Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45722

Collaborative Online Interactive Laboratory on Software Defined Radio Fundamentals

Dr. Otilia Popescu, Old Dominion University

Dr. Otilia Popescu received the Engineering Diploma and M.S. degree from the Polytechnic Institute of Bucharest, Romania, and the PhD degree from Rutgers University, all in Electrical and Computer Engineering. Her research interests are in the general areas of communication systems, wireless communications, control theory, signal processing and engineering education. She is currently an Associate Professor in the Department of Engineering Technology at Old Dominion University in Norfolk, Virginia. She served as the Program Director for the Electrical Engineering Technology Program. In the past she has worked for the University of Texas at Dallas, University of Texas at San Antonio, Rutgers University, and Politehnica University of Bucharest. She is a senior member of the IEEE.

Dimitrie C Popescu, Old Dominion University

Dimitrie C. Popescu received the Engineering Diploma with specialization in Electrical and Computer Engineering from Polytechnic Institute of Bucharest, Romania, and the Ph.D. degree in Electrical and Computer Engineering from Rutgers University, New Brunswick, New Jersey. He is currently a Professor in the Department of Electrical and Computer Engineering, Old Dominion University, Norfolk, VA. His research interests are in the area of wireless communication systems and include software defined and cognitive radios, spectrum sensing and dynamic spectrum access for cognitive radios, modulation classification, interference mitigation and transmitter/receiver optimization to support quality of service, vehicular networks, and signal processing for communications and radar systems. Dr. Dimitrie Popescu has served as ONR Senior Faculty Research Fellow at Naval Surface Warfare Center Dahlgren, and has also held summer prositions with AT&T Labs in Florham Park, NJ, and with Telcordia Technologies (formely known as Bellcore) in Red Bank, NJ. He is an active Senior Member of the IEEE currently serving as an Associate Editor for IEEE Sensors Letters and participating regularly in the technical program and organizing committees for the IEEE International Conference on Communications (ICC), IEEE Global Telecommunications Conference (Globecom), IEEE Wireless Communications and Networking Conference (WCNC), and IEEE Vehicular Technologies Conference (VTC). He has also served as Associate Editor for IEEE Transactions on Wireless Communications, IEEE Communications Letters, and the IEEE Open Journal of the Communications Society.

Emanuel PUSCHITA

Collaborative Online International Learning on Software Defined Radio Fundamentals

Abstract

Teaching of fundamentals of communication systems varies widely across programs in US and abroad, mainly due to the type of undergraduate engineering programs and the depth of the communications field within the curricula. The variety is spread across electrical engineering and electrical engineering technology programs, and programs with focus on telecommunications or which only offer core or elective courses in communications. Adding to the variety, some programs include hands-on laboratory courses, others include simulation-based laboratories most of the time using Matlab, while others may only include lecture courses with no labs. The accessibility of the new software defined radio (SDR) platforms offers the option to introduce unexpensive hardware equipment to support the laboratory component of any communications course setting. This paper presents a Collaborative Online International Learning (COIL) program, a partnership between an electrical engineering technology program in US and a telecommunication systems program in Europe, both undergraduate programs, based on software defined radio laboratories to introduce students to basic communication systems principles. The laboratories rely on using two hardware platforms, the RTL-SDR software defined radio receiver and the ADALM Pluto SDR. The paper presents the collaboration settings, describes the experiments used for the labs, and also discusses how the interactive online collaborative labs were received by the students.

Introduction

Teaching of communication systems principles varies widely across undergraduate programs and curricula, especially due to the specifics of the programs, and if the topic is treated as core material or is covered by elective courses. Depending on the level of presentation of the communications material, the courses may include lectures only or they may be accompanied by integrated hands-on components in the course or separate laboratories. For a while, for programs without specialized laboratories in communications systems, the easiest solution for a lab component was to use Matlab-based simulation experiments. This is still a very good approach in assisting students to visualize and practice the concepts covered in the communication courses. However, lately the radio and communication systems have been moving away from electronics-based hardware to software defined radio (SDR) platforms [1-3], and the pricing of such platforms became very accessible for individuals and educational settings. While top performance SDR platforms such as the Universal Software Radio Peripheral (USRP) [4] are still expensive and are usually considered for research purposes, the price range of under $50 for an RTL-SDR [5] is very affordable for a student or any individual who wants to experiment with radio receivers. RTL-SDR is a USB device using the Realtek RTL2832U chipset, which allows the device to convert received radio frequency (RF) signals to a stream of in-phase/quadrature (I/Q) samples that can be processed on a host computer, providing this way the capabilities of an SDR. Newer platforms such as ADALM Pluto SDR [6] offer better capabilities for a higher price, but for under $250 they are still at an affordable level for lab settings or even for individuals.

