Load Lines of Transistor Circuits: A Unifying Educational Approach Using Blended Learning and Flipped Classroom

Gerasimos Pagiatakis and Nikolaos Voudoukis

***Abstract* — The paper presents the application of the blended learning and flipped classroom principles to the teaching of the load line concept. Blended learning is a rapidly evolving approach towards the direction of actively engaging students in the learning process. Flipped classroom is a proposal, in the blended learning context, suggesting that in-class students' activities, supported by educational material made available to them in advance, could replace the traditional pattern of lectures led by teachers followed by homework. The lesson was designed according to established design principles. The content was divided into two parts. The first part was the preparation material, which was mainly pre-existing resources. Such resources can be notes, slides, videos, etc. taking into account self-assessment tests and the difficulties faced by students on the topic. All the preparation material was available online. The second part was the in-class activities including various design and decision problems, debates and logical exercises. The students in the class worked individually and in groups also participating in a peer-review activity. The participating students on the flipped classroom approach evaluated the project with a quite positive view compared to the conventional teaching forms. The aim of this work is to present the concept and applications of the load line in a unified and mathematically straightforward manner and, at the same time, employ the blended-learning and "flipping-the-classroom" approach in order to enhance students' understanding and learning outcomes.**

***Key words* — engineering and technology, electronics, load lines, transistor circuits, blended learning, flipped classroom, active learning.**

I. Introduction

Among other concepts, the load-line one has been a source of misconceptions for students particularly when it comes to elements with less straightforward behavior such as the diode or the transistor. For example, it has been observed that several students fail to see the general idea behind the load-line concept while others acquire a rather blur idea on what the DC and AC load lines of transistor circuits are about. On the other hand, the load-line notion is essential for comprehending circuits' operation. An additional difficulty stems from the fact that engineering and technology (ET) students have to take a series of mathematics, physics and other basic courses before they acquire the skills and knowledge to complete an ET project. There is a negative impact on students' motivation, enthusiasm and retention in the program due to the long delay between their joining an ET program and being capable of applying content knowledge in a meaningful way [1]. To meet this challenge, there are educators that have updated their curricula to engage students in hands-on design projects in their first and second year of study. Due to their limited engineering knowledge and skills, it is often difficult finding a project that students can handle successfully.

Flipped or inverted classroom is a teaching method that increases opportunities for integrating active learning [2]. The teaching approach of the flipped classroom includes two basic parts. One part is placed inside the classroom with interactive group learning activities. Another part is placed outside the classroom with technology and computer based independent learning activities. According to recent research students in a flipped classroom improve their learning outcome, become more aware of their learning activity and make connections to course content and [3]-[5]. In a study relative with a flipped-classroom engineering course, researchers reported that instructors were able to cover more course content while implementing problem-based, active learning activities in the classroom [6]. With equal importance, students when they had the opportunity to apply what they had learned, reported more innovation in the classroom [3]. The flipped classroom framework provides an opportunity for instructors to provide timely feedback on the learning process, offer a variety of learning experiences to students and create a positive instructor-student relationship thus promoting students' success. To this end, the need to present the load-line principles in a compact and unified manner was considered as a good opportunity to apply the promising flipped-classroom approach. Thus, the paper describes a 4-hour lesson on the load-line concept and the attempt to present the associated notions and ideas in a generalized, yet mathematically straightforward way by applying the blended-learning and flipped-classroom principles.

The rest of the paper is organized as follows: Section II presents the methodology and the course design, section III describes the content knowledge of the lesson, section IV contains the implementation of the traditional and flipped course (FC) formats, section V presents an evaluation of the flipped classroom, section VI discusses the findings and section VIII presents the conclusions of this work.

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II. Methodology

The paper presents the application of the principles of Blended Learning and Flipped Classroom to the teaching (through a 4-hour lesson) of the load-line concept and use. The basic aim of the lesson was to present the associated notions in a generalized manner by using the simplest possible mathematics of high-school level. Blended Learning is a rapidly evolving approach aiming at the active involvement of students into the learning process in order to achieve better learning outcomes than by simply purely online classes or traditional face to face classes. The flipped classroom is a suggestion in the context of blended learning, which suggests that the traditional scheme of instructor-led lectures followed by homework could be replaced by students' activities taking place in class and supported by learning material made available to them in advance. The flipped-classroom approach is a reversion of the traditional teaching approach, in which learning is based on lectures. The new idea is giving instruction material to the students outside the classroom. In this way, the result is freeing teaching time for student engaging activities and brain stimulating exercises inside the classroom.

