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A Hybrid Flipped Classroom Approach to Teaching Power Electronics Course to Electrical Engineering Students

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Abstract

Western Carolina University is the only educational institution that offers engineering and technology degrees in the western part of the state which is home to major national and international engineering-related companies. As the power industry has a significant share among these companies and is becoming one of the major recruiters of our graduates in the Department of Engineering and Technology at Western Carolina University, developing an emphasis in electric power engineering plays a vital role in educating the next generation of the region's power industry workforce.

To that end, a curriculum development effort was planned and is projected to train, prepare for research, and educate the students enrolled in the Department of Engineering and Technology for careers in the power industry. The curriculum includes three fundamental power engineering courses:

1. Electric Power Systems
2. Power Electronics
3. Electrical Machines and Drives

The first two courses have been developed and implemented under the guidance of the Consortium of Universities for Sustainable Power (CUSP^{TM}) at University of Minnesota.

This paper describes in detail the first two pilot implementations of the Power Electronics course for Electrical Engineering (EE) undergraduates and presents its assessment results.

The pedagogical concept that was used is called "Flipped Classroom Pedagogy" in which active student engagement is facilitated through on-line pre-recorded lectures. To enhance this concept, a hybrid approach to the traditional lecture was applied. In this approach, students are exposed to both on-line and face-to-face lecture methods. In addition, this approach included a short online quiz through Blackboard^{TM} before each course module and a short quiz at the start of class session after each course module to improve student participation. In fact, a 2010 U.S. Department of Education report[1] concluded that "Instruction combining online and face-to-face elements had a larger advantage relative to purely face-to-face instruction than did purely online instruction". However this report targeted very broad population including K-12, career technology, medical and higher education, as well as corporate and military training. In addition, many studies in this report did not attempt to equate (a) all the curriculum materials, (b) aspects of pedagogy and (c) learning time in the treatment and control conditions. Therefore, the study presented in this paper is unique in a sense that the analysis is only for electrical engineering students based on specific curriculum contents and hybrid flipped classroom pedagogy where on-line and in-class lecture components present.

End of year survey data of two consecutive year course offerings were collected to evaluate the overall course and the faculty performance as well as the sustainability of the established course concept.

I. Introduction

Recognizing our additional need for clean energy in 21st century, electric energy generation through renewable sources (especially wind and solar) and nuclear gained quite a momentum over the recent years. For instance, as of November 2010, U.S. Nuclear Regulatory Commission has received 18 combined license applications for a total of 30 new reactors [2]. In terms of renewables, total non-hydro renewable energy generation (wind, solar, geothermal and biomass) in the U.S. increased by 16.6 percent in 2013, following a 12.6 percent increase in 2012. The fastest-growing component in 2013 was solar (thermal and photovoltaic) power with 108.5 percent increase. Wind energy generation increased 11.9 percent. Since 2004, generation from non-hydro renewables has almost tripled. In 2013, renewable energy generation made up 12.9 percent of total generation. The largest three contributors were hydro (6.6 percent), wind (4.1 percent), followed by biomass (1.5 percent). On the other hand, electrical energy production from fossil fuel sources coal has still the largest share of 38.9% which is followed by natural gas with a share of 27.7% [3].

Growing the demand of electrical energy from sustainable sources requires a skilled workforce that is educated and trained to take the lead on main sub-tasks of generation, transmission & distribution and utilization. In addition, it has been projected that the current power industry will soon be facing a manpower crisis due to attrition within its "soon-to-be-retiring" workforce. In a survey conducted at 2011, The Center for Energy Workforce Development analysis indicates that 36% of skilled utility technician and engineering (excluding positions in nuclear) may need to be replaced due to potential retirement or attrition, with an additional 16% to be replaced by 2020 — almost 110,000 employees in positions identified as the most critical by industry [4]. The North American Electric Reliability Corporation (NERC) in its 2007 report has also identified the aging workforce as a growing challenge to future reliability of the electricity supply and NERC continues to support action and monitor industry progress [5].

