepts as rate, ratio, proportionality, using the software defined radio (SDR) nodes of the toolkit to capture live non-encrypted information, transmitted wirelessly from overflying aircrafts. By analysing the data received, students observe information related to different airplane routes and study several variables (e.g., compute the percentage of the aircrafts landing to JFK over all the aircrafts landing to NYC). Additionally, they use the web interface of the toolkit for the live visualization of those data. Through the lesson, students demonstrate their ability to use variables for representing quantities and apply them in solving mathematical problems. The curriculum aligns with the NGSS 'PS4 Waves and their Applications in Technologies for Information Transfer' [24, 25] and the Common Core Standards [20] on 'Expressions and Equations'[26], 'Ratios & Proportional Relationships'[27].

[1]All the developed lessons are available online at https://cosmos-lab.org/cosmos-toolkit/

3.5 Computer science – Cybersecurity

In this lesson, students are introduced to the concept of cybersecurity by exploring how computer networks and wireless communications can be encrypted/decrypted and by discussing personal privacy and security concerns. The experiments running on the toolkit, involve the exchange of real-time messages over the network between students, using different types of cryptography. More specifically, students use Caesar ciphers [28] for encrypting and decrypting messages and transmit encrypted messages to their classmates. The lesson helps them to understand how computer science terminology relates to coding and privacy, as well as how it is applied to modern Internet infrastructure. Through the exploration of cryptography, students visualize algorithms in the context of computational and wireless network security issues, and demonstrate their understanding of general algebraic concepts (e.g., group/ring theory, multiplicative groups, modular arithmetic). The developed curriculum aligns with the CSTA Computer Science Standards [29]: 1.2, 3.3, 6.3, and 7.3.

4 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 helps bridge the digital and equity divide providing significant educational benefits for the local community.

4.1 COSMOS PD Program

The PD program is divided into five conceptual phases: (i) lecture and lab phase: the teachers attend classes and perform experiments related to wireless communications; (ii) design phase: the participants explore potential educational NGSS STEM lessons with hands-on wireless labs using the educational toolkit; (iii) development phase: the teachers with the engineering team collaborate to develop their ideas; (iv) implementation phase: the participating teachers and their students evaluate the developed NGSS STEM lessons and wireless labs in their schools; (v) feedback phase: the teachers provide feedback to the project team that will help improving the existing labs.

4.2 COSMOS Research Testbed

The COSMOS testbed [9, 10] 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 components, programmable hardware, and open-source software. The testbed's architecture (Fig. 2) focuses on ultra-high bandwidth low-latency wireless communications, making it applicable for edge and cloud computing applications [30].

4.3 Hardware System

The COSMOS Educational Toolkit needs to support a wide range of applications and in Section 3 we show a few examples. The goal of the system is to provide students with a platform that enables wireless experimentation at a very low-cost. Inspired by the testbed's

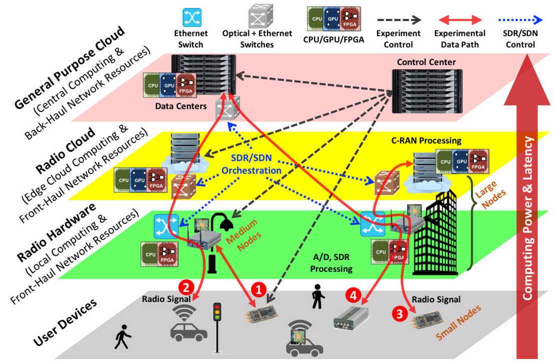

Figure 2: COSMOS' multi-layered computing architecture.

nodes we design the hardware system based on various off-the-shelf components, which, in combination with dedicated software, allow teachers and students to execute a vast number of real-world experiments. The components of the toolkit are evolving over the years through the PD program based on the requirements of the new lessons plans. In Fig. 3 we show the hardware setup of the toolkit, and in the next paragraphs we provide all the technical details.