Blended Learning considered as one of the best teaching approaches. American Society for Training and Development has identified Blended Learning as one of the top ten emerging educational trends [7]. Blended Learning, is a way of combining instructional modalities [8]-[11], instructional methods [12], or, simply, combining online and face-to-face instruction [13]-[15]. Compared with purely online classes or purely face-to-face teaching, the Blended Learning approach has been proven more effective. Indeed, different applications of Blended Learning have resulted in a significant increase in student engagement and academic performance [16]. It is important to be mentioned that experiments on the Flipped Classroom concept have shown that replacing live lectures with online lectures material followed by enriching, learner engaging, classroom activities, has greatly enhanced the value, usefulness, and convenience of the lesson for the majority of students [3], [17]. In general, one disadvantage of Blended Learning and Flipped Classroom is that the preparation of online material takes a lot of time and the overall effort for this type of teaching is quite demanding. The creation of educational audiovisual educational material is a demanding and complex procedure that often requires the provision of special technical means, resulting in all this at an increased cost. Although lecture filming could be a solution, it often results in low quality videos that are unattractive to students and have limited ability to stimulate and retain adequate attention. The advantages of this method have been recognized. So, it is a need for creation and process of high-quality teaching-educational material (such as video editors, animation software, voice production, compilation and subtitling tools, etc.). Nowadays, this has become relatively easy, due to the availability of specific digital tools, software and the overall digital progress in general. The use of these tools for the creation and processing of the teaching-educational material (with high standards and quality) can significantly reduce the effort, cost and time.

In order to apply the Flipped Classroom principles and evaluate the advantages mentioned above, a 4-hour lesson was organized aiming at presenting the load-line concept and associated notions in a unified, yet mathematically straightforward manner that also made provisions for students' active participation. The lesson was a part of a Basic Electronics course (included in the Electrical & Electronic Engineering Educators curriculum). It was very important to be organized properly the in-class activities in such a way as to engage students with evidence-based practices. The desired result for the in-class activities was to the learning outcomes [3]. In order to be covered the necessary theory, the out-of-class material was designed very carefully. Also, this material was selected in such a way as to support the appropriate cognitive background for the teaching the various activities in the classroom. It was crucial for the success of the process that the working time for the students' off-class activities to be kept in a moderate level. This time, which directly related with the quantity of the proper online material, was an important parameter for discouraging or not the students involved.

The content was divided into two parts. The first part was the preparation material. This material may include a variation of resources, most of them may be pre-existing resources. Such resources can be notes, slides, videos, etc. which (all these resources) were available online. It is worth mentioned that the difficulties faced by students on the topic and self-assessment tests were taken into account for the preparation material. The second part was the in-class activities. These activities include many different kinds of problems such as, logical exercises, debates, decision and design problems. The students in the class worked in groups and individually, also participating in a peer review activity. The assessment of the process (flipped classroom approach) revealed a quite encouraging view of the participating students compared to the conventional teaching forms. Moreover, students seem to strongly prefer the described mode of instruction as compared to conventional forms of teaching.

III. Course Implementation

The study was conducted at the Electrical and Electronics Engineering Dept. of the School of Pedagogical and Technological Education (ASPETE) located in Athens, Greece, during academic years 2017-2018 and 2018-2019. The students of this department had attended the "Basic Electronics" course at the 2nd semester of their studies. This course contains the module "load-lines evaluations" which introduces students to the general characteristics of load lines, aiming at presenting them in a generalized, yet straightforward, way by means of simple mathematical concepts.

The lesson was part of a 2nd-year (3rd-semester) course in Electronics and the evaluation of the course was done from the comparison of the exam results following the traditional course format and the proposed course format. The exams were held at about the same time during the semester. Upon successful completion of the course, the learning objectives were that students should be able to:

- Describe the operation of basic transistor circuits such as the CE and the CC ones.
- Perform relevant calculations.
- Design and optimize simple CE and CC transistor

circuits.
- Identify practical applications.
- Implement CE and CC circuits using common laboratory procedures.
- Demonstrate skills of problem solving and critical thinking in hands-on team-based engineering activities.

The traditional course (TC) was taught to a class of 74 students (59 males and 15 females) that served as the control group. The 4-hour lesson (1 hour lesson is 45 min) is divided into two 90-min class sessions. In each 90-min class session, students took notes as they were taught by the instructor concepts (with the use of Power Point). Students were given sometimes problems to solve (on their own) with the instructor monitor student progress and provide individual feedback, as he was walking around the classroom. Students were encouraged to refer periodically to the text textbook, from which there were the most problems solved during class. In a separate lab course were introduced hands-on activities on the various course concepts.

The proposed course (PC) was taught with a flipped-classroom format to the experimental group, which was a class of 71 students (57 males and 14 females). All student activities incorporated critical thinking strategies and all in-class activities incorporated several active and collaborative learning strategies. The course included four (4) steps, that is (1) pre-class activities, (2) in-class activities, (3) post-class activities and (4) final-class activities using active learning strategies.

