Novel gateway stay/add policy used to increase student success rates in an introductory circuits class

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***Abstract*— Students were made to earn at least 90% on eight automatically graded (using MyOpenMath) online homework assignments to either remain enrolled (stay) or get permission to enroll (add) in a blended-instruction introduction to circuit analysis class. While this stay/add policy has caused some controversy, it was the only effective treatment to decrease the DFW rate (percentage of students who earn a D, F, unauthorized withdrawal or authorized withdrawal in one section of a course) in the regular semester offerings of the course. The DFW rate before this treatment was typically around 35% and as high as 53%. The DFW rate dropped to 17% for the same instructor after the gateway assignment policy was implemented. The DFW rate remained lower (19% and 26%) even when new (no prior teaching experience), part time faculty taught the class with the same materials, and stay/add policy. While other treatments that were tried such as making the class activities more realistic, flipped classroom, I-clickers, changing the pre-requisite from D- to C for the pre-requisite physics course, enforcing the differential equation co/pre-requisite, and switching the flow of the course to "impedance first", did not decrease the DFW rate, they did lead to increased student learning.**

Keywords—Flipped Classroom, I-clickers, Active Learning, Entry Behaviors, Circuits

I. Introduction

Introduction to circuit analysis courses exist at all community college, California State University (CSU) and University of California (UC) pre/engineering programs in the state of California and is required by most engineering degrees nationwide. In California, there is a high degree of articulation between community colleges and the CSU. While this allows students to graduate sooner, saves the state of California money and this level of cooperation is considered by the faculty to be beneficial, it can make it difficult to improve/update the curriculum. The topics generally presented in these articulated courses are:

- Passive circuit elements:
  - R,L,C combinations, impedance, Ohm's Law
  - AC response (Frequency is fixed and non-zero)
  - First and second order transient response of passive circuits
- KCL, KVL:
  - Nodal and Mesh
- Circuit analysis transformation techniques:
  - Source transformation
  - Norton, Thevenin circuit transformations
  - Superposition
- Power
  - Maximum power transfer
  - Derivation of Root Mean Square (RMS) values for periodic signals
- Non-Linear Devices
- OPAMPS
  - Inverting and non-inverting configurations

These topics listed above are not arranged in order that they are covered in class. Usually all analysis techniques are introduced with DC circuits (resistors and OPAMPS), then first and second order passive responses are taught. AC and power analysis are normally presented last.

A major issue in teaching this course at SJSU, is that there can be high DFW rates. The DFW rate is the percentage of students who earn a D, F or an authorized withdrawal, in other words it is the percentage of students that have to repeat the course. Faculty at SJSU felt that the reason that students were having to repeat the class was that the students were not doing the work required to succeed in the class. Possible reasons for this perceived lack of effort, were that the course was not interesting to the students (especially to non-electrical or computer engineering majors), grades were curved (this leads to students giving up), and that large class sizes existed (students feel disconnected from class.) Another possible reason was that the pre-requisite grade for the previous physics course was set too low and thus some students had to work harder than anticipated to succeed in the course. In

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addition to these reasons, a false sense of security in the student could also be developed by the student, because the instructor would review certain topics as if the student did not need to know the previous pre-requisite course material. At first, this might seem contradictory: The pre-requisite grade in physics was set too low vs. the instructor spending too much time reviewing. At SJSU this is not the case as students spend about two weeks seeing if a course is the right fit for them. If a course seems easy before the last day to drop, some students will stay enrolled, and thus possibly be over committed in their work, school or life to be able to put in the correct amount of time in the course to succeed.

Other researchers have tried to improve student learning in an introductory circuit analysis class by developing electronic learning environments [1]-[3], adjusting how concepts are displayed/represented [4], [5], flipping the class[6] and selecting a textbook[7].

The rest of this work consists of description of the treatments examined in chronological order, and a discussion of what treatments improved the DFW rates and student learning.

II. INTERVENTIONS:

The class size, DFW rate and interventions semester by semester can been seen in Table 1. All semesters included in class time for team building and a constructing and documenting a realistic project.

