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The evaluation of a new hybrid flipped classroom approach to teaching power electronics

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ABSTRACT: Developing an emphasis in electric power engineering plays a vital role in educating the next generation of southeastern US power industry workforce. To that end, a curriculum development effort was planned and is projected to train, prepare for research and educate students enrolled in the Department of Engineering and Technology at Western Carolina University for careers in the power industry. This article describes in detail the first three pilot implementations of the Power Electronics course, which is an integral part of the curriculum for Electrical Engineering (EE) undergraduates, and presents its assessment results, which are based on end of year survey data of three consecutive year course offerings. The new pedagogical concept that was used is called *Hybrid or Partially Flipped Classroom Pedagogy* in which active student engagement is facilitated through both on-line and face-to-face lecture methods. In addition, this approach included a short on-line quiz before each course module and a short quiz at the start of class session after each course module to improve student participation.

Keywords: Hybrid flipped classroom pedagogy, power electronics, electrical engineering education, workforce development

INTRODUCTION

Growing the demand of electrical energy from sustainable sources requires a skilled workforce that is educated and trained to take the lead on the main sub-tasks of generation, transmission and distribution and utilisation. 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 current skilled technical and engineering positions in all US utilities (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 [1]. 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 [2].

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 too few educational programmes 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 the skilled workforce, Sergeyev and Alaraje recently described an industry-driven power curriculum in an electrical and computer engineering technology programme [3]. The primary outcome of their project was to educate a larger number of better qualified engineering technology graduates with skills and knowledge that are current and relevant. 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 [4]. 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 programmes in this critical area of power and energy systems within electrical and computer engineering [5]. 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 utilise, collectively evolve and promote the curriculum developed at the University of Minnesota -

Twin Cities with the help of funding from various organisations including the National Science Foundation (NSF), Office of Naval Research (ONR), National Aeronautics and Space Administration (NASA) and the Electric Power Research Institute (EPRI) [6].

Related to this effort, two recent studies were published by Lin et al that involve self-directed learning [7][8]. 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 the flipped classroom approach. According to the most recent paper by Lin et al, the students were instructed to know theories and content by watching on-line video modules before coming to the class and solve problems with peers inside the classroom [8]. However, *flipping lectures* has not been universally embraced due to the concerns about perceived limited contacts and interactions between instructors and students [9].

A US Department of Education report, issued in 2010, 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* [10]. This report targeted a 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.

The study presented in this article is unique in a sense that a hybrid approach, which flips lectures partially so as to provide the basics of theories and content in the classroom, as well as instructing students to watch on-line video modules ahead of face-to-face session was implemented. Interactive problem-solving and Q&A still comprised a good part of the classroom activities. Preliminary findings of this study are presented in Karayaka and Adams [11].

TEACHING THE POWER ELECTRONICS COURSE

The Power Electronics course was designed to support sustainable power engineering initiatives, such as CUSP™. 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 Enrolment Figures and Background

The Department of Engineering and Technology with an undergraduate enrolment close to 600 students at Western Carolina University includes four undergraduate majors 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) concentration.

The first three majors are well established, ABET-accredited, and have been serving the region for many years. The BSE programme is a new programme that was added in Fall 2012 with an ME concentration. In addition, two other specialisations are scheduled to be launched in Fall 2015:

- Bachelor of Science in Engineering with an Electric Power Engineering (BSE-EPE) concentration;
- Bachelor of Science in Engineering with a Manufacturing Engineering (BSE-MFE) concentration.

In addition to the undergraduate programmes indicated above, the Department also has a graduate programme, which offers a Master of Science in Technology (MST) major.

As mentioned earlier, Power Electronics is a senior level course and is currently offered only to EE majors. Therefore, the course enrolment and assessment data in this article only includes the EE major. Consequently, the student demographics data are solely presented for EE majors. As of Spring 2015, the enrolment numbers for all EE majors at Western Carolina University have an average of 22 students for each level from freshman to senior. For the Power Electronics course, the total enrolment in the first year was eight, including seven BSEE students and one MST student all of whom are male. In the second year, the enrolment number was thirteen, including three female and nine male BSEE students along with one female MST student. In the third year, the total enrolment was 14 students, including one female and 12 male BSEE students along with one male MST student. The course in the discussed implementation was offered in the Spring semesters of 2013, 2014 and 2015. Each week the class meetings were scheduled twice for the total of three contact hours of lecture sessions.

