



RESEARCH ARTICLE

Evaluating the Educational Effectiveness of Radar Systems Laboratory Sessions in the Undergraduate Curriculum

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Citation:

Yalcinkaya, B., Benzaghta, M., Coruk, R.B., Kara, A. (2024) *Evaluating the Educational Effectiveness of Radar Systems Laboratory Sessions in the Undergraduate Curriculum*, Journal of Science, Technology and Engineering Research, (5) 2:186-198. DOI: 10.53525/jster.1571904

HIGHLIGHTS

- A full laboratory module for undergraduate radar systems courses.
- Iterative design of modular radar system as well as fully operational commercial radar platform.
- Educational effectiveness measurement: both quantitative and qualitative assessments of the proposed teaching method.

Article Info

Received: October 22, 2024

Accepted: December 3, 2024

DOI:

10.53525/jster.1571904

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ABSTRACT

Introductory courses regarding radar technologies are very popular in the undergraduate curriculum of many electrical and electronics engineering programs. Hands-on experience is crucial for understanding the theoretical concepts covered in lectures. However, acquiring experimental radar systems is often unaffordable, especially for universities in developing countries. This paper presents a detailed description of a cost-effective, easy-to-deploy radar system laboratory sessions and measures the educational effectiveness of the proposed material. The provided radar models allow undergraduate students to grasp the working principles of frequency modulated continuous wave (FMCW) radar systems, as well as assist graduate-level research activities. The educational effectiveness of the laboratory sessions was assessed through both qualitative and quantitative methods, focusing on the proposed learning process and students' performance. The results indicate that the proposed lab sessions have increased the students' understanding of the course topics, and the students' general perception is positive.

Keywords: Educational Technology, Engineering Education, Frequency Modulated Continuous Wave, Radar Systems

I. INTRODUCTION

Research in engineering education has progressed significantly over the years, with rapid technological advancements introducing new teaching and learning methods [1,2]. In faculty of engineering, improving the effectiveness of education is a critical concern, given the complexity of self-learning and the requirement of advanced computational skills [3]. Numerous applications, such as project-based learning, computer-based simulation tools, and hands-on laboratory sessions, have been implemented to enhance traditional teaching approaches [4-6].

Introductory radar technology courses are essential for deepening students' knowledge and equipping them to apply concepts to practical engineering challenges, such as advanced driver assistance systems, autonomous driving, industrial applications, and defense technologies [7]. However, years of teaching experience have revealed a common challenge: students often struggle to apply theoretical radar concepts to real-world scenarios. To illustrate, interpreting the radar baseband signals and reasoning the use of Fourier transform to transfer the echoed signal into range calculations are examples of such concepts that undergraduate students have difficulties understanding. Thus, laboratory sessions designed to complement in-class lectures are essential.

A laboratory model of five training sessions was proposed in [8]. The sessions demonstrate the use of monopulse tracking systems and their use cases in engineering applications. An experimental setup based on the use of commodity WiFi hardware, two commercial panel antennas, and MATLAB signal processing package was presented in [9] to teach amplitude monopulse radar models. In [10], hands-on learning modules were proposed for teaching weather radar applications. The learning modules provide theoretical and practical understanding by allowing students to visualize and analyze weather data. A frequency modulated continuous wave (FMCW) based Synthetic Aperture Radar (SAR) lab model was developed in [11]. Two simple SAR methods were applied on the data obtained from a 24 GHz FMCW radar implemented on a linear drive for educational purposes in [12], and a similar model based on the use of a Vector Network Analyzer was proposed in [13]. In [14], the material described the development and testing of low-cost Inverse Synthetic Aperture Radar (ISAR) turn table system having a machine learning back end. These radar lab models were found to be very useful for both undergraduate and graduate students in their research activities. Also, an X-band lab model of SAR was given in [15]. However, many of these approaches rely on components that are either expensive or not readily available.

A firmware program was given in [16] regarding interactive control of an FMCW ground-penetrating radar (GPR). Students were able to realize control functionalities; for example, selecting the signal period, frequency range, and waveform type of the transmitted signal. Similar methods were proposed in [17,18], in which students built their own radar systems from provided kits of off-the-shelf components and made use of simulation environments to understand the operational concepts of FMCW radars. In [19], the authors presented a phased array, multiple-input, multiple-output radar system built for educational uses. Students were able to build and test those radar systems. A set of RF and Microwave modules that may be accumulated into a short-range modulated scattered radar system was given in [20]. The module blocks were used by students in the senior and graduate level curriculum.

