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A Radio Controlled Race Car Project to Evaluate Student Learning in Electronics

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A Radio Controlled Race Car Project to Evaluate Student Learning in Electronics

Abstract

As educators we want to make sure that our students are learning and understanding the material we teach them and that they will know how to apply it to solve real engineering problems. A vast amount of research has been dedicated to the study of new teaching methods and laboratory curricula to ensure that our students are understanding, learning, and applying this knowledge to solve problems.

Our university emphasizes a hands-on approach to engineering education. From the beginning of the freshman year to the senior year, students participate in different levels of engineering projects. For our (analog) Electronics and Lab course we looked for a project-based learning experience that would help us to evaluate (1) how well our junior engineering students could apply the knowledge acquired in their freshman and sophomore engineering courses, (2) if they could integrate this knowledge with what they were learning in the current Electronics course, (3) how to put it into practice when interfacing the Arduino microcontroller to practical analog circuits and (4) if they could be challenged to seek to learn concepts from future engineering courses.

For this purpose a Radio Controlled Race Car Project was selected as a semester-long project. The electronic project was divided into four distinguishable subsystems, 1) analog radio control, 2) radio transmitter/receiver, 3) control unit, based on an Arduino microcontroller, and 4) power subsystem. Except for the Arduino microcontroller, the use of microchips was restricted and only common analog components were allowed.

At the beginning of the semester, the students were presented with the project challenge. They were divided into groups of 4 to 5 and began by clarifying the problem they wanted to solve, assessing how much they already knew about the problem and how much they needed to research. The next time they met, with the results of their research, they brainstormed for possible solutions, divided the work in accordance with the project subsystems, and prepared to work during the semester to implement a final solution.

On the final report students were requested to identify where and explain how the following concepts were applied in their project: resonance, impedance, impedance matching, maximum power transfer, voltage regulation, DC/AC voltage conversion, filtering, Barkhausen's criterion, oscillators, frequency modulation, energy conversion and transformation, power losses and efficiency. The positive results of student understanding, learning and application of acquired knowledge to solve engineering problems may prompt the implementation of other projects that may include multidisciplinary collaboration and integration of projects between classes.

Introduction

As educators working in higher education institutions we want to make sure that our students are learning and understanding the material we teach them and we expect that they will be able to apply it to solve real engineering problems in the workplace. A vast amount of research has been dedicated to the study of new teaching methods and laboratory curricula to ensure that our students are understanding, learning, and applying this knowledge to solve problems[1,2,3].

Project-based learning (PBL) provides students with a broader context to the material learned in class. With project-based learning students shift from a passive to an active learning pattern that is likely to improve knowledge retention as well as the ability to integrate material from different courses[4]. Each project provides students with the opportunity to apply the knowledge they have learned in classes, and each problem they face in the project inspires them to explore the material more deeply in future study[5].

Project-based learning can develop the ability of students to work in interdisciplinary teams. Interdisciplinary teamwork is not only an expectation of industry but has also become a required outcome of the ABET engineering criteria. Many obstacles may arise when working in interdisciplinary teams, but a series of curriculum tools have been initiated at our school to insure that students will have a measure of success in project teamwork. PBL is an instructional method that demands from a student the acquisition of critical knowledge, problem solving proficiency, self-directed learning strategies, and team participation skills[6,7]**.**

Background

Our university emphasizes a hands-on approach to engineering education. From the beginning of the freshman year to the senior year, students participate in different levels of engineering projects. Several courses have been intentionally introduced into the curriculum of the Electrical, Biomedical, Computer, Mechanical, and Materials Joining engineering concentrations to provide for such hands-on experience. Prior to their participation in the project in Electronics, students have taken ENGR 1513 Introduction to Engineering Practice I followed by ENGR 1523 Introduction to Engineering Practice II during the freshman year, and ENGR 2704 Project Management, Design and Entrepreneurship during their sophomore year.

Electrical engineering students registered in our program take a classical Circuits course during the first semester of their sophomore year and Advanced Circuits (or Circuits II) during their second semester of the year. Advanced Circuits is a 3 credit hour lecture course which covers such topics as series and parallel RLC circuits, frequency response, series and parallel resonance, mutual inductance, ideal transformers, two-port parameters, Fourier series and Fourier transforms and Laplace transforms.

The project described here is part of the EEGR 3314 Electronics and Lab class, a three-hour lecture course with a two hour lab. The content of the class introduces diodes and rectifiers, semiconductor physics, bipolar transistors, MOSFETS and power amplifiers.

The lab portion supports the topics of the class includes I-V curves, filter design, RLC circuits, thermal stability, and operational amplifiers.

A semester- long project was introduced into the Electronics class to help us to evaluate student learning. First, we wanted to evaluate how well our junior engineering students could apply the knowledge acquired in their freshman and sophomore engineering courses; second, if they could integrate this knowledge with what they were learning in the current electronics course; third, to provide hands-on experience interfacing Arduino microcontrollers to practical analog circuits; and fourth, if they could be challenged to seek to learn concepts from future engineering courses.

Project Description

A radio-controlled race car project was selected for the semester-long project. The project was divided into four distinguishable subsystems, 1) remote control, 2) radio transmitter/receiver, 3) logic control unit, based on an Arduino microcontroller, and 4) power subsystem. The specifications for the four subsystems were made as flexible as possible. The remote control could have been designed around a joystick or through the use of several buttons. The radio transmitter/receiver could have been designed using AM, FM, ASK, or FSK technology and built using LC oscillators and BJT transistors. Students were free to decide on the frequency of the carrier and the type of modulation (analog or digital). Except for the Arduino microcontroller, the use of microchips was restricted and only such analog components as diodes, Zener diodes, bipolar junction transistors and MOSFETs were allowed. The power subsystem required a 9–18 volts DC to AC conversion and rectification.

The semester-long electronics project was scheduled as follows:

First week:

- Initial presentation of the project to the students.
  A block diagram and general specifications of the project given (Appendix 1)
- Students were divided in groups of four to five.
- First task:
    - To identify the problem, what is the desired outcome;
    - To state the basic objective or goal;
    - To identify what is known about the problem, and what needs to be learned;
    - To determine how the research and learning would be divided among the team members.

Second week:

- Homework/research assignment:
    - To study AM, FM, ASK and FSK communication theory;
    - To research how AM, FM, ASK and FSK transmitters and AM receivers work;
    - To look for possible electronic car boards or commercial RC cars

Third week:

- Students identified a cost effective solution for the chassis of the RC car
    - Each team ordered for their car chassis the same commercial RC car;
    - The electronics of each car was swapped out.

- In the regular weekly lab session an experiment dealing with a diode detector circuit was added.

Fourth week:

- In the regular weekly lab session an experiment dealing with a Colpitts oscillator circuit was added.

Fifth week:

- In the regular weekly lab session an experiment dealing with an AM transmitter circuit was added.

Sixth week to eleventh week

- Students were given free access to work in the university's electronic labs at their own pace.

Twelfth week

- All teams prepared a report of their findings and calculations.
- Students presented power point presentations and demos of their projects
- Students completed exit surveys of their projects (Appendix 2 through Appendix 6).

Following is a summary of concepts from the freshman and sophomore engineering concepts that we wanted students to recognize and understand in the project subsystems.

	Concept	Where concept is covered	Where concept might be applied
1	Impedance	Circuits & Advanced circuits	All but logic unit subsystem
2	Impedance matching	Circuits & Advanced circuits	All but logic unit subsystem
3	Maximum power transfer	Circuits & Advanced circuits	All but logic unit subsystem
4	Energy conversion	Circuits & Advanced circuits	All but logic unit subsystem
5	Power losses	Circuits	All subsystems
6	Resonance	Advanced Circuits	Transmitter/receiver subsystem
7	Filtering	Advanced Circuits	Transmitter/receiver subsystem, power subsystem
8	Barkhausen criteria	Advanced Electronics (future course)	Transmitter/receiver subsystem
9	Oscillation (general)	Advanced Electronics (future course)	Transmitter/receiver subsystem, power subsystem
10	Modulation	Advanced Electronics (future course)	Transmitter/receiver subsystem

Table 1 – Summary of concepts to be recognized and understood in the project subsystems

Selected samples are included of the circuits designed by the students for the transmitter/receiver, the logic unit and the power subsystem. The transmitter/receiver circuit diagram of Figure 1 shows a voltage regulator circuit, an AM transmitter circuit with the carrier provided by a Colpitts oscillator, and the modulating signal supplied by an Arduino at the emitter terminal of transistor Q2.