(1) **Sofware defined radio (SDR):** Unlike traditional radios that are designed and configured to transmit and receive radio-frequency signals (RF) in a specific frequency range, an SDR can be reconfigured through software, based on the application. For instance, students can program the SDRs to receive ambient wave signals (i.e., FM and AM), transmit music and video between the nodes, study the effect of distance and obstacles on electromagnetic wave propagation and localize a hidden node based on the signal-strength of the wireless signal.
We selected two devices that meet the above requirements: (i) The ADALM PLuto SDR [31] developed by Analog Devices for educational purposes, providing hands-on experiences for college students taking digital and wireless communications classes. These transmitter/receiver devices can support a wide frequency range (70 MHz – 6 GHz); (ii) The RTL-SDR (RTL2832U) [32] device, which can receive radio-frequency signals from 500 kHz up to 1.75 GHz. This receiver device has very low cost which enables us to support more students.

(2) **Sensor nodes:** These are small battery-powered micro-controller devices with various wireless interfaces (i.e., XBEE, Wi-Fi, and Bluetooth). Theses devices are equipped with several sensors such as air and soil temperature, humidity, light luminosity and color, carbon dioxide (CO_2) levels, dust (PM1.0, PM2.5, PM4.0, and PM10), noise sensor, and accelerometer. Using the sensor nodes, the students can build a small scale wireless sensor network (WSN) and monitor the environmental conditions of their classroom, or collect measurements of a field trip to study phenomena such as the 'Heat Island Effect'. The students can deploy the sensor nodes in their class to study the popular Internet-of-Things (IoT) applications in their computer science classes. The measurements of the sensor nodes can also be used to study statistics in a mathematics class.
To develop the sensor nodes we selected the following sensors based on their specifications: (i) the air quality sensor

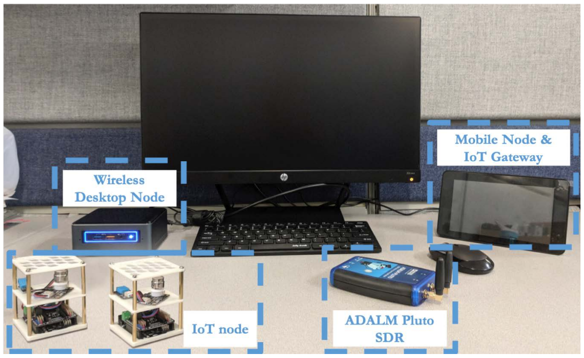

Figure 3: Hardware system of the COSMOS Educational Toolkit

SCD30 [33] from Sensirion with the nondispersive infrared sensor (NDIR) measurement technology for detecting CO_2, that has an integrated high-quality humidity and temperature sensor on the same sensor module, and provides measurements from 400 ppm to 10.000 ppm; (ii) the particulate matter (PM) laser-based sensor from Honeywell [34], that detects and counts particles using light scattering with concentration ranges from 0 µg/m3 to 1000 µg/m3.

(3) **Processing units:** For the processing units we selected the Intel NUC [35] since it is a small form factor computer with enough processing power to drive the SDR and perform the lab experiments in the class. Since this is a computer, it can be used for multiple purposes inside the class.
(4) **Mobile node:** For the experiments that require mobility or are performed outside of the classroom, we have a device based on the Raspberry-Pi [36] platform. This device allows students to collect real-time environmental measurements from the sensor nodes during field trips.

4.4 Software System

The software system [11] was designed around a web-based graphical interface Fig. 1 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 in the COSMOS testbed. The software system is divided into the following components:

(1) **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 communicating with a back-end server.
(2) **Web back-end server:** The server is based on the popular python programming language and is responsible to orchestrate the experiments and collect IoT measurements.
(3) **GNU radio:** An open-source software suite [37], that provides necessary signal processing blocks to implement software radios. It is used in combination with the Web front-end interface.
(4) **IoT management framework:** The measurements are collected by the server, stored in a database (influxdB [38]), and then analyzed and presented to the users using a visualization tool (Chronograf [39]).

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	4.0
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 EVALUATION

The developed PD program was evaluated during 2019 by an external evaluator, who examined whether the objectives of the program were achieved. The evaluator was appointed based on previous expertise that she had in similar education based projects, with focus on applications of technology, and thus was able to comprehend and evaluate the goals of the PD program. The evaluator collected data from the 2019 participants through the program, using online surveys as well as in-person interviews. The evaluator visited the program's site to conduct interviews with program personnel, mentors, and teachers.

A pre-survey was administered at the beginning of the summer program, during the intensive lecture series, and hands-on wireless activities. From the responses, 100% of participants strongly agreed or agreed that the lecture series were informative and interesting while 80% of them agreed that content contained more information than they could absorb during two-weeks.