An approach to substitute laboratory experiments with virtual sessions utilizing advancements in computer technology and electromagnetic modeling software was presented in [21]. An Android-based electronic module application having an intuitive graphical user interface was proposed in [22] for science, technology, engineering, and mathematics (STEM) education. The application was used to teach advanced signal processing systems such as Radar, Lidar, and Sonar. The application provided students the ability to determine distances to objects by allowing them to virtually manipulate several signal shapes, signal envelopes, and frequency constraints. In [23], employing a systematic literature review methodology, the necessity of a virtual electronics laboratory to enhance students' learning process is investigated. Along with several research questions, the need for an aeronautical radar simulator to increase the efficiency of learning in education is pointed out. Simulation based experiments are very useful, as they can provide understanding of the physics phenomena's that could be difficult to understand when using a lab-bench approach.

Although simulation-based experiments are attractive due to the advantages mentioned, they cannot replace the hands-on experience of building real radar systems and performing real-time advanced measurements to fully understand the operation concepts of those systems [21]. Different from many examples of hands-on radar laboratory sessions that can be found in literature [8,9,24-26], which rely on extensive and expensive projects, this study presents a laboratory module for undergraduate radar courses that emphasizes cost-effectiveness, ease of deployment, and alignment with lecture topics. The module includes ten laboratory sessions that incorporate both modular radar system design and fully operational commercial radar platforms.

The contributions of this study are as follows: it presents a full laboratory module for undergraduate radar systems courses, consisting of ten laboratory sessions which are structured based on the lecture topics. The proposed laboratory structure includes iterative design of modular radar system as well as fully operational commercial radar platform. Importantly, unlike previous studies, this paper evaluates the educational impact of the proposed materials on students' success using both qualitative and quantitative assessments. The findings offer new insights into the effectiveness of radar laboratory sessions.

The rest of the paper is organized as follows: In section 2, the proposed laboratory sessions are described along with the quantitative and qualitative measurement methods regarding the effectiveness of the developed materials. In section 3, we provide the results of the assessments. Finally, section 4 draws conclusions and points out potential future work.

II. MATERIALS AND METHODS

In this section, we provide a detailed description of the two different radar system setups that have been used in the laboratory sessions, followed by an explanation of the objectives and the methods used for each session.

A. Experimental Setups

Laboratory sessions based on FMCW radar systems are examples of real-world applications, invested in extensive physical and mathematical contents. The laboratory sessions focus on FMCW radar systems, which emphasize frequency-domain operations over conventional time-domain methods. Therefore, spectral and phase analyses are needed to determine the range and velocity of a variety of targets. Thus, to proceed with the laboratory sessions, students are introduced to signal processing topics such as Fourier transform, sampling as well as amplifiers and filters. In the proposed laboratory structure, two different types of FMCW radars were used;

- Radar-I: A fully modular system operating in 4.4-4.9 GHz band.
- Radar-II: A commercial radar platform operating at 77-81 GHz band.

The former is intended to develop module/component level RF design of a radar system while the latter aims to develop signal analysis, functionality as well as operational aspects of a radar system.

1) Radar-I

A low-cost modular FMCW radar system has been developed at our university's Radio Research Laboratory (RRL) for research and educational purposes [27]. It consists of key components such as a voltage-controlled oscillator (VCO) for signal generation, a DC power supply for offset voltage adjustment, a splitter, a mixer, a low-pass filter (LPF), a low-noise amplifier (LNA), and a power amplifier. Operational testing has been done in the university laboratory, using metal plates as targets. The received signals are analyzed by using a spectrum analyzer (SA). Radar-I operates with a bandwidth of 525 MHz, offering a 30 cm range resolution. In Figure 1, the prototype of the radar is shown along with the manufacturer code numbers.