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^{TM} 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 book:

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

Course Objectives/Student Learning Outcomes (or SLOs) 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 synthesise the desired output.
- Design the switching power-pole using the available power semiconductor devices, their drive circuitry and driver ICs and heat sinks. Model these circuitry in PSpice^{TM}.
- Learn the basic concepts of operation of DC-DC converters in steady state in continuous and discontinuous modes and be able to analyse 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 analyse 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, analyse 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 synthesise 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 examinations. The distribution of points for the first and second year is given in Table 1. In the third year, homework/PSpice^{TM} assignment weight was reduced to 30%, and the weight for quizzes was increased to 30%.

Table 1: Grade distribution.

1. Homework/PSpice^{TM} assignments	40%
2. Quizzes	20%
3. Midterm examination	20%
4. Final examination	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, 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 emphasised. Quizzes and examinations, which both involved problem-solving, were administered in class. However, some 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 examinations 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 examinations included ten to fifteen questions with a similar question format to quizzes. In addition, the examinations had a PSpice^{TM} problem that tested the student's simulation software usage and circuit analysis skills.

In the second and third 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:

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

After the completion of each module, a short on-line 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 in comparison to the first year and this number was the largest in the third year's implementation. Twenty four such course modules were covered throughout the semester in Year 2, which is very similar to Year 1. Twenty one course modules were completed in Year 3. Fewer modules were covered in Year 3, primarily because the students' learning styles were more inquisitive and detail oriented. As a result, the students engaged more openly in class discussions and the instructor covered the topics in more detail. The number of simulation assignments was slightly reduced in the second year. In Year 3, the number of simulation and homework assignments were least in comparison to the other years. The original projected schedule of topics along with associated module sequence is given in Table 2.

Table 2: Schedule of topics for Power Electronics course.

Topic/Activity	Module	Week
Introduction to power electronic systems	1	1
Basic building block - switching power-poles	2-4	2-3
Non isolated DC-DC converters	5-11	3-6
Design of feedback controllers	12-14	6-7
Diode rectifiers	15-16	7-8
Power factor correction	17-18	8-9
Magnetic circuit concepts	19	10
Isolated switch-mode DC power supplies	20-21	11-12
Application of PE devices in motor drives, UPS and power systems	22	13
Synthesis of motor drives, UPS and power systems	23-24	14-15

The topics addressed and covered in the course in Table 2 are briefly described below:

1. *Introduction to power electronics systems*: role, applications and requirements are introduced.
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.
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.
4. *Design of feedback controllers*: topics of regulated switch-mode power supplies, linearisation, 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.
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.
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.
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.
8. *Isolated switch-mode DC power supplies*: flyback, forward, full-bridge, half-bridge and push-pull converter topologies and their operational principles are discussed.
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.
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.

Student assignments throughout the course flow specifically included:

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- PSpice^{TM} laboratory 1: pulse width modulation and filter characteristics;
- PSpice^{TM} laboratory 2: switching characteristic of MOSFET and diode in a switching power-pole;
- PSpice^{TM} laboratory 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.

Homework 2 through 5 also included a PSpice^{TM} problem. In addition to the topics listed above, reviews before midterm and final examination were scheduled. In these reviews, interactive sessions that involved problem-solving and concept understanding took place. The midterm examination was also scheduled during the regular course meeting session, which is seventy five minutes.

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. In Table 3, the survey results are shown, in each cell, starting with the first year result, followed by the second and third year. Each cell has the same arrangement. As can be seen in Table 3, there were eight respondents in the first year, 13 respondents in the second year and 14 respondents for the third year for each question. Question 4 was not answered by one student in the third year. 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 did not have a weight factor. Table 4 presents the mean, median and standard deviation for each survey question in each year of implementation. Question by question analysis of results is detailed in the paragraphs that follow.

Table 3: Student survey results.

Survey question	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 / 8	3 / 4 / 5	- / - / 1	- / - / -	- / - / -	- / - / -
2. Are mathematical relationships and calculations selected in this course appropriate?	3 / 8 / 8	5 / 5 / 6	- / - / -	- / - / -	- / - / -	- / - / -
3. Are the computational simulation tools (PSpice^{TM}) selected appropriate?	4 / 10 / 5	4 / 2 / 7	- / 1 / 2	- / - / -	- / - / -	- / - / -
4. Do you think power electronics would be a good tool to promote science, technology and engineering majors among college students?	6 / 11 / 7	2 / 2 / 6	- / - / -	- / - / -	- / - / -	- / - / -
5. Do you think you are interested to work in electrical power related industry after your graduation?	6 / 4 / 5	- / 5 / 4	2 / 3 / 4	- / 1 / -	- / - / 1	- / - / -
6. Overall quality of instruction was appropriate and useful for this class.	6 / 10 / 7	2 / 3 / 6	- / - / -	- / - / 1	- / - / -	- / - / -
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 / 2	5 / 3 / 5	- / 4 / 5	- / 2 / -	- / - / 1	- / - / 1
8. On-line and in-class quizzes before and after the lecture appropriately assessed and improved my understanding.	4 / 13 / 4	4 / - / 9	- / - / 1	- / - / -	- / - / -	- / - / -
9. I am interested in enrolling in future courses of similar subject matters.	5 / 7 / 4	3 / 4 / 9	- / 2 / -	- / - / -	- / - / 1	- / - / -