The Need for Power Engineering Education and Teaching Methodologies

The demands of the power industry for a skilled workforce in power engineering disciplines combined with a lack of educational programs that support the power industry suggest the immediate need for the development and teaching of courses in power engineering. In order to fill this gap in skilled workforce, Sergeyev and Alaraje recently described an industry-driven power curriculum in an electrical and computer engineering technology program. The primary outcome of their project was to educate a larger number of better qualified engineering technologist graduates with skills and knowledge that are current and relevant [6]. In another recent study, Karayaka and Adams provided their findings in a first implementation of a course designed within the context of power systems curriculum development efforts to bridge the gaps of regional workforce needs [7]. The paper primarily highlighted the effectiveness of student oriented project based learning.

Among the collaborative efforts, Mousavinezhad *et al.* described the work of the Electrical and Computer Engineering Department Heads Association with the support of the National Science Foundation in establishing a workshop series on the issues aimed at developing educational and research programs in this critical area of power and energy systems within Electrical and Computer Engineering [8].

Another collaborative effort is the Consortium of Universities for Sustainable Power (CUSP™) which is currently offered by the research group led by Professor Ned Mohan of the University of Minnesota which promoted flipped classroom pedagogy. This consortium includes universities that have come together to utilize, collectively evolve and promote the curriculum developed at the University of Minnesota – Twin Cities with the help of funding from various organizations including NSF, ONR (Office of Naval Research), NASA and EPRI [9]. In relationship to this effort, two recent studies were published by Lin, *et al* [10, 11]. The survey results among students in their first paper reveal that only 1/3 of the group indicated that they prepared as instructed before coming to lectures while 1/3 never did. In addition, it was observed that many students were not ready to meet the demands of self-directed study which is one of the core themes of flipped classroom approach. According to the most recent paper by Lin, *et al.* the students were instructed to know theories and content by watching online video modules before coming to the class, and solve problems with peers inside the classroom [11]. However, as mentioned in the same paper, "flipping lectures" has not been universally embraced due to the concerns about perceived limited contacts and interactions between instructors and students [12].

Therefore, the study presented in this paper attempts a hybrid approach which flips lectures partially in such a way that to provide the basics of theories and content in the classroom as well as instructing students to watch online video modules ahead of face-to-face session. Interactive problem solving and Q & A still comprised a good part of the classroom activities.

The following sections describe the new curriculum developed to support the power industry (Section 2), teaching the Power Electronics course for the first and second year (Section 3), course assessment, results and findings (Section 4), and Conclusions (Section 5).

II. New Curriculum Supporting Power Industry

At (…) University, the engineering and engineering technology curricula have been currently developing to support the power industry in the region. Specifically, the electrical engineering curriculum was selected to comprise two common fundamental sustainable power engineering education courses. The courses that have been currently implemented in the curriculum and offered for the past two academic years are:

1. Electric Power Systems
2. Power Electronics

III. The Power Electronics Course

The Power Electronics course was designed to support the sustainable power engineering initiative. This course provides the basics of switch mode power electronics which are important concepts for currently growing renewable energy, smart power grid and transportation electrification industries. This course is a standard three-credit-hour lecture course and is offered to senior level Electrical Engineering Students.

Student Enrollment Figures and Background

The department of engineering and technology with an undergraduate enrollment close to 600 students at (…) includes total of four majors of specialty as listed below:

- Bachelor of Science in Electrical Engineering (BSEE)
- Bachelor of Science in Engineering Technology (BSET)
- Bachelor of Science in Electrical and Computer Engineering Technology (BSECET)
- Bachelor of Science in Engineering with a mechanical engineering (BSE-ME) specialization

The first three majors are well established and ABET accredited majors serving the region for many years. The BSE program is a new program that was added in fall 2012 with ME specialization. In addition two other specializations are scheduled to be launched in fall 2015:

- Bachelor of Science in Engineering with an electric power engineering (BSE-EPE) specialization
- Bachelor of Science in Engineering with a manufacturing engineering (BSE-MFE) specialization

The two courses already being developed and offered in BSEE program along with Electric Machines and Drives course (to be developed) are planned to form the core concentration courses for BSE-EPE specialization which is currently being developed. In addition to undergraduate programs discussed above, the department also has a graduate program which offers Master of Science in Technology (MST) major.