TABLE I. INTERVENTIONS BY CLASS SIZE AND DFW RATE

Semester	Class size	DFW Rate	Impedance First	Flipped	Daily Quizzes	Math Co-req. enforced	Grade E&M Phys Pre-req.	CRS	Stay, Add, Policy
Summer 2013	9	11	No	Yes	Yes	No	D-	No	No
Fall 2013	72	11	No	Yes	Yes	No	D-	No	No
Spring 2014	103	21	No	Yes	Yes	No	D-	No	No
Summer 2014	13	0	Yes	No	No	Yes	D-	No	No
Fall 2014	74	36	Yes	No	No	Yes	D-	No	No
Spring 2015	81	33	Yes	Yes	Yes	Yes	C	No	No
Summer 2015	10	10	Yes	Yes	Yes	Yes	C	Yes	No
Fall 2015	78	53	Yes	Mod.	Yes	Yes	C	Yes	No
Spring 2016	65	17	Yes	Mod.	No	Yes	C	No	Yes
Fall 2016 section 1	71	19	Yes	Mod.	No	Yes	C	No	Yes
Fall 2016 section 2	69	26	Yes	Mod.	No	Yes	C	No	Yes

Given that SJSU is a commuter school, it was necessary to set aside time in class for students to get to know each other, by working on problems together. If this was not done, many students would have remained isolated and unconnected. About halfway through the semester the students join a student group consisting of two or three students that would work on the final project together.

A realistic project was added to the course to demonstrate the relevance of the class learning objectives and to give the students a vehicle to showcase their competence in design, verification, fabrication, and documentation of a simple, but realistic circuit. This project could be placed on their resume so that students could hopefully earn an internship during their sophomore summer.

Teams designed and verified with LTspice, fabricated with a solder strip board, tested with an oscilloscope or voltmeter, and documented with a word processing tool, an analog circuit. From summer 13 to spring 15, students were allowed to choose one of the following projects that related to their major: Follow a line robot[1], Motion detection circuit[9], Audio amplifier[10], Capacitive touch sensor[11], Medical shock detector[12], Heart rate monitor[13], pulse width modulation digital to analog converter (PWM DAC)[14]-[16], or variable voltage supplies. These projects topics were chosen to try and show the relevance of the course to non-EE and non-CompE majors such as mechanical, biomedical, and aerospace. In later semesters all students completed the same project to ease the teaching burden. While some class time was set aside for project work, most students would complete the project on their own or with help from the department technician or instructor.

"Flipped Classroom"[17] in which traditional lectures are moved to online videos, and lecture time is spent doing activities that engage the student was also attempted in the summer 2015 semester. This theory blends behaviorist and constructivist theories of learning, and the hope was that students would come more prepared for in class activities, because the class activities were harder for the student to come unprepared. Another perceived benefit of the flipped class room was that students could construct their knowledge of a subject in class under the supervision of an instructor rather than attempting this high level task on their own. It is also believed that students will learn more by doing, than just listening. While the perceived benefits are many, the time to prepare for class was significantly greater than a traditional lecture, because not only did lectures have to be created and captured to video, in class "laboratory" activities had to be prepared as well. In the first offering of the flipped classroom the activities consisted of starting the homework in class, daily quizzes, and the project work described earlier. While students were doing these activities in class, the professor and teaching assistant would walk around answer questions, and listen to students talk about the approaches that they would use. At times, a quick lecture to the class was needed to clear up a common misconception.

To address the perceived lack of preparation from pre-requisite courses a diagnostic online quiz in which students had to earn an 80% to stay or add the course was added to the course. The concepts that students need to have mastered after completing this physics course are being able to use Ohm's law, write KCL or KVL relationships, and understand the impedance of ideal resistors, inductors and capacitors. The students also need to know how to identify and combine series and parallel resistor networks. The students could take the quiz as many times as they liked to earn an 80%. This was done first, because it took a year to make officially make changes in pre-requisites.

At first the pre-requisite of the electricity and magnetism physics course was only a D-. In the spring of 2015 the minimum grade for this prerequisite physics course was changed from D- to C. Also at this time, the differential equations co-requisite was in the catalog, but not enforced. The relevant concepts that were needed from differential equations are solving first and second order passive (mechanical or electrical) differential equations in the time domain. Starting in the summer of 2014, the differential equations pre-co-requisite was enforced. In the summer the differential equations is effectively a pre-requisite because it is not possible to take two accelerated (5-week duration) course at the same time and learn the material of both courses.