Question 1: it was determined that 100% of students for both first and second year, and 93% of students for third year agreed at some level that the course was useful in improving their overall knowledge and skills in electrical engineering

applications. As can be seen in Table 4, Year 2 implementation with the highest mean and lowest standard deviation definitely was perceived as best by the students. This result can be attributed to the benefit of extensive topics coverage and 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 for all three years strongly agreed or agreed. Year 2 implementation has again the highest mean, median and lowest 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.

Table 4: Student survey statistical analysis.

Survey question	Mean			Median			Standard deviation		
	Year			Year			Year		
	1	2	3	1	2	3	1	2	3
1. Have you found the course useful to improve your knowledge and skills on overall electrical engineering applications?	4.63	4.69	4.50	5	5	5	0.52	0.48	0.65
2. Are mathematical relationships and calculations selected in this course appropriate?	4.38	4.62	4.57	4	5	5	0.52	0.51	0.51
3. Are the computational simulation tools (PSpice^{TM}) selected appropriate?	4.50	4.69	4.21	4.50	5	4	0.50	0.63	0.70
4. Do you think power electronics would be a good tool to promote science, technology and engineering majors among college students?	4.75	4.85	4.54	5	5	5	0.46	0.38	0.52
5. Do you think you are interested to work in electrical power related industry after your graduation?	4.50	3.92	3.86	5	4	4	0.93	0.95	1.17
6. Overall quality of instruction was appropriate and useful for this class.	4.75	4.77	4.36	5	5	4.50	0.46	0.44	0.84
7. Pre-recorded lecture videos along with interactive face to face instruction are effective ways to deliver course materials and helped my understanding.	4.38	3.69	3.54	4	4	4	0.52	1.11	1.05
8. On-line and in-class quizzes before and after the lecture appropriately assessed and improved my understanding.	4.50	5	4.21	5	5	5	0.50	0	0.58
9. I am interested in enrolling in future courses of similar subject matters.	4.63	4.38	4.07	5	5	4	0.52	0.77	1.00

Question 3: when asked if the computational tool selected (PSpice^{TM}) was appropriate, 100% of the respondents in Year 1 strongly agreed or somewhat agreed. This percentage dropped to 92.3% for Year 2 students and 85.7% for Year 3 students. However, the statistical analysis for this question in Table 4 reveals mixed results. Year 2 implementation has the best mean and median, but larger standard deviation than Year1. PSpice^{TM} simulations were part of homework assignments and in-class tests for all years that required computer usage. The only difference in implementation was slightly reduced number of PSpice^{TM} assignments in Year 2 in comparison to Year 1. Year 3 results had the worst scores for all three statistical metrics, which could possibly be due to the least exposure to PSpice^{TM} assignments.

Although it is difficult to attribute these results to the specific implementation, one can generally conclude that PSpice^{TM} 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. For Year 3 students, this result was the second best after the survey Question 2. The statistical analysis in Table 4 confirms this result. The Year 2 implementation was again perceived best 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 topics coverage and exposure to various assessments (on-line and in-class) used in Year 2.

Question 5: the first year respondents showed definitely the greatest interest working in the electrical power related industry with a strongly agree percentage of 75% and Year 3 students showed the least interest working for the industry based on the statistical metrics in Table 4. Although the second and third year respondents had also reasonably well and similar interest working in the industry, their overall average response score for both mean and median metrics was substantially lower than Year 1 as shown in Table 4. The more challenging nature of Year 2 and Year 3 implementation might possibly be a contributing factor for these results.

Overall standard deviations in this question was the largest in comparison to the other questions. It should be emphasised 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. Among Year 3 students, this was one of the top four scores. 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. Year 3 scores for all metrics were the lowest possibly due to the coverage of the least number of topics and assignments that tend to enhance the learning experience.

Question 7: concerning the use of pre-recorded lectures, students provided the most diverse responses when comparing first year to either second or third year survey participants. As mentioned earlier, the second and third year implementation regularly required students to watch pre-recorded on-line 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 emphasised and experienced in this year. The statistics in Table 4 details these results.