As mentioned earlier, Power Electronics is a senior level course and is currently offered to only EE majors in the program. Therefore, the course enrollment and assessment data in this paper only includes the EE major. Consequently, the student demographics data are solely presented for EE majors.

As of spring 2015, the enrollment numbers for all EE majors at Western Carolina University are on the average of 22 students for each level from freshman to senior. For the “Power Electronics” course, the total enrollment in the first year was eight and in the second year it was thirteen. The course in the discussed implementation was offered in the spring semesters of 2013 and 2014. Each week the class meetings were scheduled twice for total of three contact hours of lecture sessions. The enrollment statistics of the students in the class for two consecutive years are listed in Table 1 and Table 2 respectively. As can be seen in the table for year 1, total of seven senior undergraduate students and one graduate student who are all male and majoring in BSEE and MST participated in this course. In year 2, total of thirteen senior undergraduate students and one graduate student participated in this course. There were also four female (one of which was graduate) and nine male students in year 2 implementation.

Table 1. Year 1 Enrollment Figures in “Power Electronics” Course

	Level	**Gender**	**Major**
Student 1	Senior	Male	BSEE
Student 2	Senior	Male	BSEE
Student 3	Senior	Male	BSEE
Student 4	Senior	Male	BSEE
Student 5	Senior	Male	BSEE
Student 6	Senior	Male	BSEE
Student 7	Senior	Male	BSEE
Student 8	Graduate	Male	MST

Table 2. Year 2 Enrollment Figures in “Power Electronics” Course

	Level	**Gender**	**Major**
Student 1	Senior	Female	BSEE
Student 2	Senior	Female	BSEE
Student 3	Senior	Female	BSEE
Student 4	Senior	Male	BSEE
Student 5	Senior	Male	BSEE
Student 6	Senior	Male	BSEE
Student 7	Senior	Male	BSEE
Student 8	Senior	Male	BSEE
Student 9	Senior	Male	BSEE
Student 10	Senior	Male	BSEE
Student 11	Senior	Male	BSEE
Student 12	Senior	Male	BSEE
Student 13	Graduate	Female	MST

Teaching the Power Electronics Course with a Hybrid Flipped Classroom Approach

This course was designed to introduce switch mode power electronics principles with a partially flipped (or hybrid) classroom approach. Covered topics include analysis, design, and operation of power electronic circuits for motor drives and electric utility applications, power conversion from AC to DC, DC to DC, DC to AC. In addition, design and construction of power electronic circuits through simulations are studied. PSpice software is used for power electronics system analysis and design. Prerequisite courses include Solid State Electronic Devices and Linear Control Systems Theory.

Required textbook:

- N. Mohan, Power Electronics: A First Course, John Wiley & Sons, Inc., 2011.

Recommended reference books:

- N. Mohan, T. M. Undeland, W. P. Robbins, Power Electronics: Converters, Applications, and Design, Third Edition, John Wiley & Sons, Inc., 2003.

Course Objectives/Student Learning Outcomes (or SLO) were designed to enable students to:

- Describe the role of Power Electronics as an enabling technology in various applications such as flexible production systems, energy conservation, renewable energy, transportation etc.
- Identify a switching power-pole as the basic building block and to use Pulse Width Modulation to synthesize the desired output.
- Design the switching power-pole using the available power semiconductor devices, their drive circuitry and driver ICs and heat sinks. You will be able to model these in PSpice.
- Learn the basic concepts of operation of dc-dc converters in steady state in continuous and discontinuous modes and be able to analyze basic converter topologies.
- Using the average model of the building block, quickly simulate the dynamic performance of dc-dc converters and compare them with their switching counterparts.
- Design, using simulations, the interface between the power electronics equipment and single-phase and three-phase utility using diode rectifiers and analyze the total harmonic distortion.
- Design the single-phase power factor correction (PFC) circuits to draw sinusoidal currents at unity power factor.
- Learn basic magnetic concepts, analyze transformer-isolated switch-mode power supplies and design high-frequency inductors and transformers.
- Learn the requirements imposed by electric drives (dc and ac) on converters and synthesize these converters using the building block approach.
- Learn the role of Power Electronics in utility-related applications which are becoming extremely important.