Various SDR platforms were introduced and used in the last decade in different classroom or research settings, with a recent monography on the use of SDR presented in [1]. The advantages of using SDR platforms in educational settings was largely discussed in the literature as shown in [7-16], as they were used for either course delivery or project-based learning. Within this setting, collaborative projects conducted between two or more institutions are even a higher step in developing hands-on learning activities for communication systems. While study abroad programs, which expose students directly to a different culture, are strongly encouraged for their benefits to the overall student education, they are not so easily accessible or affordable for a large group of students. The Electrical Engineering Technology (EET) student body at Old Dominion University (ODU) currently has more than half of its student population as non-traditional online students, located all around the country and working at least part time, with families to care for, and for such students traveling abroad even for short periods of time may not be feasible. Because of that, the opportunity to develop an online international collaborative program was immediately considered and the details of this collaboration are the focus of this paper. This idea of collaboration is not new and other collaborative learning projects are presented in the literature [17-20] and the term COIL for Collaborative Online International Learning was established at [21]. At ODU, this new initiative for an academic setting in which students can experience global cultural perspective in an accessible and convenient way is housed with the Office of International Collaborations [22].

Collaborative Project Settings and Results

The COIL project presented in this paper is one of the first conducted at ODU, and the first related to a specialized engineering course. We recognize that in the current world economy the students need exposure to global perspective and the understanding of becoming global citizens. When study abroad and traveling in person is not a feasible option, the online resources are the best to accomplish such goals. In addition, the current technology, especially after the experiences we all had during the Covid pandemic, provides plenty of resources for remote collaboration in all fields. The main goals of this COIL project were to provide students at participating universities with a hands-on laboratory experience that complemented the class lectures for courses in wireless communications systems and to expose them to a new culture. The participating universities were ODU located in the United States, in Norfolk, Virginia, and Technical University of Cluj-Napoca (TUCN) located in Cluj-Napoca, Romania, and the students involved in the project came from the EET program at ODU and from the Telecommunication Systems (TS) program in the Faculty of Electronics, Telecommunications, and Information Technology at TUCN. The students from ODU being from an undergraduate technology program have a lighter exposure to the communication systems material. The EET curriculum includes a 300-level core course on Communication Systems Principles that introduce students to frequency analysis and basic analog and digital modulation methods and a 400-level elective course on Wireless Communications Systems, which includes a broad presentation of various wireless related topics including digital modulation, basic networking with focus on MAC layer, propagation and channel modelling, cellular systems, antennas, satellites and vehicular networks. The students participating in this project were from the wireless communications course, which does not require the communications core course as a pre-requisite since the 400-level course is also open for the EET minor and for any student outside of the program with a minimum math and programming background. This is to say that part of the students participating in the project had no previous exposure to communication systems. Moreover, from the 16 students participating in the project 2 of them were Mechanical Engineering Technology (MET) students and had no previous background with the material covered in the project. Also, most of the ODU students were distance students, and they only participated in remote fashion to the project. The partners from TUCN were from a TS engineering program specialized in electronics and telecommunications and the participants in the project were part of required communication course. Their group of 15 students was all participating in person in their course and they were gathering in the lab for the project meetings.

The specific objectives of the COIL project included:

- Teaching fundamental concepts about software defined radios.
- Providing hands-on experimentation using the RTL-SDR software defined radio receiver (for ODU students) and the ADALM Pluto SDR (for TUCN students).
- Expose students at both universities to online collaboration and cultural exchanges.

Students participating in the COIL project at both universities have been asked to attend five 75-minute sessions scheduled outside of their regular class lectures during the Fall 2024 semester. Scheduling the five sessions was challenging because of the non-overlapping academic calendars for ODU and TUCN for the Fall 2024 semester and because of the 7-hour time difference between the US Eastern Time Zone where ODU is located, and the Eastern European Time Zone where TUCN is located. With TUCN starting the Fall semester on Oct. 1 and ODU ending the Fall semester on Dec. 6, the dates for the sessions had to be chosen to occur in the second half of October and the first part of November, to avoid also the Thanksgiving break observed in US. With these constraints in mind the five interactive sessions have been scheduled for Oct. 16, Oct. 23, Nov. 6, Nov. 13, and Nov. 20, from 9:30am to 10:45am US Eastern Time, which corresponded to 4:30pm to 5:45pm in the Eastern European Time Zone. The timing of the sessions was a good compromise for students at both universities, being not too early during the day for ODU students and not too late during the day for TUCN students.