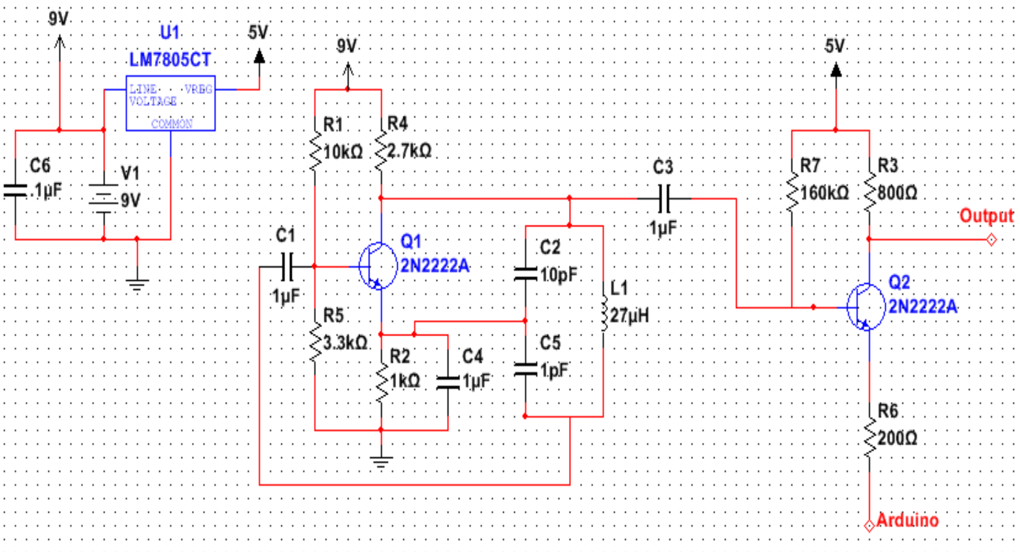

Figure 1. Transmitter subsystem

The waveforms of Figure 2 show the transmitter waveforms, the carrier frequency generated by the Colpitts oscillator, the information signal or message as a digital signal. Both of these signals are combined in the second 2N222A transistor that works as an AM modulator. The output signal is the ASK (Amplitude Shift Keying) signal.

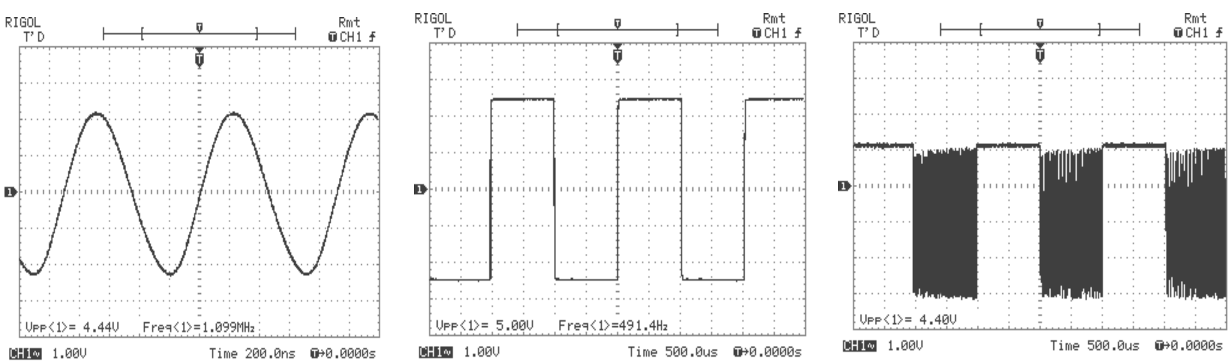

Figure 2. Transmitter circuit waveforms (carrier signal, message signal, modulated output)

The receiver circuit of Figure 3 includes a 2N222A transistor acting as a diode detector, with the amplification provided by the transistor, followed by a 555 timer for signal reconstruction before passing the received signal to the Arduino microcontroller.

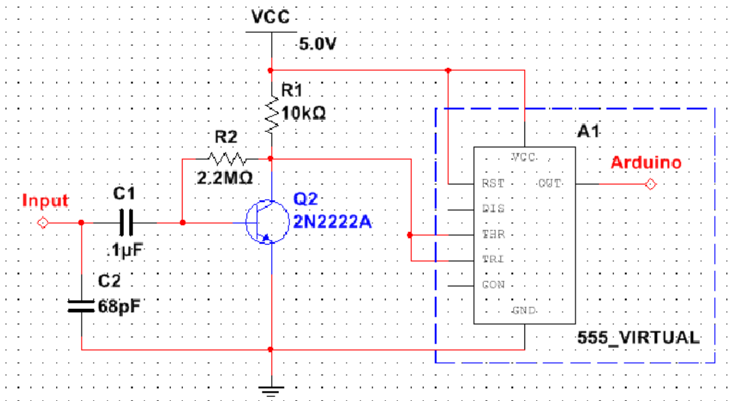

Figure 3. Receiver circuit

The waveforms of Figure 4 show the signals received at the transmitter circuit. The first waveform shows the lightly attenuated received signal at the input of a 2N2222A transistor acting as a diode detector and the second waveform shows the demodulated signal before input to the Arduino microcontroller.

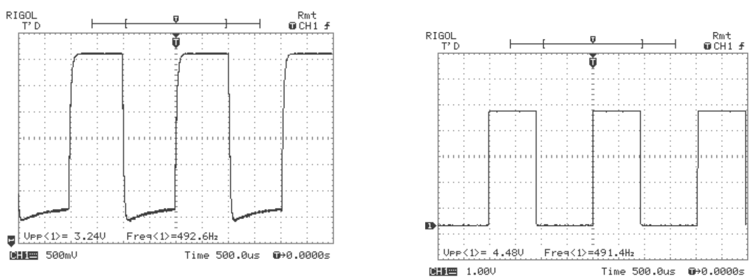

Figure 4. Sample of received signals at the transmitter circuit.

The circuit diagram of Figure 5 shows the connections of the I/O port of the Arduino to a full H bridge circuit with Darlington transistors for the control of the race car DC motor.

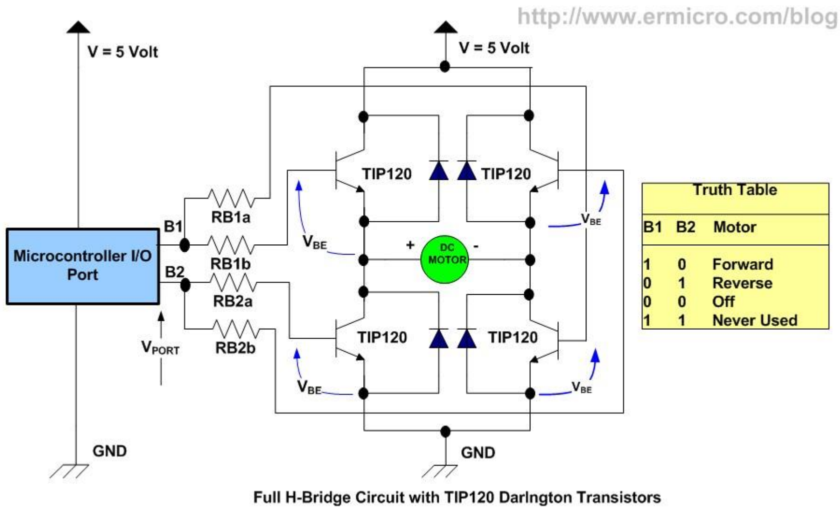

Figure 5. Sample of the Logic Unit subsystem

The circuit diagram of Figure 6 shows the various stages of the power subsystem. Voltage is changed from 7.4 V DC to 21 VAC and, through a full—wave rectifier, from AC to DC with a voltage regulator at the output.

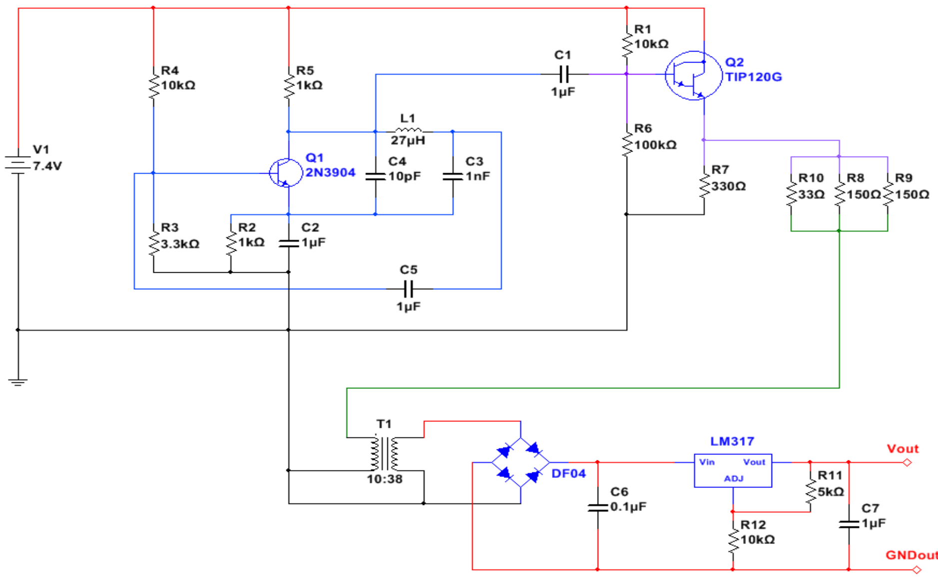

Figure 6. Power subsystem

Figure 7 shows one of the team's remote control unit with the circuit elements used to generate several signals with different frequencies. The car chassis contained the circuitry for the receiver, the logic unit and the power subsystems. The chasis used was from a commercial RC car whose electronics were swapped out and replaced by the students' circuit designs.