Instructional methods and activities for instruction included both in-class and on-line lectures, homework assignments/solutions, in-class discussions, quizzes, tests and use of simulation software.

The Grading Policy was determined by students' performance in homework/simulation assignments, quizzes, midterm and final exams. The distribution of points was given in Table 3 as follows:

Table 3. Grade Distribution

1.	Homework/PSpice Assignments	40%
2.	Quizzes	20%
3.	Midterm Exam	20%
4.	Final Exam	20%

Letter grades are assigned according to the following:
A+: 99–100, A: 92–98, A-: 90–91, B+: 88–89, B: 82–87, B-: 80–81,
C+: 78–79, C: 72–77, C-: 70–71; D+: 68–69, D: 62–67, D-: 60–61, and F: 59–0.

In the first year implementation, although the students were made aware of pre-recorded on-line lectures through CUSP^{TM}, a classical in-class lecture approach was primarily emphasized. Both quizzes that involve problem solving and exams were administered in class. However, concept quizzes were assigned on-line and the response was expected before coming to the class to prepare the students. Most of the lecture notes, questions used in the exams and the quizzes were extracted from the teaching materials provided by CUSP^{TM}. The quizzes included one or two questions involving either concept understanding or problem solving. The tests had ten to fifteen questions with similar question format to quizzes. In addition, the exams had a PSpice problem testing student's simulation software usage and circuit analysis skills.

In the second year implementation, the students were instructed to watch the pre-recorded on-line lectures for each module before face-to-face lecture sessions. The in-class session for each module included:

1. Updated CUSP^{TM} lecture materials to provide additional information.
2. Sample problems and interactive solutions.
3. PSpice simulation examples running on-site from the instructor's computer.

After the completion of each module, a short online concept quiz through Blackboard^{TM} before the next course module and another short quiz testing problem solving skills at the start of next class session were administered to improve student participation. The number of quizzes was substantially larger in the second year's implementation. A total of twenty four such course modules were completed throughout the semester which was pretty similar to the first year's implementation. The number of homework and simulation assignments was slightly less in the second year. The original projected course schedule is given in Table 4.

Table 4. Schedule of Topics for Power Electronics Course

Topic/Activity	**Week**
Introduction to Power Electronic Systems	1
Basic Building Block – Switching Power-Poles	2-3
Non isolated DC-DC Converters	3-6
Design of Feedback Controllers	6-7
Diode Rectifiers	7-8
Power Factor Correction	8-9
Magnetic Circuit Concepts	10
Isolated Switch-Mode DC Power Supplies	11-12
Application of PE Devices in Motor Drives, UPS and Power Systems	13
Synthesis of Motor Drives, UPS and Power Systems	14-15

The topics addressed and covered in the course in Table 3 along with associated module sequence are briefly described below.