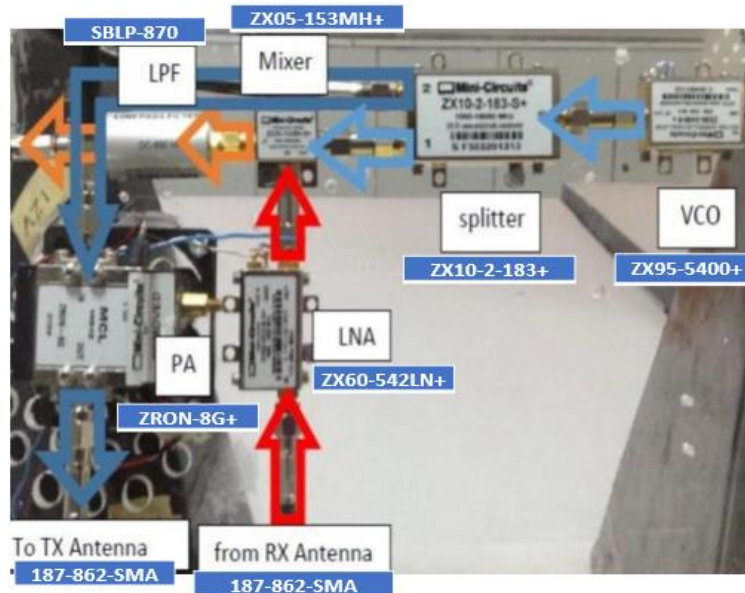


Figure 1. Radar-I Modular FMCW radar system.

2) *Radar-II*

A commercial-of-the-shelf (COTS) millimeter wave (mmWave) FMCW radar system, has been used as the second type of radar in the proposed laboratory sessions. The radar platform consists of an AWR1642BOOST evaluation module which has two transmit and four receive PCB antennas, also a DCA1000EVM data capture card that is connected to the PC for post-processing using the mmWave Studio program. The radar system operates with 4 GHz available bandwidth, allowing users to employ different applications, i.e., radar cross section (RCS) measurements, range determination, and velocity and angle estimations [28]. In Figure 2, the functional block diagram of AWR1642 is shown. As shown in the figure, the individual modules used in Radar-I are compactly integrated in Radar-II, providing students with insights into diverse radar configurations.

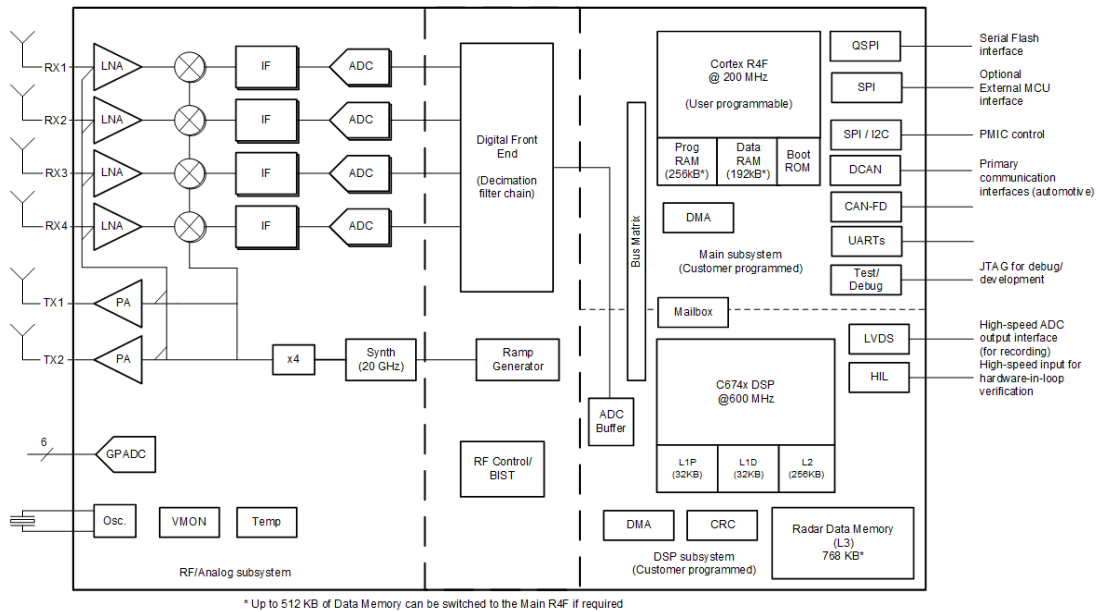


Figure 2. Functional Block Diagram of Radar-II [29].

B. Laboratory Sessions

In the laboratory sessions, two types of radar systems described previously, and their modular components are used for teaching fundamental and advanced concepts. While Radar-I is used in sessions from 1 to 8, Radar-II is featured in sessions 9 and 10. Students are first introduced to each of the modular components which were used to build the FMCW radar, as described in sessions from 1 to 5. Later, understanding the use of the complete radar system and performing experimental measurements are done in sessions from 6 to 8. The last two experiments (9-10) introduce the compact commercial off-the-shelf radar version of the previous experiments. Laboratory experiments and course videos are shared online to enhance accessibility [30]. The details of the lab session are as follows:

1) *FMCW radar waveform generation*: Understanding the operation of Voltage Control Oscillator (VCO), FMCW signal generation using VCO, and experimental analysis of FMCW signals in the frequency domain are performed in this lab session. VCO is connected to the DC voltage supply and an analog wave generator. These are adjusted to tune with the frequency in the range of 4200 MHz to 4600 MHz. The output is connected to a SA to see the generated FMCW signal in the frequency domain.