After a review of the physics pre-requisite course materials and a push for engineering programs to reduce to 120 semester units, it was determined that there was too much overlap between the physics and circuits courses. It was also found that by teaching impedance and phasors at the end of the semester resulted in students not learning these important concepts. After review midterms, it also seemed that students felt that the circuits course was a repeat of their college and high school physics courses, and thus the course did not require much time dedicated to learning circuit analysis concepts. This would result in students attempting to take too may units for the work/school balance required to succeed in engineering. To address all these issues, the course material was rearranged to "impedance first". The impedance first method starts where the previous physics course ended. The impedance of ideal R, L and C elements are reviewed and their series parallel combinations of impedance (Z) is taught. The concept of phasors, voltage division, and the $s=j2\pi f$ transform is taught was well, which lead to the first introduction to filtering. Average power is then taught. After these topics are presented, the course follows the traditional timeline ending with second order transients.

I-clickers, a classroom response system (CRS)[18]-[22] were introduced in the summer of 2015. At first the I-clickers were received favorably because the students felt that the daily quizzes made sure that they did not let themselves fall behind. This positive response from this class encouraged their use in the fall 2015 semester.

MyOpenMath [23]-[28] (similar to WIRIS [29], but open source) automatically graded homework was introduced in the summer of 2015. MyOpenMath is a free learning management system that has a very rich set of question types. MyOpenMath can evaluate complex numbers, as well as functions (numerical equivalence). For instance, it will evaluate the following equations for the gain of a non-inverting OPAMP configuration as the same:

$$Gain = 1 + \frac{R_2}{R_1} = \frac{R_2}{R_1} + 1 = \frac{1}{\frac{R_1}{R_1+R_2}}$$

This was done because the class size was increasing so that regular homework could not be graded in time for students to use the homework feedback to any effect. Is was also noticed that many problems in a circuit analysis course, could be graded automatically. By automatically grading some of the homework, the instructor was able to concentrate of providing feedback on student that cannot be automated such as project documentation, circuit layout, and drawing transient responses. (While there are tools for laying out a circuit, it was felt learning these tools put too much of a cognitive load on the student.) Not only does automating the grading of the assignments free the instructor from mundane grading, it gave the students instant feedback[28][30]. The automated MyOpenMath system has the ability to have random variables assigned to each question, and random questions selected from a bank of questions so that each HW was mostly unique to each student. The MyOpenMath system also allows for one than one question to be answered per problem. For instance, a nodal analysis problem solved with matrix methods was created with 22 question/answers that led the student though their first problem of this type. Thus, the student could see exactly where they made a mistake. This follows the approach given in [30].

In the summer and fall 2015 the students were allowed unlimited attempts to succeed on MyOpenMath problems and while there were suggested due dates, the homework sets were never closed using. In addition, there were midterm and final exam generators that would create midterm and final exams from the same homework banks that the real midterm and final were created from. These online exam practice exercises did not count towards the final grade for the summer 15, fall 2015 and spring 2016 semesters.

In the spring of 2016, the online homework assignments were modified so that the warm up questions used for review an underlying concept were worth less points. Most homework assignments committed of warm up questions, followed by relatively easy questions on the new concept, and finally questions that might appear on a midterm or final. In fall 2015 each question in an assignment was worth the same amount. This led some students to do enough work to get what was a passing grade for the course on the home work. For example, some students would stop doing problems once they had achieved an 80% (which seems like a good grade) on a particular homework assignment. Unfortunately, this would lead to a false sense of security in some students, because only the final problems in a homework set were of a level to demonstrate mastery on an exam. In spring 2016 the home work points in a particular set were adjusted so that students could not earn over 70%, unless the exam level questions were answered correctly. This was done by making the exam problems worth much more than the review problems.

Also in spring 2016, a unique stay/add policy was implemented. This policy consists of only allowing to students to stay enrolled or to add the course if they maintained a homework average of greater than 90% on all homework assignments due by the last day to instructor drop a student. The homework consisted of online, automatically graded assignments created with MyOpenMath and delivered via Canvas. The students could attempt the assignments as many times as they wished until the due date.

III. Results and Discussion:

Looking at the DFW rate by intervention in table one and fig. 1, it seems most treatments did not reduce the DFW rate or that the DFW rate is somewhat random, given that the DFW rates prior to the summer 2013 varied from 20% to 50%. (This data is not shown or published.)