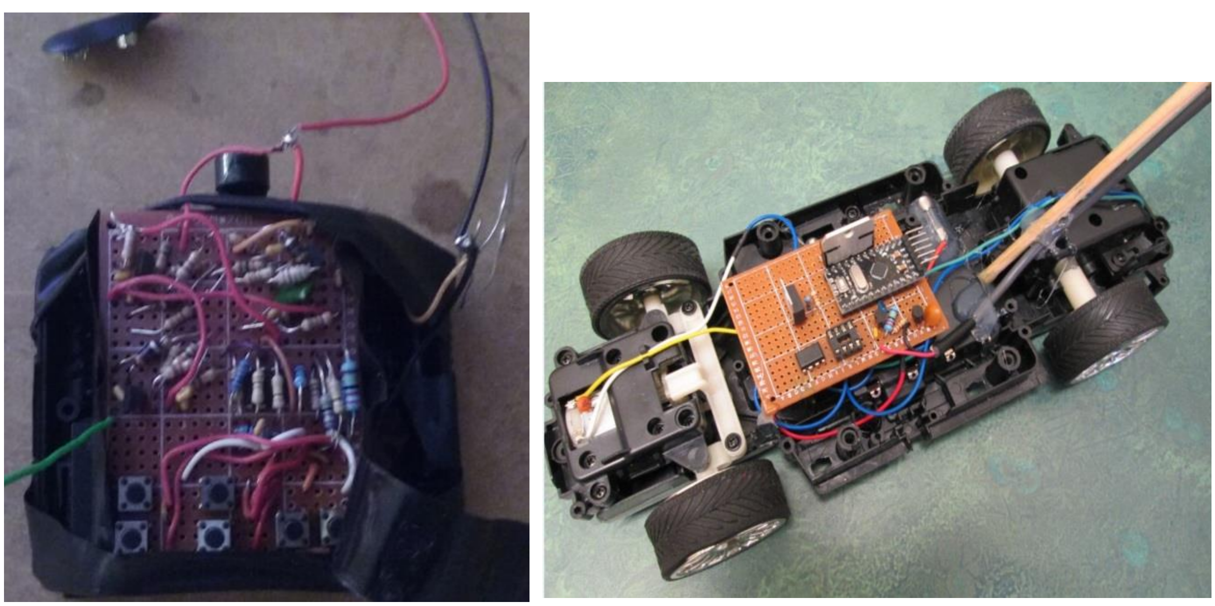

Figure 7 Remote control subsystem and race car chasis

Results

While five teams participated in this project, none of the teams were able to design the proper antennas for the transmission and reception of the radio signals. Four weeks before the end of the semester the requirement for the antennas was removed. Students were allowed to have direct connection to their cars using a six to eight foot long wire. With the antenna requirement lifted, two of the teams that were having problems with the generation of ASK signals changed their modulation approach to a pulse width modulation. On the day of the presentation and demonstration three teams presented completed projects, but only two cars were able to compete for the test of speed and maneuverability.

Survey #1 was developed to evaluate whether the students were able to recognize, understand, and apply their previous electrical engineering knowledge taught in EEGR2053 Electric Circuits and EEGR2163 Advanced Circuits. Previous knowledge in concepts such as: impedance, impedance matching, maximum power transfer, energy conversion and transformation, power losses, resonance, and filtering. It also tried to evaluate whether the students were able to recognize, understand, and apply electrical engineering concepts being taught or to be taught in future engineering courses. Future engineering concepts like: oscillation, Barkhausen criterion, and AM/FM frequency modulation.

The project was divided in four subsystems: remote control subsystem, transmitter/receiver subsystem, logic unit Arduino subsystem and the power subsystem. For each subsystem two questions were asked; the first question asked the student to recognize which concepts were present or applied and the second question asked the student to rate on a scale of 1 to 5 his/her understanding of the concept.

Results of survey one

1. Evaluation of recognition of previous electrical engineering concepts for the remote control subsystem.

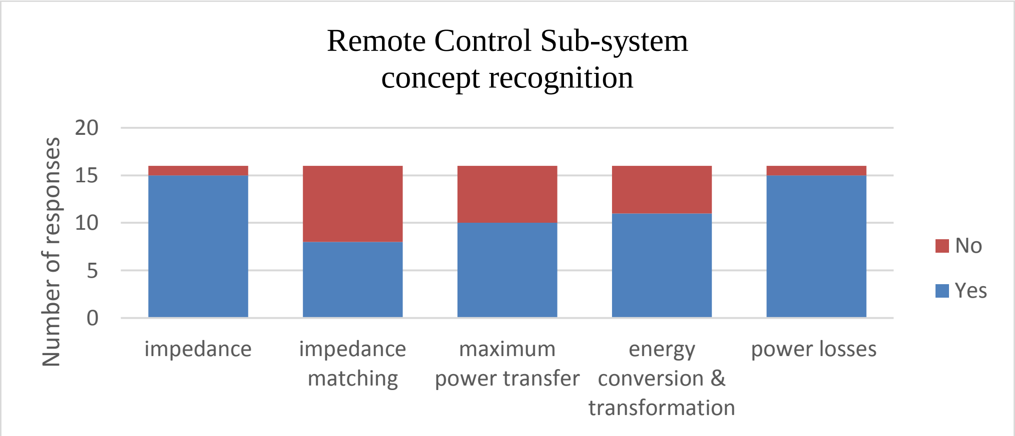

Figure 8 Concept recognition in the remote control subsystem

Assuming the null hypothesis Ho to be: 100% of the students should be able to recognize all the concepts" with ux=16, if the measured mean is uy= 11.8, then the one sample t test results in t=3.0154, df=4 and the two tailed P=0.0393 is considered to be statistically significant.

2. Evaluation of understanding of electrical engineering concepts for the remote control subsystem

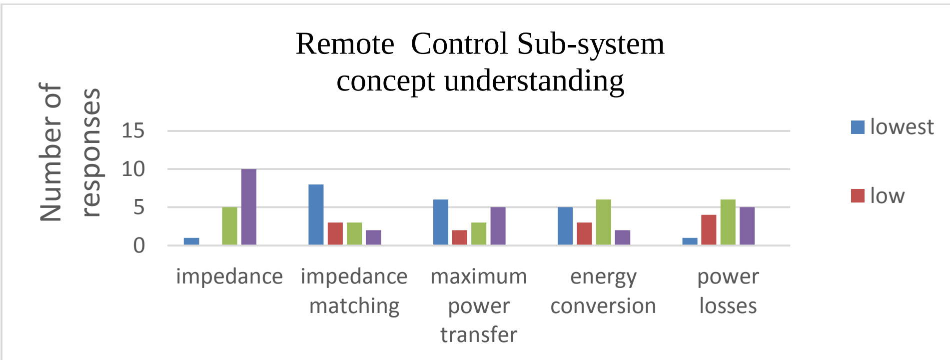

Figure 9 - Concept understanding for the remote control subsystem

For the analysis of the concept understanding of the remote control subsystem, the following hypothesis was assumed: Out of the 16 students, 0 will score lowest, 2 will score low, 4 will score medium 7 will score high and 3 will score highest, this had a mean= 3.688.

With the data of survey number 1, a sample t test was run and the results showed that the one tailed P was not statistically significant for the concept of impedance, but all the other concepts were very and extremely statistically significant. See table #1 in Appendix 7.

3. Evaluation of recognition of previous electrical engineering concepts for the transmitter/receiver subsystem. The evaluation of the transmitter/Receiver subsystem included 5 more concepts than the remote control subsystem.

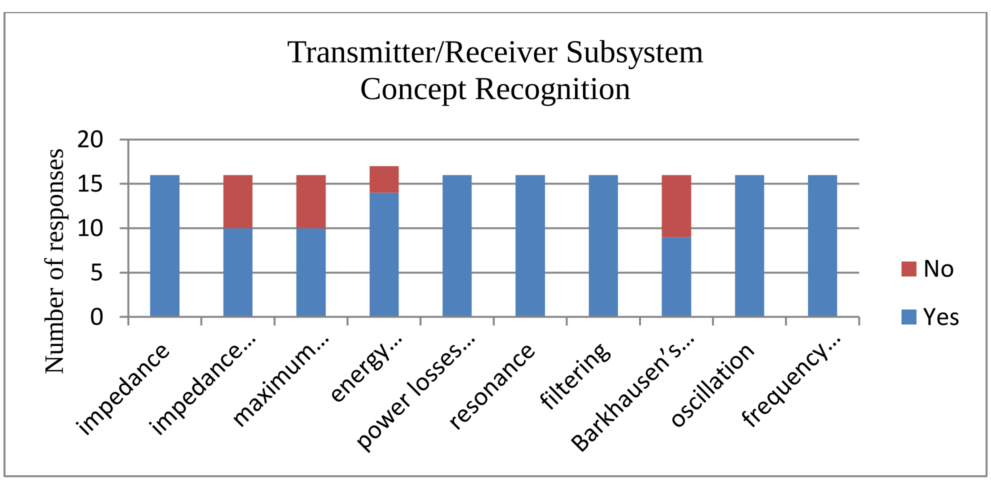

Figure 10 Concept recognition for the transmitter/receiver subsystem

Assuming the null hypothesis Ho to be: 100% of the students should be able to recognize all the concepts" with a mean =16. Running the one sample t test resulted in a measured mean= 13.9 , with a t=2.2150, df=9 and the one tailed P=0.0270, which is considered to be no statistically significant.