2) *Up/Down conversion*: Understanding frequency mixing in FMCW Radar systems, and experimental analysis of the use of the mixer for down conversion are given in this lab session. The original signal to be down converted is at 4272-4600 MHz band. The aim is to obtain a down-converted signal at a frequency over 272-600 MHz. The original signal is transmitted using the VCO and applied to the RF input port of the Mixer. A signal generator is used to transmit a signal of frequency 4000 MHz to the LO input port of the Mixer. The output (IF port of the Mixer) is connected to an SA in order to observe the down converted signal spectrum.

3) *Amplification and attenuation*: Experimental analysis of Power Amplifiers (PA) and Low Noise Amplifiers (LNA) for use in FMCW radar systems and understanding of amplification and attenuation of RF signals are implemented in this lab session. The experimental setups are given in Figure 3. The experiment is conducted in two parts using PA and LNA, separately. Experimental setups are set up to observe the power of the signal. This process is repeated for different bandwidths and for different attenuator values (e.g., 3 dB, 10 dB, and 15 dB).

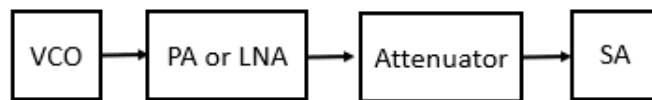


Figure 3. Amplification and attenuation experimental setup for PA and LNA.

4) *Signal mixing and filtering*: Analysis of the use of the combination of a mixer and an LPF in FMCW radar systems is performed in this lab session. By repeating the procedures in Experiment 2, an IF signal is obtained at the mixer output. The presence of harmonics beyond the desired wideband down-converted signal (270-783 MHz) is interpreted. On the other hand, the output of the mixer is connected to LPF. Results are compared using SA to understand the effect of the LPF.

5) *Antennas, connectors, and cabling*: Basic concepts regarding antenna gain and connectors/cabling loss are covered in this lab session, as well as analysis of the radio link in terms of link budget. The experimental setup of this experiment is given in Figure 4. In this experiment, the received signal power is going to be recorded from the SA for different separation distances between the two antennas, as well as for different frequency bands. Finally, the theoretical values of the received signal power are compared with the experimental values. The difference margins between the theoretical and experimental results are discussed and analyzed.

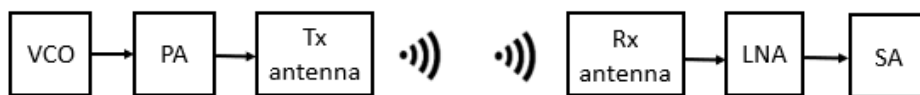


Figure 4. Experimental setup for radio link.

6) *Modular transmitter design:* The modular transmitter design used for the FMCW radar system is explained in this lab session. Furthermore, the experimental analysis regarding determining the radar range is performed. Using the recorded received signal on the SA at different distances, the link budget equation is written and all the losses (cable, connectors, channel, etc.) are estimated. The bandwidth of the FMCW signal is determined such that the range resolution is 30 cm. The range resolution formula is given as $d_{res} = c/2B$ where B is the bandwidth of the signal and c is the speed of the light. The maximum distance between the Tx and Rx has been estimated such that the peak power to noise power level is higher than 25 dB.

7) *Modular receiver design:* The modular receiver design used for the FMCW radar system is given in this lab session. Additionally, determining the RCS of a reflector plate is measured by performing an experimental demonstration to the students. The experimental setup is given in Figure 5. The FMCW radar used in this experiment is a monostatic radar system. In this experiment, the received signal power is recorded from the SA for different separation distances between the radar and the target. Using the radar range equation formula given in (1), the RCS (σ) of the target at every distance of observation is estimated.