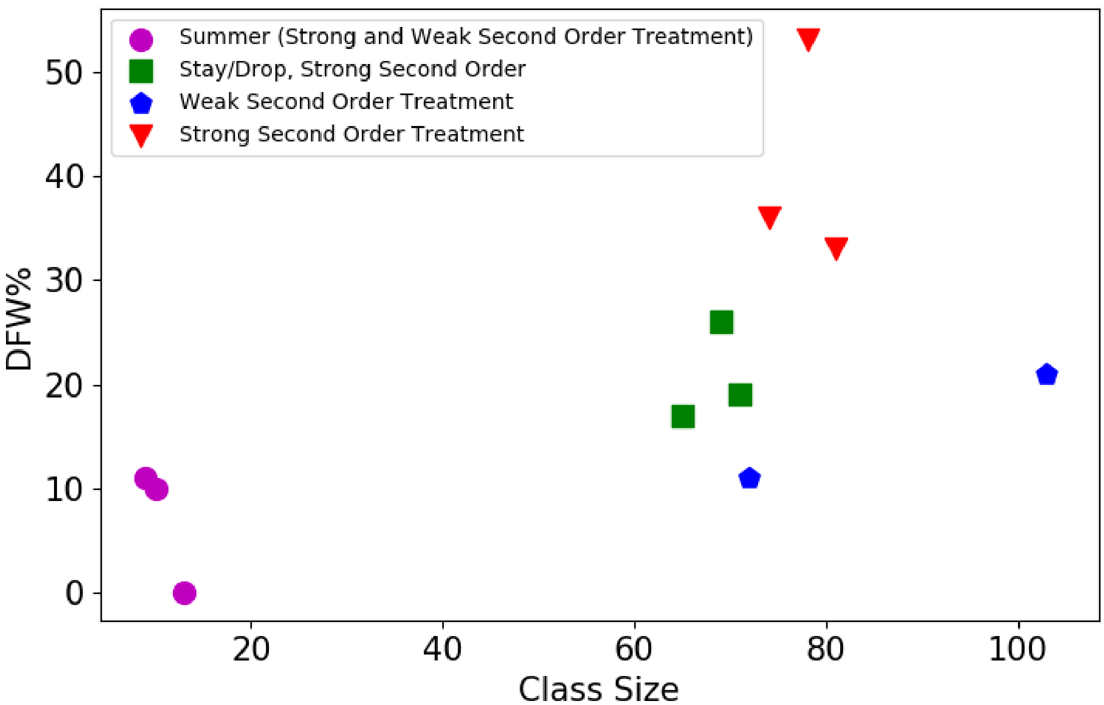

Fig. 1. DFW rate in the introduction to circuit analysis class vs. class size color code by intervention.

It seems that encouraging team work and making the class more relevant to all majors did not change the DFW rate. This is incredible given all the research that supports team based learning positively impacting student learning, and the fact that this approach had worked in upper division EE courses at SJSU. (This is based on the author's experience teaching.)

It is also hard to understand why the DFW rate did not decrease since our student's main goal is to find a job in engineering and the class project and circuit examples were designed to help them get an internship, even for non-EE or CompE majors. Even though this was a disappointing result, the students who passed the class we certainly learned more at a deeper level [32], and were more prepared for industry. Another benefit was that some students formed study groups that persisted after the course was offered. Although no formal survey was conducted, students would come back and talk about how the project was a significant talking point during their job interviews. Another positive outcome was that non-EE majors would also come back for advice on the circuit part of their senior project.

It seems that enforcing the co-requisite of differential equations and changing the pre-requisite of the physics course from D- to C did not improve the DFW percentage and in fact it seems to go up. This can be explained by the fact that the first semesters (blue pentagons of fig 1.), second order circuits were not covered well by the instructor, and the equation sheet given by the instructor gave too much information. (This was decided after much self-reflection.)

Once the impedance first method was adopted, however it was much easier to cover second order circuits, such as when a circuit will be over, under or critically damped, because the students were already used to the s domain analysis. The DFW rate rises significantly when second order circuits are properly accessed (red triangles fig 1.).

Another trend that seems to appear is that there is a correlation between class size and the DFW rate. (fig 1.) The DFW rates prior to the summer 2013 varied from 20% to 50%. While this may be true, the trend seems to disappear when the data in plotted in a manner that captures the differences in the course each semester. The low DFW rate in class sizes of about ten (summer sessions-purple circles fig 1.) are most likely due to the fact the only students who can keep up with the material in a five week vs. sixteen-week course attempted the course. Upon reflection, is seems that the summer is so intense that the students realize on the first day whether they can keep up with the pace of the course or not and drop the class if they feel they cannot keep up. In other words, students committed to the class right away or they left when attempting a summer (accelerated) course.