The mean and median for Year 1 and Year 3 are among the lowest scores in similar statistics for Question 1 through 9; however, the standard deviation for Year 1 is moderate. The standard deviation for Year 3 is second largest after Question 5. For Year 2, all statistics are in the extremes meaning lowest mean and median and highest standard deviation for all questions. These statistics revealed that there is a delicate balance between pre-recorded and in-class lecture combination that students like to see and regularly emphasised/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 and the third year. The level of agreement on the benefit was still quite positive, but definitely lower than the second year. In the third year, the quiz management structure was similar to that of Year 2 and the scores were neither as good as Year 2 nor Year 1. However, for Year 3, on-line and in-class quiz mix were definitely perceived better than pre-recorded on-line lecture and in-class lecture mix. It should be emphasised that the instructor preparation and evaluation time for these quizzes was quite intense, especially, in the second and third year.

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

Question 9: the first year respondents showed definitely the greatest interest in enrolling in future courses of similar subject matters. Although the second year respondents also had a reasonably strong interest in enrolling in the future courses, their overall average response score for mean metric was lower, as shown in Table 4. The least interest came from the third year respondents. The statistical metric trends in this question were similar to those for Question 5 where students' future interest in power related industry was inquired.

It should also be noted that the second and third year respondents were larger and more diverse populations as mentioned earlier, and a one-to-one comparison among these populations may not always be informative.

In general, the survey responses among all respondents were somewhat close in a majority of the questions. The greatest separation between first and second year surveys occurred in Questions 5, 7 and 8. The greatest separation between first and third year surveys occurred in Questions 5, 7 and 9. Finally, the greatest separation between second and third year surveys occurred in Questions 3, 8 and 9.

From the instructor's perspective, Year 2 and 3 implementations were definitely more costly in terms of time and effort for emphasised on-line/in-class lecture/assessment approaches. The survey definitely showed the effectiveness of hybrid assessment approach of Year 2 and 3, and hybrid lecture approach of Year 1.

The overall mean score for Year 1 and Year 2 was in the range of 4.5, with the first year having a slightly better score. The overall mean score for Year 3 was approximately 4.2, which is possibly due to the smaller level of interest in power related fields. The return investment for this course was verified when more than two thirds of all students over the three year period 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, B in the second year and B+ in the third year. The greater course load due to substantially increased amount of quizzes and extensive topics coverage is likely to play a role in the lowest average grade in the second year. The distribution of grades on all assignments followed a fairly normal distribution in all years. In general, students excelled on the on-line concept quizzes.

Additional Course Assessment Results for Year 3

The Year 3 survey included two additional questions to help differentiate effective lecture methodology. Table 5 summarises these results.

Table 5: Additional survey results for Year 3.

Survey question	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Not applicable
1. Pre-recorded lecture videos alone is an effective way to deliver course materials and helped my understanding?	1	2	3	5	2	1
2. Interactive face-to-face instruction alone is an effective way to deliver course materials and helped my understanding?	3	7	4			

These results combined with Question 7 of Table 3 yield the following common statistical metrics. In Table 6, the statistical results shown in hybrid column represent Question 7 of Table 3, the ones in on-line column represent Question 1 of Table 5, and the ones in face-to-face column represent Question 2 of Table 5.

Table 6: Student perceptions of learning: lecture delivery related survey statistics for Year 3.

Mean			Median			Standard deviation		
Hybrid	On-line	Face-to-face	Hybrid	On-line	Face-to-face	Hybrid	On-line	Face-to-face
3.54	2.62	3.93	4	2	4	1.05	1.19	0.73

The metrics in Table 6 clearly reveal that the preferred method of lecture delivery for the third year participants is face-to-face.

CONCLUSIONS

In this article, a hybrid flipped classroom approach to teaching Power Electronics for three consecutive years at Western Carolina University has been presented. The study analysed lecture and quiz elements of instruction for on-line and/or face-to-face implementation. According to the survey results, the students in general 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 emphasised the face-to-face component, students felt that the extra in-class lectures helped improve their understanding.
2. In the second and the third year, in which a hybrid mix heavily emphasised the on-line component, students felt that the increased number of on-line and in-class assessments really helped improve their understanding. Students felt that the extra on-line lectures did not significantly improve their understanding.
3. Additional survey questions in the third year revealed that students prefer face-to-face instructions over hybrid or on-line instruction.

This study shows that combining on-line and face-to-face elements are important as suggested by the US Department of Education (DOE) report [10]. 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 the society at the same time when addressing the needs of students with diverse backgrounds and demographics. The assessment results show that the synchronised quizzes tied to specific course modules enhanced student comprehension.

As a next step, the course is projected to be offered with the combination of on-line 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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