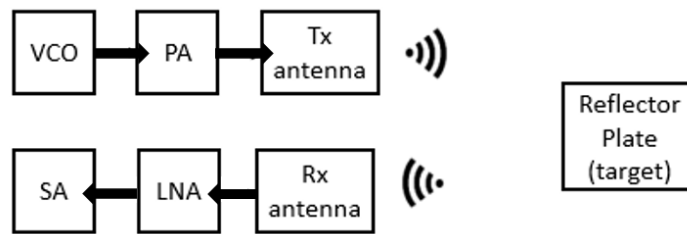


Figure 5. Experimental setup for radio link with reflector.

$$R_{max} = \left(\frac{P_t G^2 \lambda^2 \sigma}{(4\pi^3) S_{min}} \right)^{\frac{1}{4}} \quad (1)$$

where R_{max} refers to the distance that the received power is measured at, S_{min} is the recorded received power from the SA, P_t is the transmitted power, G is the gain of each antenna, and λ is the wavelength at the desired frequency.

8) *Modular radar design:* This lab session focuses on explaining the complete modular FMCW radar design given in Figure 1, as well as performing several experimental analyses for determining the range of targets. The target used in the monostatic radar system is a metallic plate (reflector plate) to be placed at four different ranges. The measurement of the beat frequency, $f_b = 4BR/cT_m$ which gives the range information is recorded from the SA and is compared with the theoretical value. Also, the presence of frequency offset due to the cables and connectors is discussed. In the later equation, B is the modulation bandwidth and T_m is the period of triangular signal (modulation period) [31].

9) *Introduction to TI mmWave Radar Platform:* Understanding of the TI mmWave radar platform [32], its hardware components, and the radar parameters that affect the practical RCS measurement of a target are discussed in this lab session. The combination of the AWR1642 radar module and the DCA1000 data capture is used. The platform transmits an FMCW signal via two transmitters and it receives back the echoed signal via four separate receiving channels. The received signal is presented in the form of complex I/Q at Intermediate Frequency (IF) band. The signal is transferred to a computer and the processed data is acquired using the mmWave studio program. The settings and calculations of the radar parameters and their association with each other are discussed [33], and the measurement of the target RCS is performed.

10) *TI mmWave radar platform:* Understanding the configuration parameters of an FMCW radar according to the maximum range, best range resolution scenarios, and RCS measurements of different objects are demonstrated in this session. With the calculation of the chirp signal parameters, several experiments based on different scenarios are conducted. Measurements of targets at different distances are conducted considering the maximum range equation

given in (3) and the measurement of the range resolution is also performed to see the ability of distinguishing two objects close to each other.

$$d_{max} = \frac{c * f_{ADC_{sampling}}}{2 * S} \quad (2)$$

where $f_{ADC_{sampling}}$ is the Analog Digital Converter (ADC) sampling frequency and S is the slope of the transmitted chirp. Finally, the relationship between the maximum range and the range resolution is considered based on the theoretical formulas.

At each of the lab sessions, a detailed repetition of the theoretical foundations which were given in the course lectures is given to the students. These are followed by practical exercises and in-lab quizzes which the students must work on. Finally, a short oral quiz is given toward the end of the lab sessions to determine the students' understanding of the topic. Additionally, students' perceptions of the contribution of the experiments are evaluated based on interviews and anonymous surveys.

C. Assessment Methods

The effectiveness measurement of the proposed laboratory activities is conducted using several qualitative and quantitative assessments, including face-to-face interviews, anonymous surveys, quizzes, along with the course exam results. Figure 6 represents the flowchart of the material preparation and assessment process. After the feedback from the assessments is collected and analyzed, deficiencies in the proposed laboratory activities are corrected and the material is improved. When the material is completed, the results are presented, and the process is finalized.