4_ Evaluation of understanding of engineering concepts for the transmitter/receiver subsystem

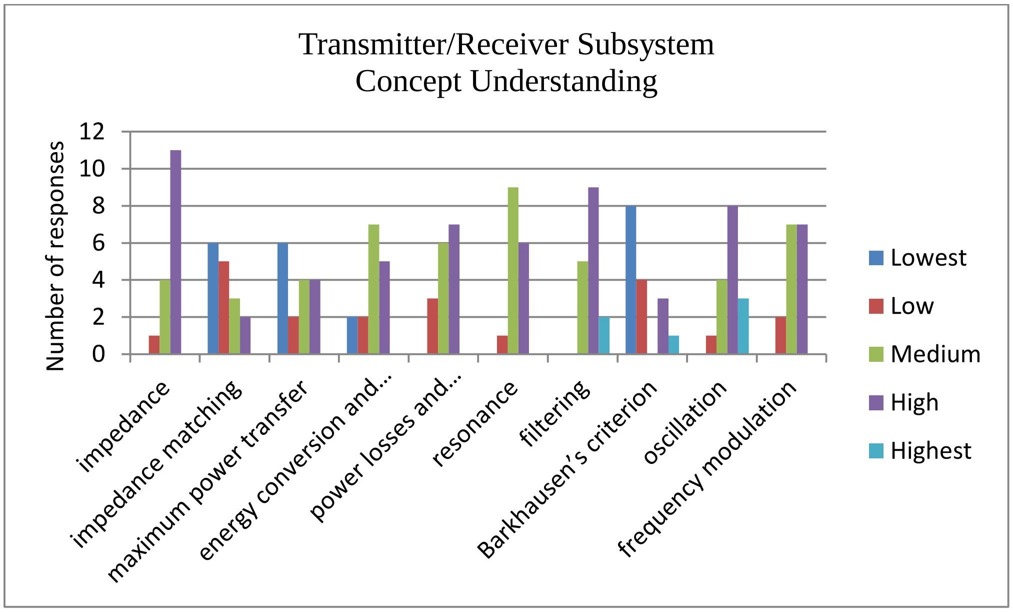

Figure 11 Concept understanding for the transmitter/receiver subsystem

For the analysis of the concept understanding of the remote control subsystem, the following hypothesis was assumed: Out of the 16 students, 0 will score lowest, 2 will score low, 4 will score medium 7 will score high and 3 will score highest, this had a mean= 3.688.

With the data of survey number 1, a sample t test was run and the results showed that the one tailed P was not statistically significant for the understanding of concepts of impedance, filtering, oscillation, frequency modulation, but statistically significant for the concepts of impedance matching, maximum power transfer, energy conversion, power losses and resonance. See table #2 in Appendix 7.

5. Evaluation of recognition of previous electrical engineering concepts for Logic Unit Arduino Subsystem

In this particular section, the students had problems with the questions. For the concept understanding of the interfacing of the Arduino to analog circuits a different approach was taken. The concepts of filtering oscillation Brakhausen's criterion (feedback), resonance and frequency modulation were classified into a more relevant category. Power losses, AC/DC and DC/AC conversion into a category of relevant and the concepts of impedance, impedance matching and maximum power transfer entered into a less relevant category.

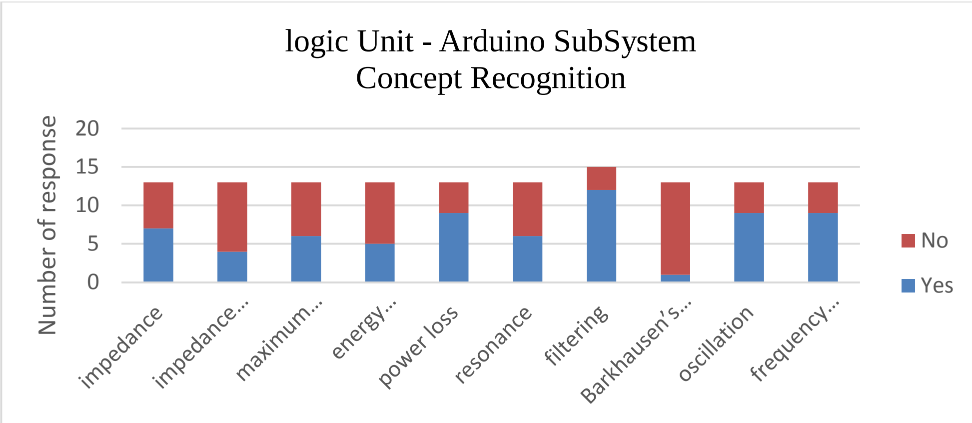

Figure 12 - Concept recognition for the logic unit Arduino subsystem

For the concept recognition the following hypothesis was adopted: 100% (13) of the students should be able to recognize the more relevant concepts, 60 % (8 out of 13) student should be able to recognize the relevant concepts and 40% (5 out of 13) students should be able to recognize the less relevant concepts. This hypothesis had a mean = 9.6. The results of the one sample t test showed a measured mean= 13.9, SD = 3.12, a t=2.8381, df=9 and the one tailed P=0.0098, which is considered to be statistically significant.

6. Evaluation of understanding of engineering concepts for the logic unit-Arduino subsystem

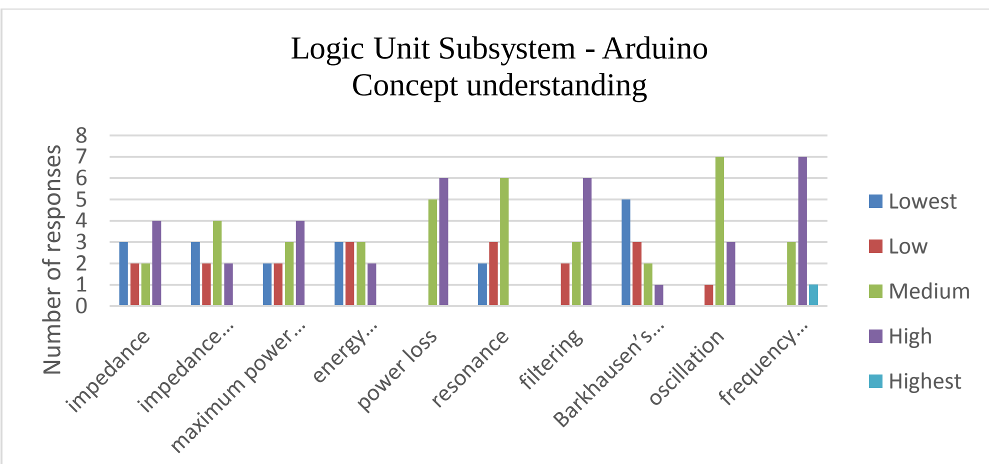

Figure 13 Concept understanding for the logic unit - Arduino subsystem

The statistical analysis of the concept understanding the following hypothesis was adopted: Out of the 11 student's responses, 0 will score lowest, 2 will score low, 3 will score medium, 4 will score high and 2 will score highest, this had a mean= 3.70.

With the data of survey number 1, a sample t test was run and the results showed that the one tailed P was not statistically significant for the understanding of concepts of power losses, filtering and frequency modulation, but were statistically significant for all the other concepts. See table #3 in Appendix 7.