Students were asked to use their personal laptops on which they were supposed to have installed a working copy of MATLAB using the campus licenses available at their respective universities. Minimum software requirements included MATLAB and Simulink along with the Communications Toolbox, and the hardware support packages for RTL-SDR and ADALM Pluto SDR were installed during the first session. The first project session was scheduled on campus in order to provide students with lab kits that contain the RTL-SDR receiver and an omnidirectional antenna (for ODU students) and ADALM Pluto SDR (for TUCN students) to use for the hands-on activities of the project. Students were allowed to keep the provided lab kits for the duration of the project, returning them to the instructors at the end of the project. Since most of the ODU students were registered online for classes and were not local to campus, they were given the option to come to the campus or participate online from their home to the rest of the sessions. The TUCN students were all attending live classes, and they were meeting in person in their lab for all the meetings, from where they connected to the online meetings with the ODU team. Note that due to the affordability of the RTL-SDR kit all online and several of the local ODU students chose to buy their own hardware, and they expressed interest in keeping it and possibly experimenting more with it outside the class. To assist them with the SDR programming, students were recommended to use the comprehensive reference [23], which is available for free download.

From each university seven teams of 2-3 students were formed. A student team from each university was paired with a team from the other school, to enable students to collaborate on the lab experiments performed and to engage in online discussions to get to know each other better. For online interaction the Microsoft Teams platform was used, to which both universities had licensed access, and a dedicated Teams group was established by the TUCN faculty for all participants in the COIL project. During each session specific activities were covered as follows:

- Session 1 (Oct. 16): the COIL project instructor team at both universities was introduced to students, with a brief overview of cross-cultural communication and online collaboration etiquette presentation given by the Global Engagement Coordinator at ODU. This was followed by ice breaking activities between the two teams, designed to get the students to know each other and become familiar with their teams.
- Session 2 (Oct. 23): students were given an online lecture introducing SDRs and their capabilities to visualize radio signals in time and frequency domains using the signal I/Q components, amplitude spectrum, and spectrogram. The lecture was followed by a hands-on interactive period dedicated to setting up the SDRs, after which the students used them to visualize signals in the FM bands using the "Spectrum Analysis of Signals" examples available at [24] or [25]. Figure 1 shows the Simulink diagram of the RF spectrum analyzer and an example of the simulation result.

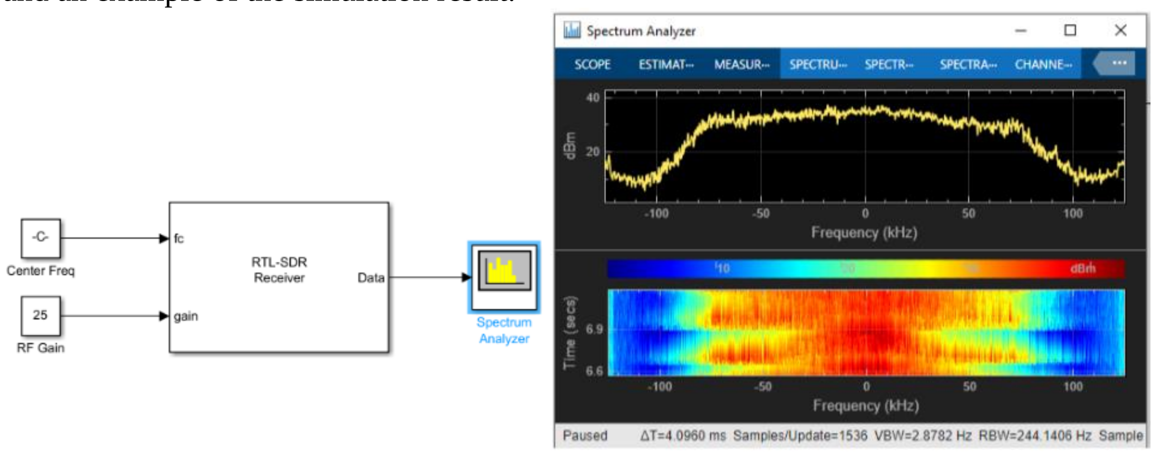

Figure 1. RF Spectrum Analyzer and Simulation Results

- Session 3 (Nov. 6): students completed another hands-on activity implementing a digital FM radio receiver following the "FM Broadcast Receiver in Simulink" examples available on the MathWorks website [24] (for RTL-SDR) or [25] (for ADALM Pluto SDR). For the Mono FM radio receiver experiment conducted with the RTL-SDR the Simulink block diagram is presented in Figure 2, and the experiment results are presented in Figures 3 and 4, for time and frequency domains respectively.