A post-survey was administered at the conclusion of the summer program, with follow-up questions similar to those from the pre-survey, as well as additional questions specific to design and implementation phases from the PD program. The 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. Overall, the program received high ratings. The lecturers were praised by the participants for their deep understanding of the subject matter and their dedication to transferring their knowledge to the teachers, as well as their willingness to troubleshoot and give advice when asked.

Regarding the implementation of the COSMOS lessons in the classroom, teachers indicated the high need for support over the school year. In Table 2 the teachers' confidence level for support in teaching lessons is shown. Teachers believe that they will have access to computer for their students, however, the confidence for having sufficient support at the school if they run into difficulties is low.

Evaluating the impact of the COSMOS platform to their students, teachers gave high rates. When asked what they thought

Table 3: NGSS developed lesson plans

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

their students would be most excited about, many wrote about the integration of technology with hands-on activities:

- *Doing something with technology and having a hands on activity ... literally!*
- *Working with the toolkit and conducting hands-on experiments related to technology.*
- *Being able to do hands-on experiments.*
- *It's really cool to feel like you have access and knowledge about cutting-edge technology (5G)!*
- *The lessons make my content come alive in a hands-on way.*

Regarding the impact of the labs' content, teachers highlighted the following aspects:

- The use of sensors and the ability of analysing the data via the COSMOS Educational Toolkit.
- The fact that through the lessons students getting to know better how the Internet works.
- The fact that students have the ability to 'see' waves.
- Understanding how the math is used behind the technology they are exposed to everyday.

Between the 2018 pilot year and the 2019 cohort, a total of 79 teacher-created lessons integrated wireless technologies and STEM curricula (see Table 3). As the program is not limited to just the six-week summer session, 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 end of the summer workshop, attend and participate in various program stakeholder meetings throughout the academic year, and also host classroom visits from the COSMOS team during implementation of the toolkit lessons/activities over the academic year.

6 DISCUSSION

During the first two years of the PD program it focused on developing new lesson plans by brainstorming on ideas about bridging the gap between K–12 curriculum and the hands-on wireless experimentation. The current implementation of the PD program and the educational toolkit, although successful, have some limitations.

Since the PD program takes place in NYC, providing training for teachers in other states or cities is very challenging. The number of participants every summer is limited to 10, due to funding constraints. At the end of the summer we provide the participants with enough equipment so that they can run the experiments in their classroom. However, the most common request is for more equipment, since some of the participating schools have limited resources. The teachers have several ideas about new lessons based on newer trends such as virtual reality (VR), but these approaches are hindered by the high cost of the equipment.

Future implementations of the PD program will be focused on remote learning, providing tutorials and pre-recorded lessons from the participating teachers. This will help promoting the educational toolkit to more schools across the United States. Using these resources teachers that do not participate in the summer program and are interested in using the educational toolkit in their class can get familiar with the lessons and the wireless lab activities. Every teacher will get the same support from the research and the educational part of our team.

Furthermore, future plans include running the developed wireless labs remotely using the resources of the COSMOS testbed. During the first two years of the PD program the COSMOS testbed was in the pilot phase, since most of the technologies involved are targeting 5G and beyond experimentation. In the future, the teachers and the students will have the opportunity the use advanced SDR platforms (e.g., NI USRP-2974) with advanced millimeter-wave (mmWave) front-ends (e.g., IBM 28 GHz programmable phased array antenna modules [40]) that support several magnitudes of higher bandwidth. This will provide students with insights about the evolution technology based on the latest trends in wireless and cellular communications. The proximity of the COSMOS testbed to university campuses and public schools will enable the students to be opt-in users and take advantage of the cloud infrastructure. Using the testbed as an experimental educational platform, engaging especially underrepresented students in real-world engineering activities, will help us achieve our goal of addressing the K–12 digital and equity divide.

7 CONCLUSION

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 urban school districts that serve 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 middle and high school teachers and students; (iii) the development of the NGSS-aligned engineering lessons. Through follow-up sessions over the academic year, teachers received support for executing the engineering labs and implementing new NGSS-based lessons for their students. Future work includes: (i) Analyzing data of students' learning outcomes; and (ii) utilize the COSMOS Educational Toolkit, the NGSS lessons and the COSMOS research testbed to scale up the PD program.

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