7. Evaluation of recognition of previous electrical engineering concepts for the power subsystem

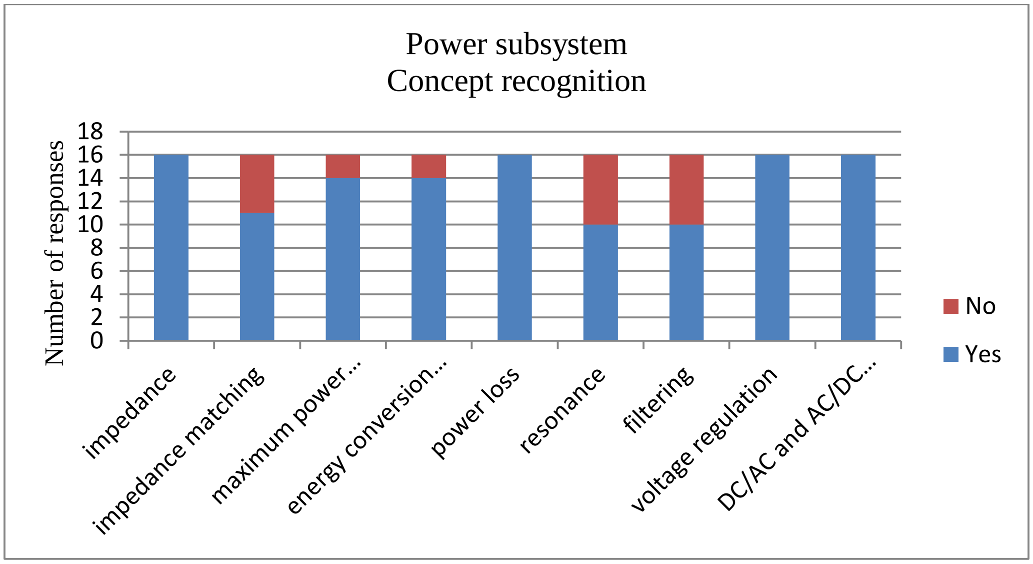

Figure 14 Concept recognition for the power subsystem

Assuming the null hypothesis Ho to be: 100% of the students should be able to recognize all the concepts" with a mean=16, if the measured mean is uy= 13.9, then the one sample t test results in t=2.2150, df=9 and the two tailed P=0.0540 is considered to be no statistically significant.

8. Evaluation of understanding of engineering concepts for the power subsystem

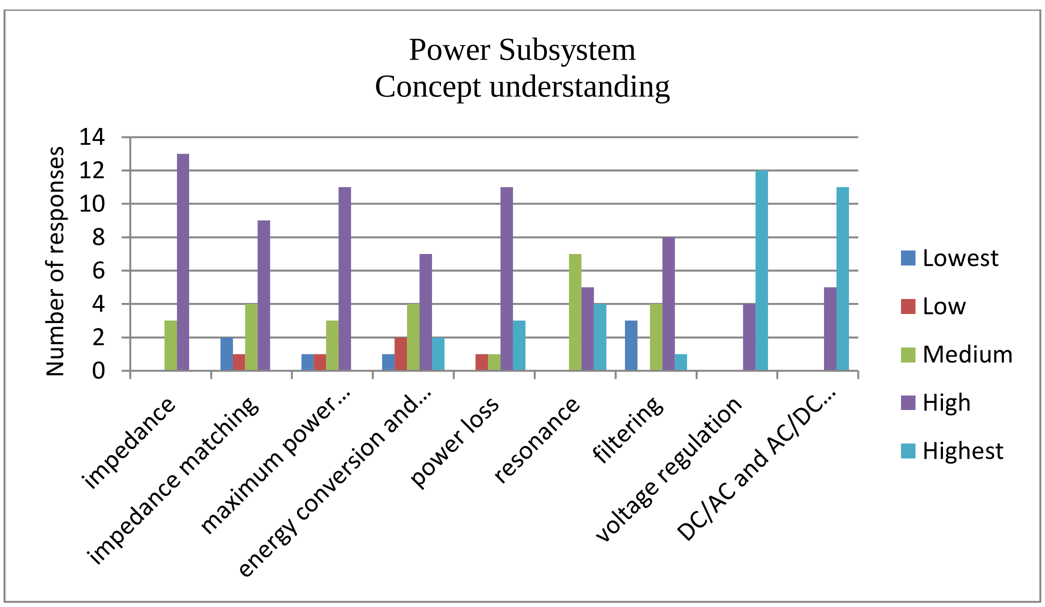

Figure 15 Concept understanding for the power subsystem

For the analysis of the concept understanding of the power subsystem, the following hypothesis was assumed: Out of the 16 students, 0 will score lowest, 2 will score low, 4 will score medium 7 will score high and 3 will score highest, this had a mean= 3.688.

With the data of survey number 1, a sample t test was run and the results showed that the one tailed P was not statistically significant for the understanding of all the concepts included in the power subsystem. See table #3 in Appendix 7.

Results of survey two

A second survey was prepared to evaluate the student's knowledge and understanding of how the different systems or components of the project. Each question in this survey was divided into three parts. The first part asked what students knew about a system or element before the project, the second part asked what they knew or understood about the system/element after completing the project, and the third part asked the student to rate on a scale of 1 (low) to 5 (high) his/her understanding of the system/element.

9. Evaluation of understanding of how a system/element works before working in the project. Figure B2, show the "Yes" or "No" responses of the knowledge of a how a system/element works before working in the project.

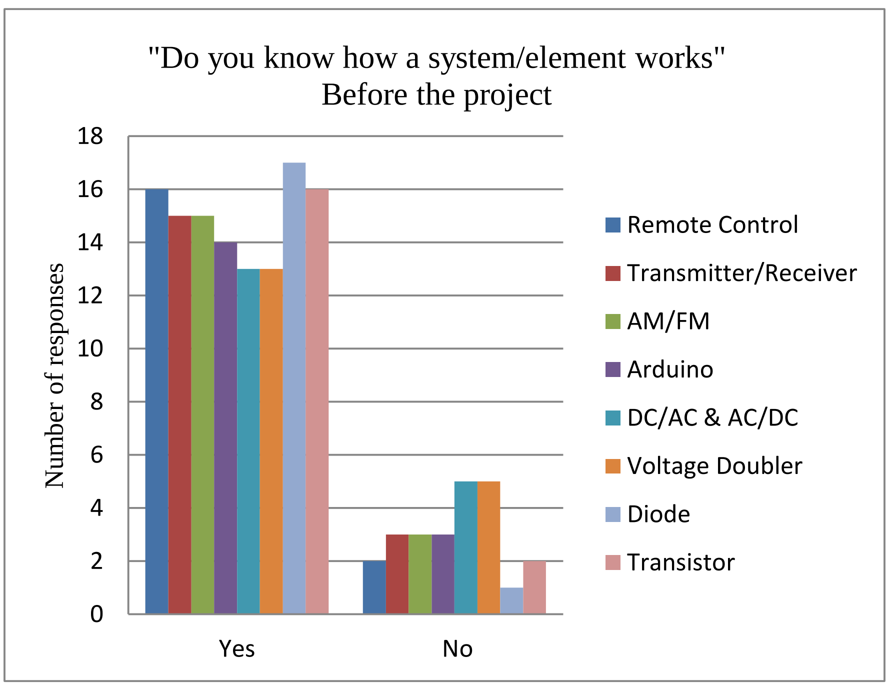

Figure 16 Yes/No answer to question: "Do you know how a system/element works" before working in the semester project.

10. Evaluation of knowledge of how a system/element works after working in the project. Figure B2, show the "Yes" or "No" responses of the knowledge of a how a system/element works after the student finished their projects.

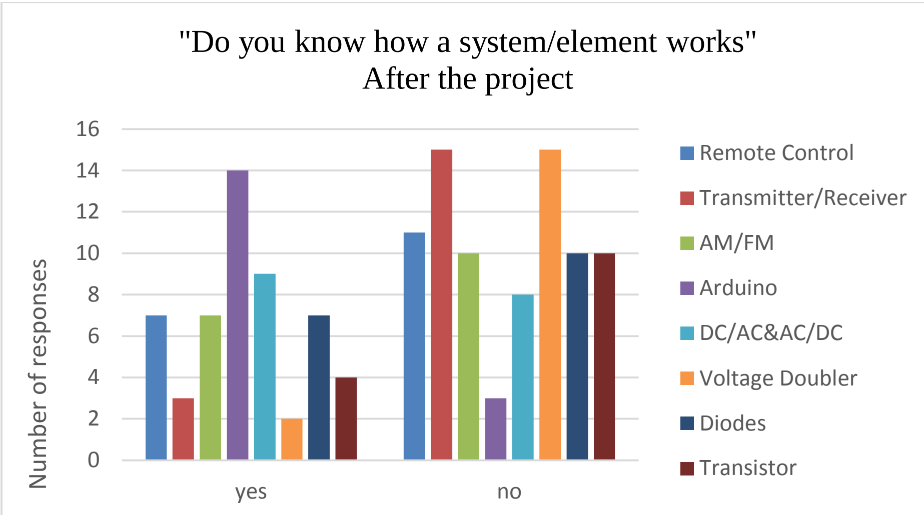

Figure 17 Yes/No answer to question: "Do you know how a system/element works" after working in the semester project.

11. Evaluation of the rating of student knowledge after completing the project. Figure B3, show the responses from a scale from 1 being the lowest to 5 being the highest of the rating of the understanding of a how a system/element works after the student finished their projects.