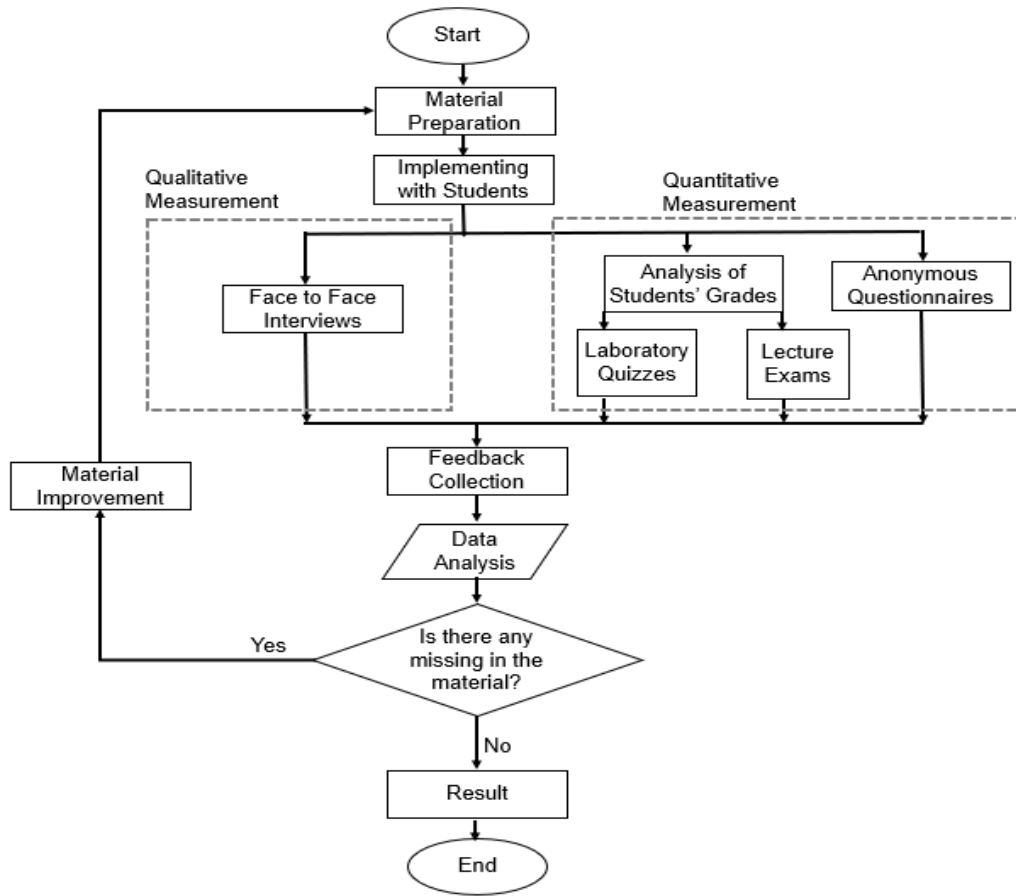


Figure. 6. Flow chart of the educational method.

The key assessment methods are as follows:

1) *Interviews*

At the beginning and middle of the semester, two different face-to-face interviews were done with the students. Interviews were conducted based on the contribution of the laboratory sessions to the students' learning process and how their perceptions changed during the course.

2) *Anonymous Surveys*

A total of three anonymous surveys containing both a five-point Likert scale and open-ended questions were conducted at the beginning, middle, and end of the semester (Survey-1, Survey-2, and Survey-3, respectively). Survey-1 was an introductory survey aiming to analyze the educational background and general skills of the students. It included questions about gender, age, cumulative GPA, knowledge/background about probability and random processes, communication systems, and signals and systems courses. Additionally, the evaluation of the ability to use laboratory equipment such as a SA, waveform generator, and oscilloscope was asked. Finally, opinions about the contribution of the laboratory sessions to their learning process and the purpose/expectation of taking the radar systems course were noted. Survey-2 and 3 aimed at obtaining information regarding the students' progress during the semester. Questions were asked aiming to observe the quality of the proposed educational method and its contribution to the learning process.

3) *Laboratory Quizzes*

An online pre-quiz was given to encourage students to study for the experiment before coming to the laboratory sessions. In the lab, two quizzes were done, one of them being before the experiment (pre-test) and the other after (post-test). This is done to continuously measure the contribution of the laboratory activities to the student's learning process. In addition, during the experiments, it was ensured that the students participated in the experiments and reinforced the subject with short oral questions.

III. RESULTS AND DISCUSSION

A comprehensive analysis of the qualitative and quantitative assessments including face-to-face interviews, anonymous surveys, and achievements on both the quizzes and exams are conducted.

A. Interviews

The first interview was applied after the second experiment. In the first interview, students were asked to evaluate the workload of the course, the provided course materials, and resources, as well as their perceptions regarding the first two experiments. Additionally, it was asked what the pros and cons of the proposed applied course material were, and how they related the experiments with the theory covered in the lectures. While students noted that the workload was heavier compared to other technical electives, they acknowledged improved comprehension of the course topics. Most of the students found that the course materials provided were sufficient and helpful enough. The common expectation from the laboratory activities is to learn the working principles of radars and to have knowledge of designing and operating radars in a simple way. As a matter of fact, it was the black spot of the lecture and the motivation of the authors. Also, they stated that the lab manuals were instructive and helped them in their learning process. They praised the lab manuals as instructive and the lab quizzes as effective in encouraging consistent study habits. They agreed that the first two experiments formed the basis of the first lectures and the laboratories helped them to visualize their theoretical background. Moreover, they added that the relation between mathematical equations and the practical applications had become clearer. They stated that they have obtained hands-on experience on how to use an oscilloscope, signal generator, waveform generator, and SA. After the second laboratory session, they stated that they completely understand the concept of up/down conversion which they had been taught in several different courses before.