A. Pre-class Activities

Prior to attending each class, students were required to watch two videos with introductory exercises (class previews) in order to encourage self-directed learning and ensure adequate class time for active discussion. These class previews, which were video recording of the computer screen and audio recording of the instructor served as the primary means of disseminating course material [6] and introduced concepts through tables, equations, schematics, etc. to engage students who are typically visual learners [18].

Pre-Class Activities – Introductory exercises: Question 1

Load-lines are useful tools for analyzing transistor amplifier circuits, but they may be hard to understand at first. As an example, for understanding the “load lines” usefulness is presented a load line to the simple two-resistor circuit of Fig. 1

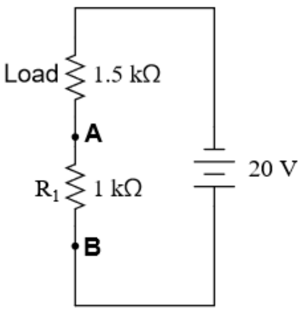

Fig. 1. The circuit for the pre-class activity (question 1).

In order to see the usefulness of the load line, it is important to plot the load line of the above along with the “characteristic curve” for one resistor of the circuit, for example R_1. This curve is defined as the voltage-current relationship between the terminals of R_1 (A and B), that is $I_{R1} = \frac{V_{AB}}{R_1} = \frac{V_S}{R_1}$.

This is shown in Fig. 2.

It has to be noted that a load line has meaning when superimposed with other plots.

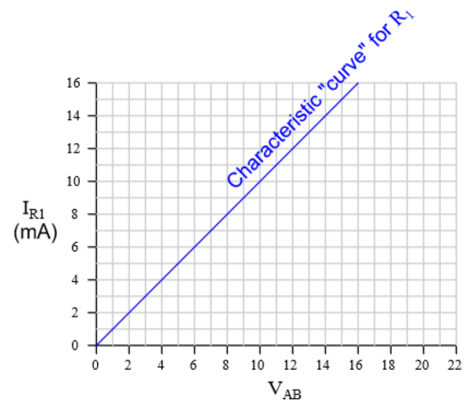

Fig. 2. The characteristic curve of resistor R_1 in the circuit of Fig. 1

At the next figure (Fig. 3) it is plotted the load line, which is defined by the equation:

$$I_{R1} = = \frac{V_S}{R_L} - \frac{1}{R_L} V_{AB} \tag{1}$$

where $R_L = 1.5$ kΩ is the load resistor. The load line, a straight line, expresses the load current as a function of the voltage V_{AB} available between the two terminals A, B.

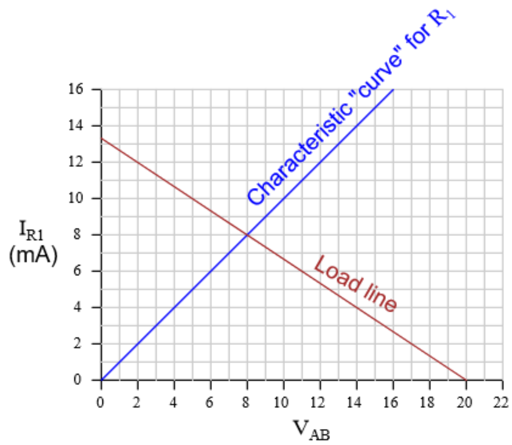

Fig. 3. The characteristic curve of resistor R_1 together with the load line in the circuit of Fig. 1

Which is the value of current I_{R1} that the two lines (characteristic curve and load line) intersect? Explain the meaning of this value of current (which is the importance of this value).

Pre-Class Activities - Introductory exercises: Question 2

Load lines is a useful tool for analysing transistor amplifier circuits. Also, they may be applied to other types of circuits as well, such as for example a diode-resistor circuit (Fig. 4).

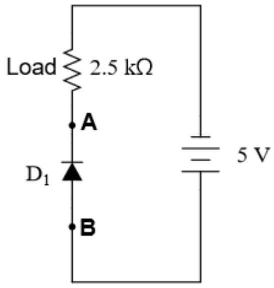

Fig. 4. A simple diode circuit (pre-class activity, question 2).

The diode's characteristic curve of the diode (Fig. 5) is given (already plotted). The task for the students is to plot the load line for the circuit on the same graph, and note where the two lines intersect:

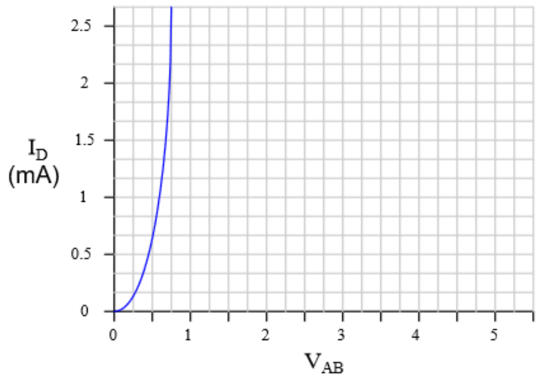

Fig. 5. Diode characteristic.