1. *Introduction to Power Electronics Systems*: Role, applications and requirements are introduced (Module 1).
2. *Basic Building Block – Switching Power-Poles*: Types of converter structures, concept of pulse width modulation, switching power-pole circuit topology are presented. Power semiconductor devices, losses in switching power-poles and practical considerations in designing switching power poles are introduced (Modules 2-4).
3. *Non isolated DC-DC Converters*: Operational principles of Buck, Boost and Buck-Boost converter topologies and average models representing these topologies are introduced. Continuous and Discontinuous Conduction modes and associated models are studied (Modules 5-11).
4. *Design of Feedback Controllers*: Topics of regulated switch-mode power supplies, linearization, generic control objectives (i.e. zero steady state error, fast response, low overshoot and low noise susceptibility), and phase and gain margin in Bode plots are covered. Voltage and current mode control principles as well as K-factor design approach are introduced (Modules 12-14).
5. *Diode Rectifiers*: Concepts of power factor, displacement power factor, total harmonic distortion and associated IEEE-519 harmonic guideline are introduced. Single phase, three phase diode rectifiers and associated the non-linear characteristics are presented (Modules 15-16).
6. *Power Factor Correction*: Power factor correction using single phase rectifier and boost converter topology are introduced. Controller design involving inner current loop control mechanism for current shaping as well as outer voltage loop control for output voltage regulation are studied (Modules 17-18).
7. *Magnetic Circuit Concepts*: Ampere's circuital law, B-H curves, magnetic circuit losses (hysteresis and eddy current), flux/flux density, reluctance, inductance, Faraday's law and magnetic transformer topics are covered (Module 19).
8. *Isolated Switch-Mode DC Power Supplies*: Flyback, forward, full-bridge, half-bridge and push-pull converter topologies and their operational principles are discussed (Modules 20-21).
9. *Application of PE Devices in Motor Drives, Uninterruptible Power Supplies (UPS) and Power Systems*: Voltage and current ratings in converters for Electric Machine Drives (DC machine, permanent magnet AC machine and induction machine), UPS and utility scale power system applications are presented (Module 22).
10. *Synthesis of Motor Drives, UPS and Power Systems*: Definition, average representation and pulse width modulation of bidirectional switching power-pole are introduced. Converters for DC machine drives and associated average representation and switching waveforms are studied. Synthesis of single phase AC systems including UPS and photovoltaic applications are also covered (Modules 23-24).

Student assignments throughout the course flow specifically included:

PSpice lab 1: Pulse width modulation and filter characteristics
PSpice lab 2: Switching characteristic of MOSFET and diode in a switching power-pole
PSpice lab 3: Step-up (Boost) DC-DC converter
Homework 1: Buck, boost, buck-boost converters
Homework 2: Design of feedback controllers
Homework 3: Diode rectifiers
Homework 4: Power factor correction, magnetic circuits and isolated DC power supplies
Homework 5: Application of PE Devices in Motor Drives, UPS and Power Systems and synthesis of single phase AC systems.

In addition to the topics listed above, reviews before midterm and final exam were scheduled. In these reviews, interactive sessions that involve problem solving, concept understanding took place. The midterm exam was also scheduled during the regular course meeting session which is seventy five minutes.

IV. Course Assessment, Results and Findings

In the final class meeting, the students were asked to complete a survey regarding the course experience and its potential impact in their career. The survey results shown in black font represent the first year and the ones in red font represent the second year. As can be seen in Table 5, there were 8 respondents in the first year and 13 respondents in the second year for each question. Each survey question had a choice varying from Strongly Agree to Not Applicable. In the analysis, each of these options was given a weight ranging from 5 (Strongly Agree) to 1 (Strongly Disagree). Not Applicable option didn't have a weight factor. Question by question analysis of results are detailed in the following paragraphs.

Table 5. Student Survey Results

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Not Applicable
1. Have you found the course useful to improve your knowledge and skills on overall electrical engineering applications?	5 / 9	3 / 4				
2. Are mathematical relationships and calculations selected in this course appropriate?	3 / 8	5 / 5				
3. Are the computational simulation tools (PSpice) selected appropriate?	4 / 10	4 / 2	1			
4. Do you think power electronics would be a good tool to promote science, technology and engineering majors among college students?	6 / 11	2 / 2				
5. Do you think you are interested to work in electrical power related industry after your graduation?	6 / 4	5	2 / 3	1		

6. Overall quality of instruction was appropriate and useful for this class.	6 / 10	2 / 3			
7. Pre-recorded lecture videos along with interactive face to face instruction are effective ways to deliver course materials and helped my understanding.	3 / 4	5 / 3	4	2	
8. On-line and in-class quizzes before and after the lecture appropriately assessed and improved my understanding.	4 / 13	4			
9. I am interested in enrolling in future courses of similar subject matters.	5 / 7	3 / 4	2		

Question 1: It was determined that 100% of students for both first and second year agreed at some level that the course was useful in improving their overall knowledge and skills in electrical engineering applications. The common statistical analysis metrics yield the following.