The second interview was conducted after the sixth experiment. In the second interview, the workload was asked again. It was found that the students do not think that the workload is heavy for them anymore. They emphasized

once again that they found the course resources provided sufficient. They stated again that the logic of the lessons was understood together with the experiments. They confirmed that the experiments are understandable, and the content is adequate and supplementary. Also, they highlighted that the laboratory activities are strongly related to the lectures and had a great impact on the learning process. Observing each component individually, and then combining them to obtain a fully operating radar system is what the students found to be the best about the laboratory activities.

B. Anonymous Surveys

In the first survey, the average CGPA of the class was found as 3,15. The average letter grade of the probability and random processes course, and communication systems course was BB. Students are asked to score the course materials on a five-point Likert scale (1: absolute insufficient, 5: absolute sufficient), the average result was found as 4,1. The ability to use the hardware laboratory equipment was asked again as in interviews, all of the students indicated that they know how to use them. The general contribution of other courses' laboratories in the past 4 years to the students' learning process is asked and 66% of the class graded this question as 5. It can be said that students' opinion about the general laboratory activities is quite positive. Students' expectations from the radar systems course are asked. The following comments were reported by some of the students:

- “I enjoyed the signals and systems and the communication systems courses. So, I believe I will be successful in the radar systems course.”
- “I want to gain knowledge about radar systems and perform a simple radar design.”
- “I am currently interested in the RCS applications. I think this course will be helpful for this.”
- “I want a career in which I can advance in the defense industry in the future.”

In the second survey, the content of the course and the laboratory were investigated individually. The list of the items asked for in the survey and the mean values of each item are presented in Table 1. All the students attended the lectures and the experiments regularly. From Table 1, we can say that they were quite satisfied with the content and the materials of the course. Similar questions were asked in both the course and experiment assessments to observe the consistency of the scores. Students gave the lowest score on the face-to-face quizzes for both the course and the laboratory, which is understandable since they are more challenging than online quizzes. Also, students found that the contribution of the experiments to their learning process was notably sufficient. The ability to relate the theory to the experiments was asked both in the course and the experiment assessments. A large majority of the students graded that item as 5 with reasonable consistency. Their overall comments were also asked in the survey. While some of them criticized taking pre and post-quizzes every week, a large majority of them found that the quizzes were helpful, and they stated that they came prepared for the lectures and experiments and it made the topic more understandable for them.

The questions asked in the final survey and the mean values of each question (out of 5) are given in Table 2. After the low grading of face-to-face post-tests in Survey-2, the students were asked regarding it, and it has been observed that the score given to this item has increased both for the course and the laboratory activities.

The score of the contribution of the laboratory activities to the students' learning process showed consistency with Survey-2. However, when the difficulty of the course and the experiments were asked, the average score showed up as equal. From these results, we can say that the hands-on experiments were quite effective in terms of the contribution to the students learning of the radar systems course, especially in the introductory levels. When their perception about whether they have obtained enough knowledge about the radar systems was asked, a decrease is observed in the average score compared to Survey-2. The final answers can be considered more realistic as they learn more, they realize there is more to learn.

Table I. Survey-2

Item Asked	Avg. score	
About the course	1. Content of the course:	4,4
	a. Information about theory.	4,2
	b. The relationship between theory and experiments.	4,5
	c. Contribution of the course to the learning process.	4,5
	2. Visuals of course videos.	4,7
	3. Audio of course videos.	4,7
	4. Do you consider yourself having enough knowledge about radar system course?	4,3
About the experiments	5. Contribution of online quiz for theory (pre-test) to your learning process.	4,5
	6. Contribution of face-to-face quiz for theory (post-test) to your learning process.	3,3
	7. How many courses did you attend? (L1-L5)	4,7
	1. Content of the experiments:	4,5
	a. Information about theory.	4,3
	b. The relationship between theory and experiments.	4,7
	c. Contribution of experiments to your learning process.	4,5
2. Visuals of experiment videos.	4,5	
3. Audio of experiment videos.	4,3	
4. Do you consider yourself having enough knowledge about experiments?	4,7	
5. Contribution of online quiz for experiment (pre-test) to your learning process.	3,5	
6. Contribution of face-to-face quiz for experiment (post-test) to your learning process.	4,8	
7. How many experiments did you attend? (Exp1-Exp10)	4,5	