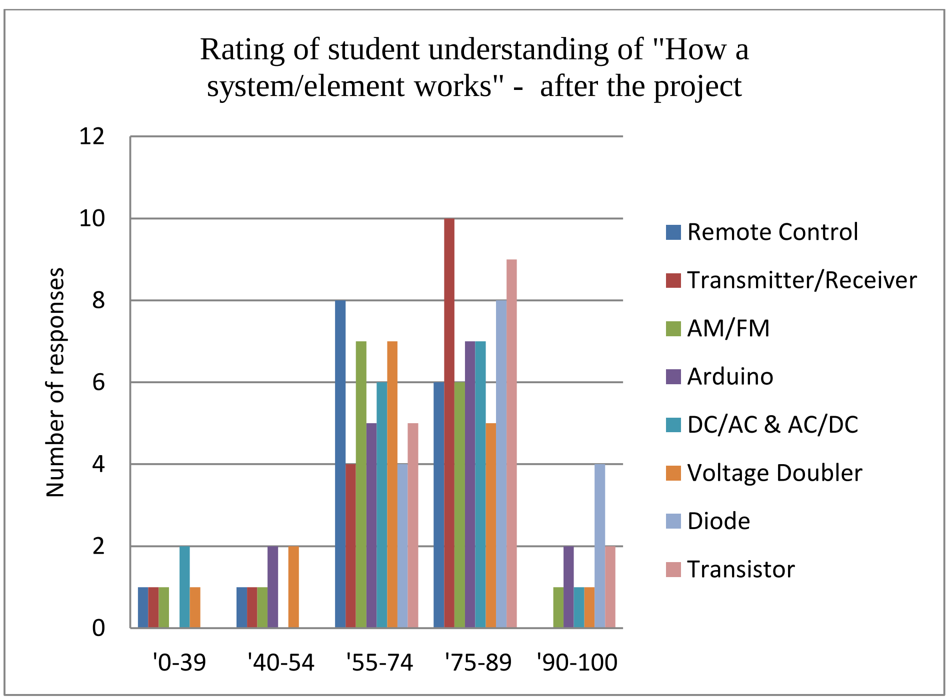

Figure 18 Rating from a scale of 1 to 5 from the answer to the question: "Do you understand how a system/element works"

Summary of results

The results of survey number one for the remote control subsystem showed that the concepts of impedance and power losses are the highest recognized by the students, both showed P's considered to be not statistically significant. The concepts of impedance matching, maximum power transfer and power conversion showed P's considered to be statistically significant. When teaching we will need to make efforts to help the students understand these concepts.

The results of survey number one for the transmitter/receiver subsystem showed that the concepts of impedance, resonance, filtering, oscillation and frequency modulation showed P's considered to be not statistically significant, but the concepts of impedance matching, maximum power transfer, energy conversion Barkhausen's criterion and resonance showed P's considered to be statistically significant. Special attention needs to be placed on making the efforts to help the students understand these concepts. Although every team was able to deliver a working Colpitts oscillator, none of the teams were able to design suitable antennas for their projects. This may be in direct relationship with the fact that RF and antenna theory are concepts of courses of future study.

From the results of survey number one, for the concept understanding in the logic unit subsystem shown in figure 12 and figure 13, one can see that the students had problems with the questions for the logic – Arduino subsystem. They had problems understanding how the given analog concepts can be integrated with a digital logic unit or Arduino. To obtain a better interpretation of the results of the survey a different approach was taken. The concepts of filtering oscillation Brakhausen's criterion (feedback), resonance and frequency modulation were classified into a more relevant category. Power losses, AC/DC and DC/AC conversion into a category of relevant and the concepts of impedance, impedance matching and maximum power transfer entered into a less relevant category. The one tailed P showed that the students were able to understand three of the more relevant concepts: power losses, filtering and frequency modulation, but missed the rest of the concepts. More efforts need to be made to help student understand the issues that arise when interfacing analog and digital circuits.

The results of survey number one, for the power subsystem are interesting because all the concepts were recognized and understood. It showed all the concepts with P's considered to be not statistically significant, and two of the concepts with P's extremely significant show better understanding than the expected values. This result raise new questions: Why did students have problems recognizing these concepts in the remote control and transmitter/receiver subsystem? Why were they able to make the connection in the power subsystem but not in the other subsystem?

In the results of survey two, the first two questions (knowledge or understanding before/after the project), were positive as expected. Most of the students did not have a previous knowledge of electronic components, or applications before the project, but their knowledge and understanding significantly improved after working on the project.

Conclusions

A radio-controlled race ca project was included in the first electronics lab for our EE students. Results showed that not all concepts from earlier courses were recognized and applied. These results point to a need for finding new ways of teaching that will help the student recognize, understand and apply the engineering concepts learned from the freshman to the senior year. The results are not conclusive, since these are the results of the first year of the project. To obtain more consistent data, the principal investigator plans to include similar projects in his electronics class for the following two years. The surveys will be improved to include questions that will intentionally focus on the concepts with weakest understanding. The results of this project may lead other disciplines in the school of engineering to develop their own projects to help them determine if their students are able to recognize, understand and apply the engineering concepts taught in their fields.

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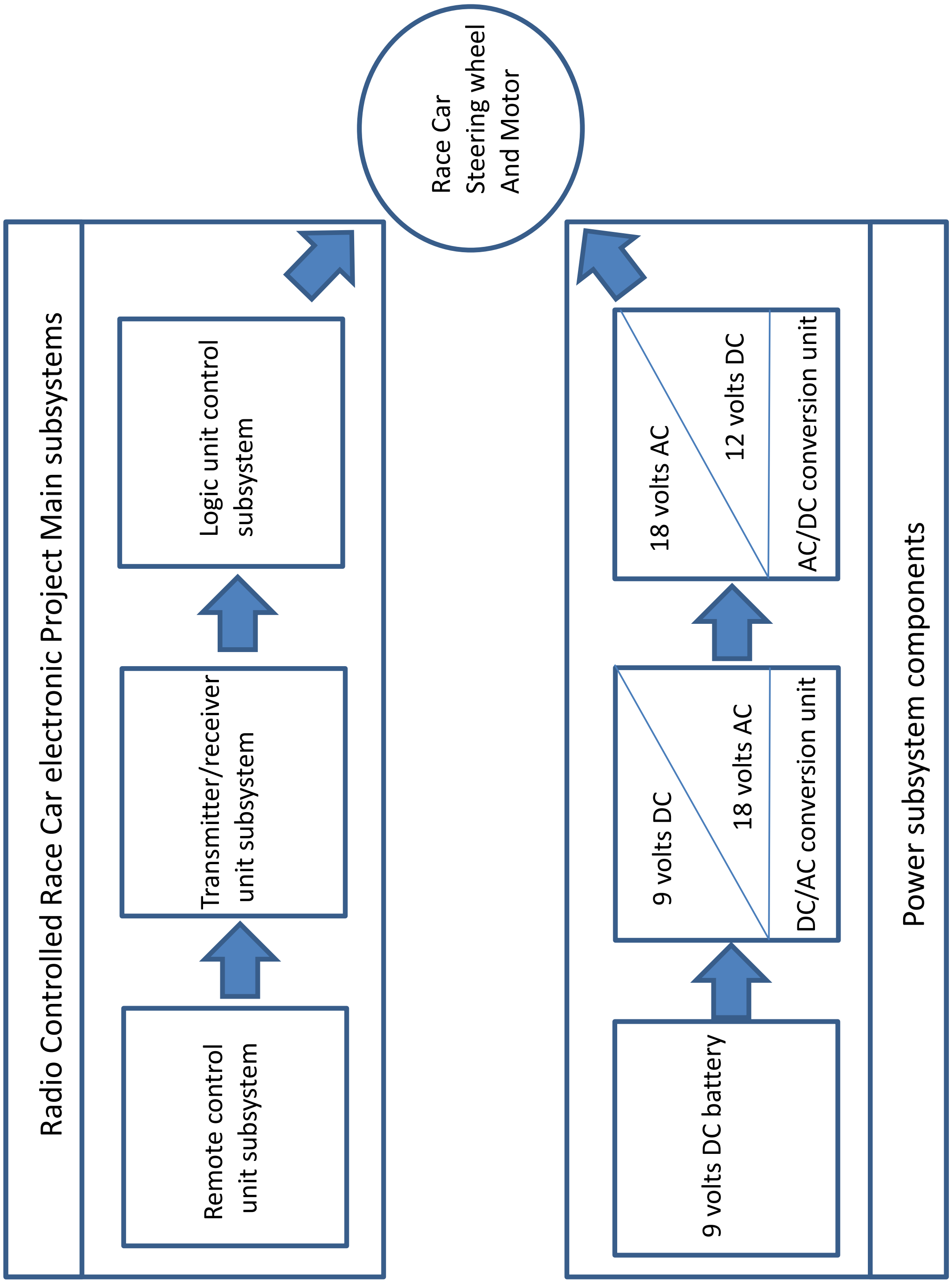
Appendix 1 - Radio Controlled Race Car Project Subsystems