Table 6. Question 1 Survey Statistical Analysis

Population	Mean	Median	Standard Deviation
Year 1	4.63	5	0.52
Year 2	4.69	5	0.48

As can be seen in Table 6, Year 2 implementation with higher mean and lower standard deviation definitely was perceived better by the students. This result can be attributed to the benefit of extensive assessment strategies (on-line and in-class) used in Year 2.

Question 2: When asked if mathematical relationships selected were appropriate and useful, 100% of the respondents again strongly agreed or somewhat agreed. The common statistical analysis metrics for this question yield the following.

Table 7. Question 2 Survey Statistical Analysis

Population	Mean	Median	Standard Deviation
Year 1	4.38	4	0.52
Year 2	4.62	5	0.51

Year 2 implementation has higher mean, median and slightly lower standard deviation which are the indicators of better student perception. This result can be attributed to the benefit of Year 2's extensive in-class assessments where mathematical relationships were commonly introduced.

Question 3: When asked if computational tool selected (PSpice) was appropriate, 100% of the respondents in Year 1 strongly agreed or somewhat agreed. This percentage dropped slightly to 92.3% for Year 2 students. However, the following analysis in Table 8 reveals mixed results.

Table 8. Question 3 Survey Statistical Analysis

Population	Mean	Median	Standard Deviation
Year 1	4.5	4.5	0.50
Year 2	4.69	5	0.63

Year 2 implementation has better mean and median but larger standard deviation. PSpice simulations were part of homework assignments and in-class tests both Year 1 and Year 2 that required computer usage. The only difference in implementation was slightly reduced number of PSpice assignments in Year 2. Although it is difficult to attribute these results to the specific implementation, one can generally conclude that PSpice is an appropriate computational tool for the course.

Question 4: In terms of promoting STEM majors through Power Electronics, both Year 1 and Year 2 students had the highest strongly agree percentage among all questions. The following analysis in Table 9 confirms this result.

Table 9. Question 4 Survey Statistical Analysis

Population	Mean	Median	Standard Deviation
Year 1	4.75	5	0.46
Year 2	4.85	5	0.38

The Year 2 implementation was again perceived better by the students which is statistically proven by higher mean and lower standard deviation metrics. This result can be attributed to the benefit of extensive exposure to various assessments (on-line and in-class) used in Year 2.

Question 5: The first year respondents showed definitely greater interest working in the electrical power related industry with a strongly agree percentage of 75%. Although the second year respondents had also reasonably well interest working in the industry, their overall average response score for both mean and median metrics was substantially lower as shown in Table 10. The more challenging nature of Year 2 implementation might possibly be a contributing factor for this result.

Table 10. Question 5 Survey Statistical Analysis

Population	Mean	Median	Standard Deviation
Year 1	4.5	5	0.93
Year 2	3.92	4	0.95

However, the standard deviation was pretty close for both years. It should be emphasized that this was a required course for all EE majors.

Question 6: Concerning quality of instruction, both Year 1 and Year 2 students had one of the largest strongly agree responses and one of the lowest standard deviations. The following analysis in Table 11 details this result.

Table 11. Question 6 Survey Statistical Analysis

Population	Mean	Median	Standard Deviation
Year 1	4.75	5	0.46
Year 2	4.77	5	0.44

This question yielded closest scores between the first and second year respondents. Although Year 2 implementation yielded slightly better statistics, the spread is not large enough to derive a conclusion. The same faculty member teaching the course for both years is likely to be a contributing factor.

Question 7: Concerning the use of pre-recorded lectures, students provided the most diverse responses when comparing first and second year survey participants. As mentioned in section 3, only the second year implementation regularly required students to watch pre-recorded online lecture videos. Surprisingly, only about half of the class agreed on the benefit of the hybrid (or partially) flipped lecture approach. Although the first year respondents were only informed and not really instructed to watch these pre-recorded lectures, 100% of students agreed at some level on the benefit of the hybrid approach, which was much less emphasized and experienced in this year. The following statistics in Table 12 details these results.