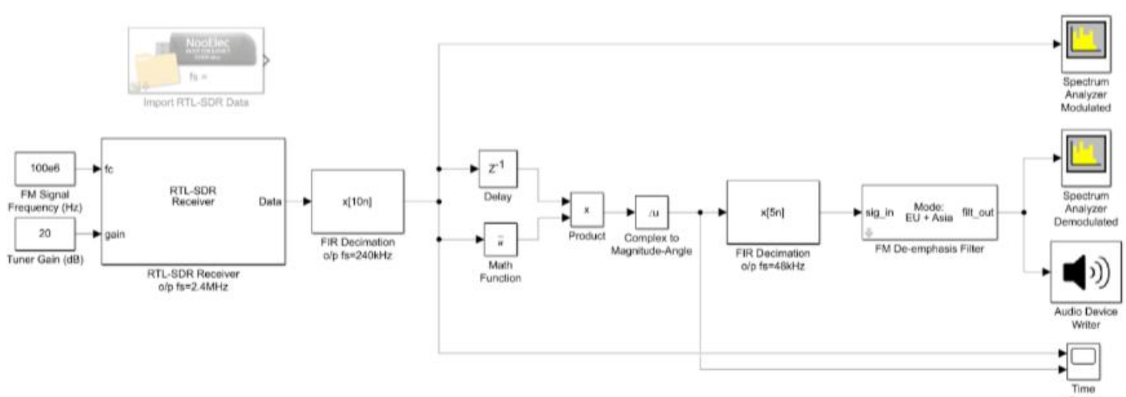

Figure 2. The Simulink Block Diagram for the Mono FM Radio Receiver Experiment

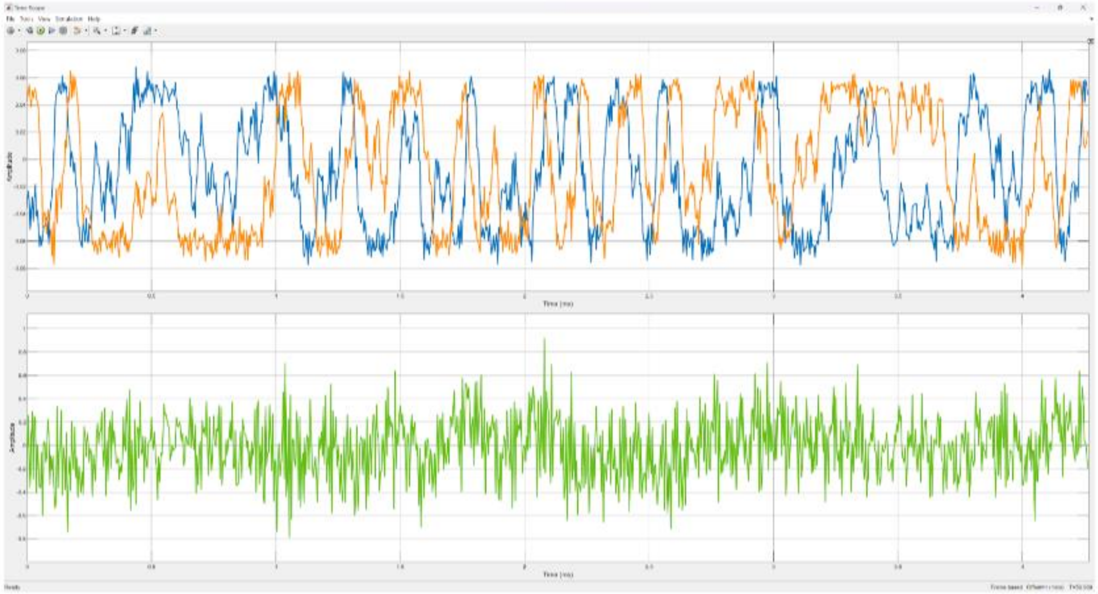

Figure 3. Time Domain Graphs of the Amplitude Response for the Mono FM Receiver

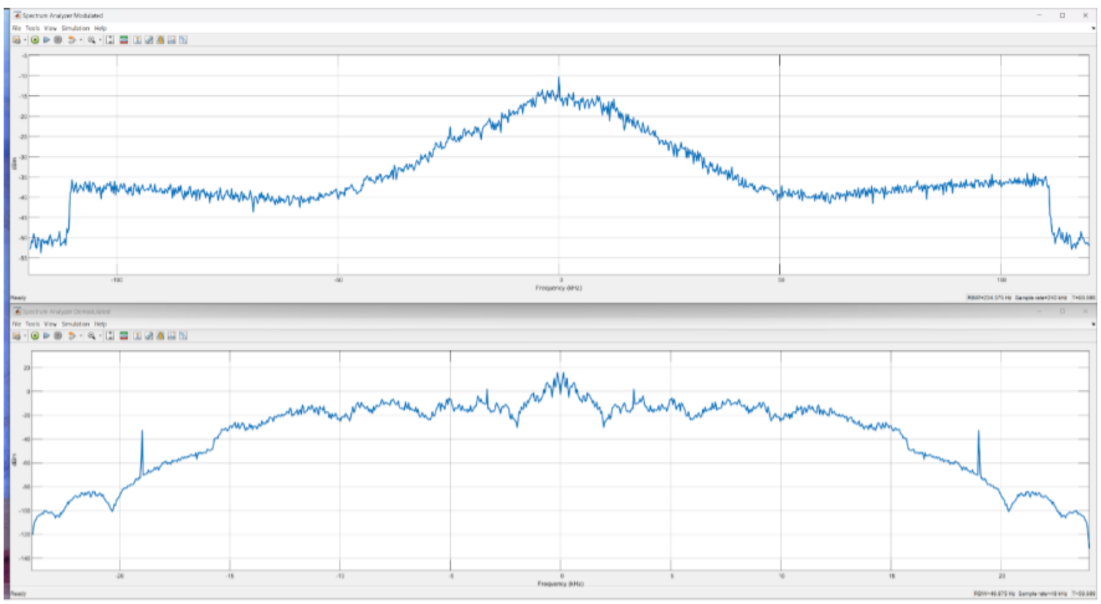

Figure 4. The Modulated vs. Unmodulated Spectrum Analyzer output of the Mono FM Receiver Experiment

- Session 4 (Nov. 13): students implemented a 3D simulation of their respective campuses in MATLAB to analyze communication links and coverage areas for cellular base stations following the “Urban Link and Coverage Analysis Using Ray Tracing” example available on the MathWorks website [26] and extracting the details regarding the mapping of the base stations and other relevant specifications needed using the CellMapper (https://www.cellmapper.net/map) and Google Earth (https://earth.google.com/) websites.