Table II. Survey-3

Item Asked	Avg.	
General Questions	1. What is the contribution of the course videos, pre-test and post-tests to your learning process?	3,7
	2. What is the contribution of the lab experiments, laboratory pre-tests and post-tests to your learning process?	4,0
	3. Evaluate the difficulty of the course.	3,4
	4. Evaluate the difficulty of the experiments.	3,4
	5. Evaluate whether you were able to spend enough time to learn the course.	4,3
	6. Evaluate whether you were able to spend enough time to learn the experiments.	4,4
	7. Considering the scope and topics of the course, do you think you have learned radar systems?	3,6
	8. How useful did you find the experiments?	4,1

C. Laboratory Quizzes

It is aimed to evaluate the performance of the new educational method by comparing the GPA of the students in the last three terms. When the average of the students' grades is observed in the 3rd term, during which the proposed laboratory activities were applied, a significant increase is observed as can be seen from Table 3. It should be noted

that the difficulty level, content, and types of questions on the exams of the course were the same for all 3 terms. In the 1st and 2nd terms, only Radar-I was used in the experiments, while in the 3rd term, by adding Radar-II, students had the chance to work on different radar modules. In the first term's laboratory, 5 experiments which are a combination of the first 8 experiments mentioned earlier were conducted. In the last term, the full 10 laboratory activities were carried out. For each experiment, both the online and in-class pre-tests along with in-class post-tests were given to the students. The average grade for the laboratory online pre-tests is 85,8 and for the in-class pre-tests was 71,9. Although the control of the students is a challenging issue in online exams, no significant difference is observed between the online and in-class quizzes. The average grade of the post-tests applied after each laboratory activity was 79,9. We observed that most of the class came to the laboratories prepared, and they followed the experiments during the session. Also, a question-based assessment was conducted for the laboratory quizzes. It was seen that the average score of the class regarding the questions that evaluate the ability to relate theory to practice was 81,1. In the first 5 experiments, the main components of a radar system such as VCO, mixer, LPF, antennas, connectors, and cables were introduced, and their operation principles were discussed. At each laboratory session, a new component was added to the system and its output was observed. The total average of the exam results regarding these experiments is 84,4. In the following three experiments, all the individual components are combined, and a modular structure of the transmitter and the receiver is obtained. Various radar ranges, RCS, and link budget experiments are conducted. The total average exam result regarding these experiments is 74,06. A decrease is observed according to the first five experiments since the students are expected to use their theoretical knowledge more as the content of the course develops further. The last two experiments cover a COTS ready-to-use radar in a compact form. This radar platform was quite different from what they have worked on so far in terms of principle and platform. However, the total average of the exam results regarding these experiments was 73,93 not so different than the previous average. Thus, it was observed that students were able to adapt very easily and learn the working logic faster when they encountered different radar types.

Table III. Grades

Exams	1st Term	2nd Term	3rd Term
Laboratory Average	53,3	81,3	77,0
Course Quiz Average	56,5	55,7	74,2
Midterm Average	51,5	67,0	60,1
Final Average	46,7	40,7	67,7
Grade Average	52,7	58,6	71,4

IV. CONCLUSION

In this paper, a laboratory for the radar systems course and a methodology for measuring its effectiveness are presented. Ten radar lab sessions are designed to give a comprehensive understanding of the theoretical topics covered in the course. By understanding the radar components one by one in each session, the theoretical knowledge of the students based on radar systems is examined experimentally. Students gain experience in radar design and operation when the final system is shown. Then, with a different radar structure, students showed their ability to adapt by using their previous hands-on experience. To measure the effectiveness of these laboratory activities in the students' learning, both qualitative and quantitative assessments are employed. Considering the assessments, the proposed applied course material has affected the students' success level positively. In addition, the perception of the students regarding the lab structure and material was found satisfactory.

STATEMENT OF CONTRIBUTION RATE

Authors' contribution rates to the study are equal.

CONFLICTS OF INTEREST

They reported that there was no conflict of interest between the authors and their respective institutions.

RESEARCH AND PUBLICATION ETHICS

In the studies carried out within the scope of this article, the rules of research and publication ethics were followed.

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