Table 12. Question 7 Survey Statistical Analysis

Population	Mean	Median	Standard Deviation
Year 1	4.38	4	0.52
Year 2	3.69	4	1.11

The mean and median for Year 1 are one of the lowest scores among all similar statistics for question 1 through 9, however the standard deviation is pretty moderate. For Year 2, all statistics are in the extremes. These statistics revealed that there is a delicate balance between pre-recorded and in-class lecture combination that students like to see and regularly emphasized/instructed on-line lectures were not perceived well.

Question 8: Concerning on-line and in-class quizzes during class time, the second year respondents unanimously strongly agreed to the benefit of this approach to improving their understanding of the course material. This was overall the best evaluation by the students. The number of quizzes in the first year was substantially less than that of the second year. The level of agreement on the benefit was still quite positive, but definitely lower than the second year. It should be emphasized that the instructor preparation and evaluation time for these quizzes was quite intense, especially in the second year. The statistics in Table 13 confirm these results.

Table 13. Question 8 Survey Statistical Analysis

Population	Mean	Median	Standard Deviation
Year 1	4.5	4.5	0.50
Year 2	5	5	0

These results showed that emphasized hybrid on-line/in-class assessment approach was well received by the respondents as opposed to the results of question 7 where less emphasized hybrid on-line/in-class lecture approach was perceived well.

Question 9: The first year respondents showed definitely greater interest in enrolling in future courses of similar subject matters. Although the second year respondents had also reasonably strong interest in enrolling in the future courses, their overall average response score for mean metric was lower as shown in Table 14. The more challenging nature of Year 2 implementation is likely a contributing factor for this result.

Table 14. Question 9 Survey Statistical Analysis

Population	Mean	Median	Standard Deviation
Year 1	4.63	5	0.52
Year 2	4.38	5	0.77

It should also be noted that the second year respondents were more diverse population as shown in Table 2 and a one-to-one comparison between these populations may not always be informative.

In general, the survey responses among first and second year respondents were somewhat close in most questions. The greatest separation between first and second year surveys occurred in questions 5, 7 and 8.

From the instructor's perspective, Year 2 implementation was definitely more costly in terms of time and effort for emphasized on-line/in-class lecture/assessment approaches. The survey definitely showed the effectiveness of hybrid assessment approach of Year 2 and hybrid lecture approach of Year 1.

Overall mean score for both years was in the range of 4.5. However, the first year had a slightly better score. The return investment for this course was verified when 71% of all students expressed an interest in working in the electrical power industry after graduation.

The average grade on all assignments for all students in the course was A- in the first year and B in the second year. The greater course load due to substantially increased amount of quizzes is likely to play a role in the lower average grade in the second year. The distribution of grades on all assignments followed a fairly normal distribution in both years. In general, students in both years excelled on the on-line concept quizzes.

V. Conclusions

In this paper, a hybrid flipped classroom approach to teaching Power Electronics for two consecutive years at Western Carolina University has been presented. The study analyzed lecture and quiz elements of instruction for online and/or face-to-face implementation. According to the survey results, the students in both years were motivated and greatly benefited from this hybrid approach. The survey results showed that:

1. In the first year in which a hybrid mix heavily emphasized the face-to-face component, students felt that the extra in-class lectures helped improve their understanding.

2. In the second year in which a hybrid mix heavily emphasized the online component, students felt that the increased number of online and in-class assessments really helped improve their understanding. Students felt that the extra online lectures did not significantly improve their understanding.

This study shows that combining online and face-to-face elements are important as suggested by DOE report[1]. However, the level of combination at the right amount is critical to improve student perception of learning. This course aims to address the emerging needs of our society at the same time when addressing the needs of students with diverse backgrounds and demographics. The assessment results show that the synchronized quizzes tied to specific course modules enhanced student comprehension.

As a next step, the course is projected to be offered with the combination of online and face-to-face elements as suggested above. In addition, it is also planned to develop in-class laboratory demonstration activities for further understanding and analysis of the subject matter.

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