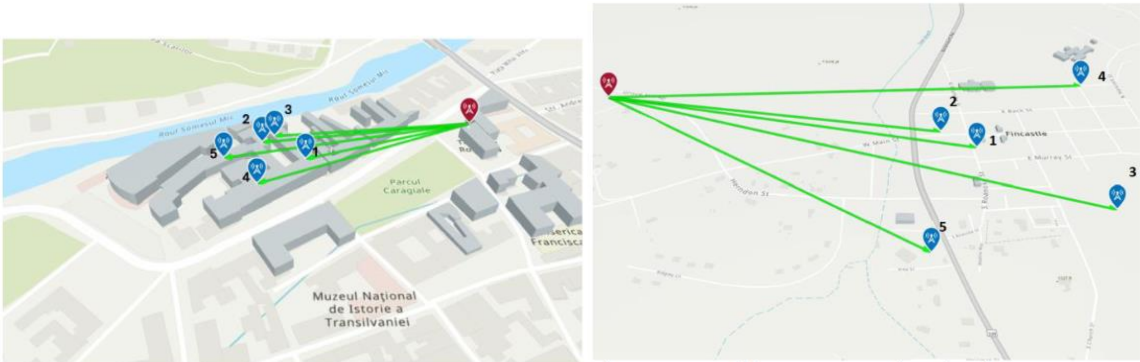

Figure 5. Graphical rendering of the two University Campuses, showing Tx and Rx locations for coverage analysis

- Session 5 (Nov. 20): students were asked to define a set of measurement points on their campus maps and to take measurements (before the session) of the received spectrum using their RTL-SDR or ADALM Pluto SDR devices from the neighboring cell towers, as discussed in the previous lab session. During the class, students compared their measurements taken on campus with the simulation results obtained running the MATLAB simulation and evaluated the accuracy of the implemented simulation scenario in terms of its use as a radio planning tool. The students were asked to work in mixed groups allowing students from one campus to compare simulated results with actual campus measurements taken by their partners located in the other campus.