Appendix 2 - Survey of electronic project effectiveness

	STUDENT EVALUATION OF ELECTRONIC PROJECT EFFECTIVENESS "Participation in this survey is voluntary. The results of the survey will be accumulated and shared with ASEE members only. No individual results will be reported on or connected to any faculty, staff or student respondent. **Do not sign your name.**"									
1	Before working in this project did you know how a remote control works?							yes		No
	After working in this project, Do you have a better understanding of how a remote control works?							yes		No
	From a scale of 1 being lowest and 5 being the highest, rate your knowledge of how a remote control works									
	1	lowest	2	low	3	Neutral	4	high	5	highest
2	Before working in this project did you know how a radio transmitter/receiver works?							yes		No
	After working in this project, Do you have a better understanding of how a transmitter/receiver works?							yes		No
	From a scale of 1 being lowest and 5 being the highest, rate your knowledge of how transmitter/receiver works									
	1	lowest	2	low	3	Neutral	4	high	5	highest
3	Before working in this project did you know how AM/FM works?							yes		No
	After working in this project, Do you have a better understanding of how AM/FM works?							yes		No
	From a scale of 1 being lowest and 5 being the highest, rate your knowledge of how AM/FM works									
	1	lowest	2	low	3	Neutral	4	high	5	highest
4	Before working in this project did you know how an electronic control unit works? (Arduino)							yes		No
	After working in this project, Do you have a better understanding of how an electronic control unit works?							yes		No
	From a scale of 1 being lowest and 5 being the highest, rate your knowledge of how an electronic control unit works									
	1	lowest	2	low	3	Neutral	4	high	5	highest
5	Before working in this project did you know how DC to AC conversion works?							yes		No
	After working in this project, Do you have a better understanding of how it works?							yes		No
	From a scale of 1 being lowest and 5 being the highest, rate your knowledge of how DC to AC conversion works									
	1	lowest	2	low	3	Neutral	4	high	5	highest
6	Before working in this project did you know how a voltage doubler works?							yes		No
	After working in this project, Do you understanding how a voltage doubler works?							yes		No
	From a scale of 1 being lowest and 5 being the highest, rate your knowledge of how a voltage doubler works? works									
	1	lowest	2	low	3	Neutral	4	high	5	highest
7	Before working in this project did you know how a diode works?							yes		No
	After working in this project, Do you have a better understanding of how diodes works							yes		No
	From a scale of 1 being lowest and 5 being the highest, rate your knowledge of how a diode works									
	1	lowest	2	low	3	Neutral	4	high	5	highest
8	Before working in this project did you know how a transistor amplifier works?									
	After working in this project, Do you understanding of how transistors works?									
	From a scale of 1 being lowest and 5 being the highest, rate your knowledge of how a transistor works									
	1	lowest	2	low	3	Neutral	4	high	5	highest

Appendix 3 – Survey of learned EE concepts for remote control subsystem

STUDENT EVALUATION OF LEARNED EE CONCEPTS

"The participation on this survey is anonymous. The results of the survey will be accumulated and shared with ASEE members only. No individual results will be reported on or connected to any faculty, staff or student respondent. **Do not sign your name**."

	REMOTE CONTROL SUBSYSTEM									
1	Was the concept of **impedance** present in the remote control subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **impedance** was part or was used in the remote control subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **impedance** present or used?									
2	Was the concept of **impedance matching** present in the remote control subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **impedance matching** was part or used in the remote control subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **impedance matching** present or used?									
3	Was the concept of **maximum power transfer** present in the remote control subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **maximum power transfer** was part or used in the remote control subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **maximum power transfer** present or used?									
4	Was the concept of **energy conversion or transformation** present in the remote control subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **energy conversion or transformation** was part or used in the remote control subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **energy conversion or transformation** present or used?									
5	Was the concept of **power loss** present in the remote control subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **power loss** was part or used in the remote control subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **power loss** efficiency present or used?									

Appendix 4 – Survey of learned EE concepts for Transmitter/Receiver subsystem (page 1 of 2)

STUDENT EVALUATION OF LEARNED EE CONCEPTS

"The participation on this survey is anonymous. The results of the survey will be accumulated and shared with ASEE members only. No individual results will be reported on or connected to any faculty, staff or student respondent. **Do not sign your name**."

	RADIO TRANSMITTER/RECEIVER SUBSYSTEM									
1	Was the concept of **impedance** present in the radio transmitter/receiver subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **impedance** was part or was used in the radio transmitter/receiver subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **impedance** present or used?									
2	Was the concept of **impedance matching** present in the radio transmitter/receiver subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **impedance matching** was part or used in the radio transmitter/receiver subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **impedance matching** present or used?									
3	Was the concept of **maximum power transfer** present in the radio transmitter/receiver subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **maximum power transfer** was part or used in the radio transmitter/receiver subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **maximum power transfer** present or used?									
4	Was the concept of **energy conversion or transformation** present in the radio transmitter/receiver subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **energy conversion or transformation** was part or used in the radio transmitter/receiver subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **energy conversion or transformation** present or used?									
5	Was the concept of **power loss** present in the radio transmitter/receiver subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **power loss** was part or used in the radio transmitter/receiver subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **power loss** present or used?									

Appendix 4 – Survey of learned EE concepts for Transmitter/Receiver subsystem (page 2 of 2)

	STUDENT EVALUATION OF LEARNED EE CONCEPTS "The participation on this survey is anonymous. The results of the survey will be accumulated and shared with ASEE members only. No individual results will be reported on or connected to any faculty, staff or student respondent. Do not sign your name."									
	RADIO TRANSMITTER/RECEIVER SUBSYSTEM									
6	Was the concept of **resonance** present in the radio transmitter/receiver subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **resonance** was part or was used in the radio transmitter/receiver subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **resonance** present or used?									
7	Was the concept of **filtering** present in the radio transmitter/receiver subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **filtering** was part or used in the radio transmitter/receiver subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **filtering** present or used?									
8	Was the **Barkhausen's criterion** present in the radio transmitter/receiver subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how the **Barkhausen,s criterion** was part or used in the radio transmitter/receiver subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the **Barkhausen's criterion** present or used?									
9	Was the concept of **oscillation** present in the radio transmitter/receiver subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **oscillation** was part or used in the radio transmitter/receiver subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of energy conversion or transformation present or used?									
10	Was the concept of **frequency modulation** present in the radio transmitter/receiver subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **frequency modulation** was part or used in the radio transmitter/receiver subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **frequency modulation** efficiency present or used?									

Appendix 5 – Survey of learned EE concepts for Logic Unit Arduino subsystem (page 1 of 2)

	STUDENT EVALUATION OF LEARNED EE CONCEPTS "The participation on this survey is anonymous. The results of the survey will be accumulated and shared with ASEE members only. No individual results will be reported on or connected to any faculty, staff or student respondent. **<u>Do not sign your name</u>**."									
	LOGIC UNIT - ARDUINO SUBSYSTEM									
1	Was the concept of **<u>impedance</u>** present in the logic unit – Arduino subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **<u>impedance</u>** was part or was used in the logic unit – Arduino subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **<u>impedance</u>** present or used?									
2	Was the concept of **<u>impedance matching</u>** present in the logic unit – Arduino subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **<u>impedance matching</u>** was part or used in the logic unit - Arduino subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **<u>impedance matching</u>** present or used?									
3	Was the concept of **<u>maximum power transfer</u>** present in the logic unit - Arduino subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **<u>maximum power transfer</u>** was part or used in the logic unit - Arduino subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **<u>maximum power transfer</u>** present or used?									
4	Was the concept of **<u>energy conversion or transformation</u>** present in the logic unit - Arduino subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **<u>energy conversion or transformation</u>** was part or used in the logic unit - Arduino subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **<u>energy conversion or transformation</u>** present or used?									
5	Was the concept of **<u>power loss</u>** present in the logic unit - Arduino subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **<u>power loss</u>** was part or used in logic unit - Arduino subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **<u>power loss</u>** present or used?									

Appendix 5 – Survey of learned EE concepts for Logic Unit Arduino subsystem (page 2 of 2)