The genesis of the stay/add drop policy was the fact that all the attempted treatments resulted in DFW rates between 0 and 10% when piloted in the summer, but failed to reduce the DFW rate when used in the regular semester classes. The second development in adopting the stay/add policy was recognizing that what was really different about the summer classes and the regular semester classes, was that they were accelerated (five weeks instead of 16) and only students who could keep up with the material stayed enrolled. The final observation that led to the development of this policy was that the DFW rate in fall 2015 was the highest (53%), despite having the most treatments that should have led to increased student success. That semester's treatments involved I-clickers and creating sophisticated online home work that could be completed as many times as the student wanted. An analysis of the online homework data showed students who did not do well were showing signs of not keeping up early in the semester, and that students who succeeded in the class tended to do their homework on time and to a high level. Students who did not pass did not attempt the online practice exams that were created with the same MyOpenMath exam generator that was used to create the actual midterms and final.

These observations of non-successful student behaviors seemed to indicate that the most important predictor of success was whether the student was keeping up with the work or not. The benefits of making sure students demonstrate a strong commitment to the course before the add/drop date can be seen (green squares fig. 1), where the DFW rate drops to 20-25%, even though the course learning objectives are accessed at a high level. Still this is higher than the average DFW rate for the college of engineering. Another issue is that there is an extremely generous grade forgiveness policy at SJSU (only the highest grade counts towards GPA), so that the only penalty for not passing a class is having to retake it later. Students do not seem to think there are in academic trouble because the GPA is unaffected by repeating a class.

Some SJSU centric issues for the DFW rate are that some departments push this introduction to circuits class to the last or second to last semester. This makes student effort to pass the course increase, because students will need to spend more time reviewing their physics pre-requisites course, which might have been taken two years prior to the circuit analysis course. This idea seems to be supported by the fact that majors that have an introduction to circuit analysis courses in their pre-requisite critical path to graduation (EE, CompE, and ME), have a significantly lower DFW rate. Another counter intuitive factor appeared after the college of engineering went from requiring around 138 to 120 units to graduate. Many seniors who did not pass, seemed to take courses loads that were excessive because they felt that they could now graduate one semester early. This seems to indicate that the students did not really believe it was important to master the material in the first place. This is not surprising because non-EE, CompE or ME faculty advisors placed this course at the end of their program's course sequence. Possible other student characteristics to consider to further reduce the DFW were outlined in [33].

While is seems obvious that students who do their homework to a high level will succeed after teaching this course for nine semesters, and that the only way to reduce the DFW rate is to enforce proper study habits, why was it that they flipped classroom approach did not encourage students did Flipped Class room not work to motivate students? While flipped classroom in theory seems to be a good method for improving student outcomes, there seems to be little evidence of it working [17]. The reasons for this could be that constructivist type activities are appreciated by mature learners, and that the act of constructing effective new knowledge is a considered a research task [34]. Other studies have shown that constructivist approaches such as Problem Base theory [35] will lead to weaker students learning significantly less, than stronger students. It seems that only experienced learners do well in these educational settings. Some researchers show that students need an expert to explain concepts [36], and that large class sizes can make the expert unavailable when using the flipped classroom approach [37]. It has also shown that minimal guidance (due to large class size) in flipped classroom could backfire [38]. Another reason is that lectures at SJSU are already interactive because they typically consist of an introduction to the theory being used during that class person followed by problem solving and students are encouraged to ask questions like they were in a tutorial or recitation session.

IV. Conclusions:

Even though adding realistic projects, emphasizing team work and using flipped classroom or other constructivist approaches do not seem to improve DFW rates, classes taught with these interventions manner can improve student learning in ways that are not captured by a DFW rate. Teaching small section classes in the flipped style was energizing and more fun for the instructor, and prevented the instructor boredom. In addition, instructors who use the flipped classroom approach need to prepare the students on why it used, because there can be push back from students who prefer a traditional learning environment.

Although not the subject of this study, students who were falling behind were contacted by the instructor and paths were created to help the student pass. Students were told that could still pass the course if they did well on the final. In addition to letting the student know they could still succeed, students were also asked what was going on in their life that might be preventing them from success. Depending on the situation, students were directed to counseling (recent death in family or family member cancer diagnosis), the accessibility resource center (test anxiety). Other issues that negatively impacted student performance were homelessness and food insecurity.

Since the data suggested that keeping up with the work was a stronger predictor of the group's success, students with only a C- (not C) in the previous physics class were allowed to stay or be allowed to enroll in the course. In the three classes studied, five out of eleven who earned a C- (not C) in the previous physics class, earned less than a C- in the class. This data could be used to make better decisions about when a pre-requisite can be relaxed and will be the subject of future study. In addition, how the students do in follow on classes needs to be explored.

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