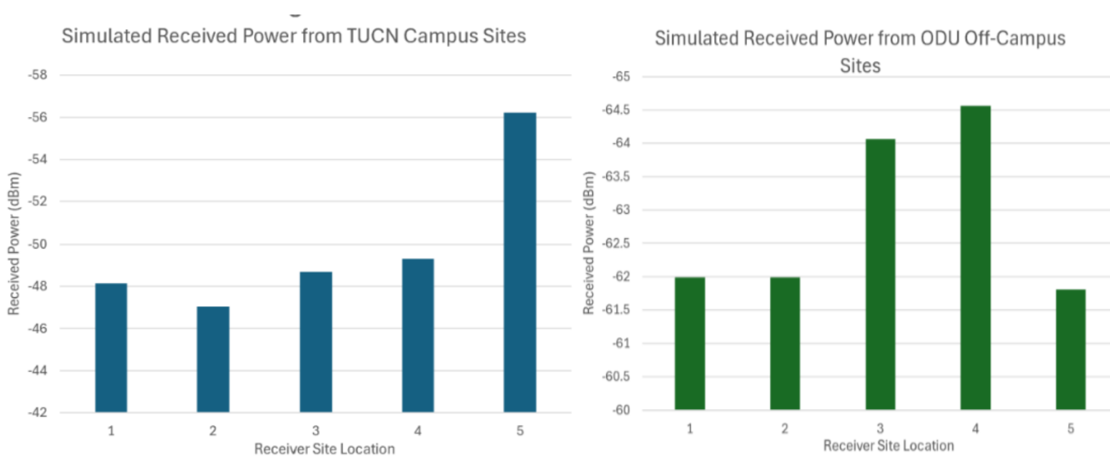

Figure 6. Simulated Received Power for the Two Campuses

Because radio systems are best experienced in an open environment that is free of obstructions, students have also been encouraged to perform additional hands-on activities on their own that were similar to the ones discussed during the lab sessions, which they would summarize as part of their term project reports for the wireless communication systems classes they took during Fall 2024 semester.

EET students were also asked to pick and extra exercise of their choice to experiment with the RTL-SDR to perform with their team and include in the final report. For this additional exercise they were directed to use the [23] reference. The range of these additional experiments varied from basic AM-DSB-SC (amplitude modulation, double side band suppressed carrier) modulation, to phase locked loops (PLL) with phase detectors and loop filters, and a reconstructed image transmitted via FM, as shown in Figure 7 where the image of a Christmas tree was decoded from an FM transmission.

Figure 7. Reconstructed Image of a Christmas Tree Transmitted via FM

The Cultural Component

The student teams consisting of 2-3 students from each of the two universities were paired one-to-one with the goal for the students to collaborate on the experiments but, more importantly, for them to get in touch and get to know each other. Other than the official project meetings and platforms the students were strongly encouraged to contact each other and engage in discussions outside of the class. For this they shared their email addresses and then it was up to each group to use any other social platform if preferred. While the US students were more open and easier to engage, their partners were more reserved and not so easy to get to talk. Because of this the Global Engagement Coordinator from ODU initiated two Padlet [27] activities to stimulate student engagement. The Padlet platform is great for social interactions because all the postings are open to the whole group, and everybody can comment to a posting or respond to questions. With everybody seeing everything that is posted the whole group gets to know each other better and an inclusive environment is created. The first Padlet activity was for each person in the group to introduce themselves with “3 things and 1 I wish I could item” about themselves. This really stimulated the students and postings started to flow. Participants listed funny things about themselves, hobbies, experiences that marked them, or special accomplishments. Such special accomplishments included one student who hiked the entire 2190 miles of the Appalachian Trail, or another student who visited all 50 US states. People also expressed interest in sports, music, cooking and traveling, and it was nice to see that both groups shared similar hobbies and interests. The second Padlet activity was mostly related to the countries of each participant and cultural aspects. Students were to post a cultural question for the other team. This activity also stimulated a lot of discussions with each question engaging several responses and comments. Questions raised were related to music, sports, movies, city settings, specific holidays and very much about cooking and specific dishes for which even recipes or websites were included. Overall, these activities were very much enjoyed by the two groups, and they helped to break the barriers and get the students to talk to each other. After the project, several students expressed interest in learning more about the other country and even travel there if the opportunity will be given.

Students' Feedback

This was the first time the authors worked on such collaborative project and some of the details were updated during the semester. Because of this, the students' feedback was very important. The faculty were continuously communicating with the students about the settings and to assist them with any help needed. Furthermore, to get a better understanding of the students' perspective and to be able to learn from their experience for any future implementation of a similar project, two surveys were conducted, one at the very beginning of the project and another one after its completion. 28 students participated in the pre-survey and 23 in the post-survey. The questions of the pre-survey were related to their theoretical background for the project and their familiarity with programs from other countries, and the post-survey was asking students about the learnings from this project both in terms of technical and cultural aspects. The results of these surveys are summarized below.