<table>
<tr><td></td><td colspan="10">STUDENT EVALUATION OF LEARNED EE CONCEPTS

"The participation on this survey is anonymous. The results of the survey will be accumulated and shared with ASEE members only. No individual results will be reported on or connected to any faculty, staff or student respondent. Do not sign your name."</td></tr>
<tr><td></td><td colspan="6">LOGIC UNIT - ARDUINO SUBSYSTEM</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td colspan="6">Was the concept of <u>resonance</u> present in the logic unit - Arduino subsystem?</td><td></td><td>yes</td><td></td><td>No</td></tr>
<tr><td></td><td colspan="10">If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how <u>resonance</u> was part or was used in the logic unit - Arduino subsystem</td></tr>
<tr><td></td><td>1</td><td>lowest</td><td>2</td><td>low</td><td>3</td><td>Neutral</td><td>4</td><td>high</td><td>5</td><td>highest</td></tr>
<tr><td></td><td colspan="10">Explain where was the concept of <u>resonance</u> present or used?</td></tr>
<tr><td>7</td><td colspan="6">Was the concept of <u>filtering</u> present in the logic the unit - Arduino subsystem?</td><td></td><td>yes</td><td></td><td>No</td></tr>
<tr><td></td><td colspan="10">If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how <u>filtering</u> was part or used in the logic unit - Arduino subsystem</td></tr>
<tr><td></td><td>1</td><td>lowest</td><td>2</td><td>low</td><td>3</td><td>Neutral</td><td>4</td><td>high</td><td>5</td><td>highest</td></tr>
<tr><td></td><td colspan="10">Explain where was the concept of <u>filtering</u> present or used?</td></tr>
<tr><td>8</td><td colspan="6">Was the <u>Barkhausen's criterion</u> present in the logic unit - Arduino subsystem?</td><td></td><td>yes</td><td></td><td>No</td></tr>
<tr><td></td><td colspan="10">If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how the <u>Barkhausen,s criterion</u> was part or used in the logic unit - Arduino subsystem</td></tr>
<tr><td></td><td>1</td><td>lowest</td><td>2</td><td>low</td><td>3</td><td>Neutral</td><td>4</td><td>high</td><td>5</td><td>highest</td></tr>
<tr><td></td><td colspan="10">Explain where was the <u>Barkhausen's criterion</u> present or used?</td></tr>
<tr><td>9</td><td colspan="6">Was the concept of <u>oscillation</u> present in the logic unit - Arduino subsystem?</td><td></td><td>yes</td><td></td><td>No</td></tr>
<tr><td></td><td colspan="10">If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how <u>oscillation</u> was part or used in the logic unit - Arduino subsystem</td></tr>
<tr><td></td><td>1</td><td>lowest</td><td>2</td><td>low</td><td>3</td><td>Neutral</td><td>4</td><td>high</td><td>5</td><td>highest</td></tr>
<tr><td></td><td colspan="10">Explain where was the concept of energy conversion or transformation present or used?</td></tr>
<tr><td>10</td><td colspan="6">Was the concept of <u>frequency modulation</u> present in the logic unit - Arduino subsystem?</td><td></td><td>yes</td><td></td><td>No</td></tr>
<tr><td></td><td colspan="10">If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how <u>frequency modulation</u> was part or used in the logic unit - Arduino subsystem</td></tr>
<tr><td></td><td>1</td><td>lowest</td><td>2</td><td>low</td><td>3</td><td>Neutral</td><td>4</td><td>high</td><td>5</td><td>highest</td></tr>
<tr><td></td><td colspan="10">Explain where was the concept of <u>frequency modulation</u> efficiency present or used?</td></tr>
</table>

Appendix 6 – Survey of learned EE concepts for Power subsystem (page 1 of 2)

STUDENT EVALUATION OF LEARNED EE CONCEPTS

"The participation on this survey is anonymous. The results of the survey will be accumulated and shared with ASEE members only. No individual results will be reported on or connected to any faculty, staff or student respondent. **Do not sign your name**."

	POWER SUBSYSTEM									
1	Was the concept of **impedance** present in the power subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **impedance** was part or was used in the power subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **impedance** present or used?									
2	Was the concept of **impedance matching** present in the power subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **impedance matching** was part or used in logic unit - Arduino subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **impedance matching** present or used?									
3	Was the concept of **maximum power transfer** present in the power subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **maximum power transfer** was part or used in in the power subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **maximum power transfer** present or used?									
4	Was the concept of **energy conversion or transformation** present in in the power subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **energy conversion or transformation** was part or used in in the power subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **energy conversion or transformation** present or used?									
5	Was the concept of **power loss** present in in the power subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **power loss** was part or used in in the power subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **power loss** present or used?									

Appendix 6 – Survey of learned EE concepts for Power control subsystem (page 2 of 2)

STUDENT EVALUATION OF LEARNED EE CONCEPTS

"The participation on this survey is anonymous. The results of the survey will be accumulated and shared with ASEE members only. No individual results will be reported on or connected to any faculty, staff or student respondent. Do not sign your name."

	POWER SUBSYSTEM									
6	Was the concept of **resonance** present in in the power subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **resonance** was part or was used in logic unit - Arduino subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **resonance** present or used?									
7	Was the concept of **filtering** present in in the power subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **filtering** was part or used in in the power subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **filtering** present or used?									
8	Was the **Barkhausen's criterion** present in in the power subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how the **Barkhausen,s criterion** was part or used in in the power subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the **Barkhausen's criterion** present or used?									
9	Was the concept of **oscillation** present in in the power subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **oscillation** was part or used in in the power subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of energy conversion or transformation present or used?									
10	Was the concept of **frequency modulation** present in in the power subsystem?							yes		No
	If your response is yes, from a scale of 1 being lowest and 5 being the highest, rate your knowledge or understanding of how **frequency modulation** was part or used in in the power subsystem									
	1	lowest	2	low	3	Neutral	4	high	5	highest
	Explain where was the concept of **frequency modulation** efficiency present or used?									

Appendix 7 – Statistical Results of the One sample t test (page 1 of 2)

For the analysis of the concept understanding of the remote control subsystem, the following hypothesis was assumed: Out of the 16 students, 0 will score lowest, 2 will score low, 4 will score medium 7 will score high and 3 will score highest, with a mean = 3.688.

Table # 1_ One sample t test results for Remote control subsystem

Concept	mean	T value	D.F.	One tailed P	Observation
Impedance	3.5	0.921	15	0.1858	Not statistically significant.
Impedance matching	1.94	6.2317	15	0.00005	extremely statistically significant
Maximum power transfer	2.44	3.8039	15	0.00085	very statistically significant
Energy conversion	2.31	5.1030	15	0.00005	extremely statistically significant
Power losses			15	0.0028	Very statistically significant.

For the analysis of the concept understanding of the transmitter/receiver subsystem, the following hypothesis was assumed: Out of the 16 students, 0 will score lowest, 2 will score low, 4 will score medium 7 will score high and 3 will score highest, with a mean = 3.688.

Table # 2_ One sample t test results for Transmitter/Receiver subsystem

Concept	mean	t value	D.F.	One tailed P	Observation
Impedance	3.63	0.4038	15	0.6921	Not statistically significant.
Impedance matching	2.06	6.1169	15	0.3461	extremely statistically significant
Maximum power transfer	2.38	4.1723	15	0.0004	very statistically significant
Energy conversion	2.94	3.0063	15	0.0089	very statistically significant
Power losses	3.25	2.2592	15	0.196	Very statistically significant.
Resonance	3.31	2.4914	15	0.1245	Statistically significant
Filtering	3.81	0.7632	15	0.2286	Not statistically significant.
Oscillation	3.81	0.5994	15	0.2790	Not statistically significant.
Freq Modulation	3.31	2.1302	15	0.0251	not statistically significant

Appendix 7 – Statistical Results of the One sample t test (page 2 of 2)

For the Logic Unit or Arduino subsystem

For the analysis of the concept understanding of the Logic Unit or Arduino subsystem, the following hypothesis was assumed: Out of the 11 students, 0 will score lowest, 2 will score low, 3 will score medium 4 will score high and 2 will score highest, this had a mean= 3.70

Table # 3_ One sample t test results for Logic Unit or Arduino subsystem

Concept	mean	SD.	t value	DF	1 tailed P	Observation
Impedance	2.64	1.29	0.8129	10	0.0092	Statistically significant.
Impedance matching	2.45	1.13	3.7417	10	0.0019	Very statistically significant.
Maximum power transfer	2.82	1.17	2.5821	10	0.0137	Statistically significant.
Energy conversion	2.36	1.12	4.0379	10	0.0012	Very statistically significant.
Power losses	3.55	0.52	1.1549	10	0.1375	Not statistically significant. *
Resonance	2.36	0.81	5.5903	10	0.0001	Extremely Statistically significant
Filtering	3.36	0.81	1.4908	10	0.0835	Not statistically significant. *
Barkhausen's criterion	1.91	1.04	5.7736	10	0.0001	Extremely Statistically significant
Oscillation	3.18	0.60	3.0002	10	0.0067	Statistically significant.
Freq Modulation	3.82	0.60	0.4999	10	0.3140	Not statistically significant. *

For the Power Control subsystem

For the analysis of the concept understanding of the power subsystem, the following hypothesis was assumed: Out of the 16 students, 0 will score lowest, 2 will score low, 4 will score medium 7 will score high and 3 will score highest, this had a mean= 3.688.

Table # 4_ One sample t test results for the Power subsystem

Concept	mean	S.D	t value	D.F	1 tailed P	Observation
Impedance	3.81	0.40	1.2403	15	0.0605	Not statistically significant.
Impedance matching	3.25	1.06	1.6438	15	0.0603	Not statistically significant.
Maximum power transfer	3.5	.089	.08408	15	0.2069	Not statistically significant.
Energy conversion	3.44	1.09	.9163	15	0.1852	Not statistically significant.
Power losses	4.00	.73	1.7089	15	0.5405	Not statistically significant
Resonance	3.81	.83	0.5970	15	0.2797	Statistically significant
Filtering	3.25	1.24	1.4133	15	0.0888	Not statistically significant.
Oscillation	4.75	0.45	9.4988	15	0.00005	Not statistically significant.
DC/AC &AC/DC	4.69	.48	8.3515	15	0.00005	Not statistically significant