- Theoretical background:

- Familiarity with frequency representation of signals:
  Prior to the project: good understanding 39%; somehow familiar 57%
  After the project: project helped to understand the concept 78%; project somehow helped 13%.
- Familiarity with basic modulation methods:
  Prior to the project: good understanding 43%; somehow familiar 54%
  After the project: project helped to understand the concept 70%; project somehow helped 26%.
- Familiarity with SDR:
  Prior to the project: not at all 61%; somehow familiar 28%; familiar 11%
  After the project: project helped to understand the concept 57%; project somehow helped 39%.
- Familiarity with spectrum monitoring basics:
  Prior to the project: not at all 25%; somehow familiar 57%; familiar 18%
  After the project: project helped to understand the concept 52%; project somehow helped 43%.

Some of the questions were related to the technical settings of the project and from those it is important to note that 78% of the students found the SDR experiments moderately challenging to implement and 22% of them found them easy to implement. Also, asked about the quality and reliability of the hardware used, 17% of the students found it excellent, 57% good, and 26% fair.

- Cultural Component:
  Pre-survey

- Previous work in online team projects: yes 46%; no 54%.
- Previous participation in a cross-cultural collaboration project: yes 29%; no 71%.
- Previous familiarity with programs abroad: not at all 64%, to some degree 32%, familiar 4%.
- Find intercultural communication skills important for academic and professional growth: very important 89%, somehow important 11%.

  Post-survey

- How effective was the collaboration between teams: very effective 13%, somehow effective 74%, not effective 13%.
- How well did you communicate with your partners: very well 26%, somehow well 57%, poorly 17%.
- Did this project make you curious to learn about Romania/USA or other cultures? Significantly 57%, Somewhat 30%, no 13%
- After this project do you feel more comfortable to work with people of different cultural background: Significantly 70%, Somewhat 26%, no 4%.

- Would you participate in another online international collaboration: yes 78%, maybe 22%.

Based on the survey results, as well as on the comments students made in their final course reports or directly to the faculty, the project was very successful. From a teaching perspective the hands-on approach stimulated student learning and helped students to better visualize and understand the concepts learned in class. Even though both groups were undergraduate students, the EET students had a lighter theoretical background with almost half of them having no prior background in communication systems, or even on frequency representation of signals. However, the entire group performed very well, and the hardware-based experiments helped the students to learn the concepts. The cultural component of the project made it interesting and exciting for all. While the two project components were well balanced, it became apparent that the students would have a stronger cultural component with activities facilitating more cross-cultural exchanges. For an open-end question in the post-survey, most of the comments were that they would have liked more meetings, a longer time allocated for the project and more common activities.

Conclusions

This paper presented the details of a first implementation of a COIL project between ODU and TUCN. The project focused on the SDR based experiments for communication systems and involved two groups of undergraduate students from different types of programs. The authors find the project to be very successful and the students' feedback support this finding. The hands-on component strongly motivated the students to experiment and helped them learn. The partnership between the two teams added the cultural component which made the project very attractive and stimulated students' interest in the project and in the other culture as well. Such project settings offer an excellent alternative to study abroad, with the benefit of affordability and flexibility.

Acknowledgements

The authors would like to thank all the students participating in the project, from both universities, for their enthusiasm, commitment to the project and flexibility. Special thanks also to Dr. Scott Berlin, the Global Engagement Coordinator at ODU, for his assistance in establishing the partnership and for the strong support with the cultural component of the project. We also thank the entire faculty team from TUCN, Dr. R. Buță, Dr. C. Codău and Dr. A. Păstrăv, who participated in developing and delivering the ADALM Pluto lab experiments.

References

[1] Popescu, D. C. and Vida, R. A Primer on Software Defined Radios. *Infocommunications Journal*, vol. 14, no. 3, pp. 16–27, September 2022.

[2] Molla, D. M. & Badis, H. & George, L. & Berbineau, M. Software Defined Radio Platforms for Wireless Technologies. *IEEE Access*, vol. 10, pp. 26203–26229, February 2022.

[3] Ulversoy, T. (2010). Software defined radio: Challenges and opportunities. *IEEE Communications Surveys & Tutorials*, *12*(4), 531-550.

[4] El-Hajjar, M. & Nguyen, Q. A. & Maunder, R. G. & Ng, S.X. Demonstrating the Practical Challenges of Wireless Communications Using USRP. *IEEE Communications Magazine*, vol. 52, no. 5, pp. 194–201, May 2014.

[5] https://www.rtl-sdr.com/product/rtl-sdr-blog-v4-r828d-rtl2832u-1ppm-tcxo-sma-software-defined-radio-with-dipole-antenna/

[6] https://www.digikey.com/en/products/detail/analog-devices-inc/ADALM2000/7019661

[7] S. G. Bilén *et al*., "Software-defined radio: a new paradigm for integrated curriculum delivery," in *IEEE Communications Magazine*, vol. 52, no. 5, pp. 184-193, May 2014, doi: 10.1109/MCOM.2014.6815911.
[8] Mao, S., & Huang, Y., & Li, Y. (2014, June), *On Developing a Software Defined Radio Laboratory Course for Undergraduate Wireless Engineering Curriculum* Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana. 10.18260/1-2—22880
[9] Wu, Z., & Wang, B., & Cheng, C., & Cao, D., & Yaseen, A. (2014, June), *Software Defined Radio Laboratory Platform for Enhancing Undergraduate Communication and Networking Curricula* Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana. 10.18260/1-2—23023
[10] A. M. Wyglinski, D. P. Orofino, M. N. Ettus and T. W. Rondeau, "Revolutionizing software defined radio: case studies in hardware, software, and education," in *IEEE Communications Magazine*, vol. 54, no. 1, pp. 68-75, January 2016, doi: 10.1109/MCOM.2016.7378428.
[11] VonEhr, K., & Neuson, W., & Dunne, B. E. (2016, June), *Software Defined Radio: Choosing the Right System for Your Communications Course* Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.25838
[12] Gabulov, Azik (2017) Demo for the Communication Course using LabView software and software defined radio.
[13] Inonan Moran, M. J., & Paul, A., & May, D., & Hussein, R. (2023, June), *RHLab: Digital Inequalities and Equitable Access in Remote Laboratories* Paper presented at 2023 ASEE Annual Conference & Exposition, Baltimore, Maryland. 10.18260/1-2—44150
[14] H. Miyashiro, M. Medrano, J. Huarcaya and J. Lezama, "Software defined radio for hands-on communication theory," *2017 IEEE XXIV International Conference on Electronics, Electrical Engineering and Computing (INTERCON)*, Cusco, Peru, 2017, pp. 1-4, doi: 10.1109/INTERCON.2017.8079722.
[15] O. Popescu, S. Abraham, S. El-Tawab, "A Mobile Platform Using Software Defined Radios for Wireless Communication Systems Experimentation", *Proceedings 124th ASEE Annual Conference*, June 2017, Columbus, Ohio.
[16] O. Popescu, V. Jovanovic, A. Djuric, "Low Cost Solutions for Wireless Communication Systems for Undergraduate Engineering Technology Students", in *Technology Interface International Journal* (TIIJ), Vol.17, No. 1, Fall/Winter 2016, ISBN 1523-9926, pp 125-131. http://tiij.org/issues/issues/fall2016/fall_winter_2016.htm
[17] Rodriguez-Sanchez, M. C., Chakraborty, P., & Malpica, N. (2020). International collaborative projects on digital electronic systems using open source tools. *Computer Applications in Engineering Education*, *28*(4), 792-802.
[18] Gelonch-Bosch, A., Gonzalez-Rodriguez, M., & Marojevic, V. (2019). Collaborative-competitive methodology for wireless communications system education. *IEEE Communications Magazine*, *57*(11), 41-47.
[19] Nooshabadi, S., & Garside, J. (2006). Modernization of teaching in embedded systems design-an international collaborative project. *IEEE Transactions on Education*, *49*(2), 254-262.
[20] Dietrich, C. B., Polys, N. F., Hearn, C. W., Reid, K., & Sheridan, J. A. G. (2021, July). WIP: Collaborative Undergraduate Research Project to Develop a Remotely-Accessible,

Open-Source, Portable, Software-Defined Radio-Based Antenna Range for Research, Education, and Outreach. In *2021 ASEE Virtual Annual Conference Content Access*.
[21] https://collab-edu.com/hub/coil/p/whatiscoil
[22] https://www.odu.edu/international-collaborations/coil
[23] B. Stewart, K. Barlee, D. Atkinson, L. Crockett, A. Broadhurst, *Software Defined Radio Using Matlab & Simulink and the RTL-SDR*, available for free download in PDF format at https://www.desktopsdr.com/download-files.
[24] MathWorks Help Center, *RTL-SDR Radio Examples*, https://www.mathworks.com/help/comm/examples.html?category=rtlsdrradio
[25] MathWorks Help Center, *ADALM-Pluto Radio Examples*, https://www.mathworks.com/help/comm/examples.html?category=plutoradio
[26] MathWorks Help Center, *Urban Link and Coverage Analysis Using Ray Tracing*, https://www.mathworks.com/help/comm/ug/urban-channel-link-analysis-and-visualization-using-ray-tracing.html
[27] https://padlet.com/