Regarding the diode circuit of Fig. 4, what is the meaning and the practical significance of the intersection between the diode's characteristic and the load line?

Students were required to take a short pre-class quiz. This quiz was for evaluating students' understanding of concepts. Students' evaluation is helpful for effective use of class time (for active discussion and deeper analysis-synthesis of concepts).

B. In-class Activities

The diverse nature of in-class activities required meticulous planning of the two 90-min classes to promote active learning through discussions, demonstrations, reflection and collaborative learning. Students had to pay continuous attention which was not always easy.

The first 90-min class was devoted to the derivation of the DC and AC load line formulas for the Common Emitter (CE) transistor amplifier. In order to preserve clarity of calculations, the analysis was based on high-school level mathematics applied on simplified DC and AC transistor models. This resulted in the eqs. for the DC and AC load-line respectively shown below [19]:

$$i_C = \frac{V_{CC}}{R_C + R_E} - \frac{1}{R_C + R_E} v_{CE} \qquad (2)$$

$$i_C = \left(\frac{V_{CE,Q}}{R_C // R_L} + I_{C,Q}\right) - \frac{1}{R_C // R_L} v_{CE} \qquad (3)$$

where

$$I_{CQ} = \frac{\beta}{\beta + 1} I_E \approx I_E \approx \frac{V_B - 0{,}7}{R_E} \qquad (4)$$

and

$$V_{CE,Q} = V_{CC} - I_{CQ}(R_C + R_E) \qquad (5)$$

are respectively the collector current and the collector-to-emitter voltage at the quiescent point Q.

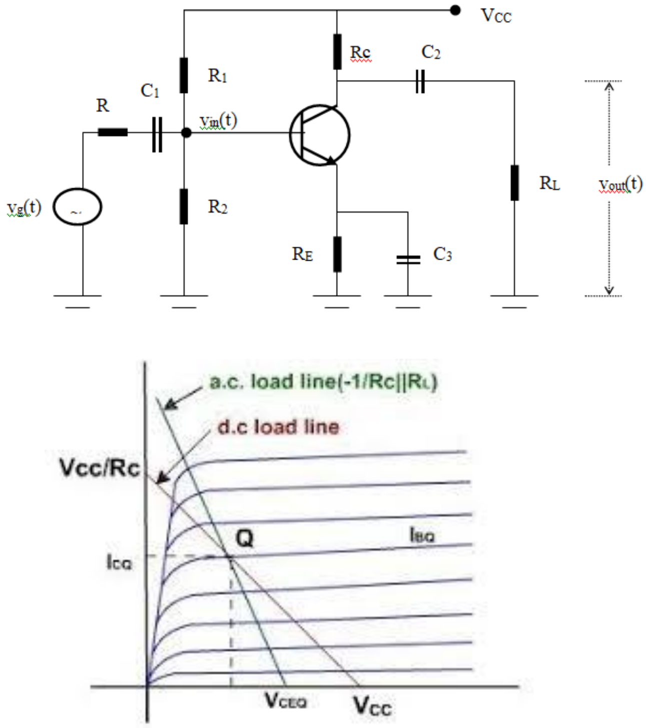

Fig. 6. The Common Emitter (CE) transistor amplifier and the associated DC and AC load lines.

C. Post-class Activities

Students took a post-test (post-class quiz), after each class session. With this test students were assessed on their conceptual knowledge. These tests proved to be helpful, timely and beneficial, because students were able to obtain feedback instantly and the instructor was able to evaluate students' comprehension-learning before the next session. The learning management system (e-class) helped the instructor-teacher evaluate students' efforts, learning, comprehension and identify concepts in which students faced some difficulty and provide timely feedback during the next session. The e-class used for supporting courses with documentation, reports, tracking, and delivery of course content. This educational process, which can be characterized as a systematic and closed-loop educational process, helped the instructor-teacher use time in classroom more effectively, teach more and various concepts, and finally engage in an active way students (making interesting the concepts) throughout the class.

D. Final-class Activities Using Active Learning Strategies (Increasing Students' Engagement with Hands-on Lab Activities)

Collaborative learning was encouraged by all student activities (through hands-on activities and a workshop). There was an emphasis actual application to build up on previous design activity and to have the potential to expand for future design activity. Also, the design activities which were developed were proved to be beneficial on collaborative learning. The first lab activity was designed in a way to engage students in circuit simulation, aiming to introduce the concept of design and verification. Students were required to design, simulate, and verify the CE amplifier circuit using the LTspice circuit simulator. With their preliminary understanding, the second lab activity taught them to read datasheets and verify circuit operation on a breadboard. The procedure of testing a circuit and circuit simulation increase students' confidence. Another lab activity (the 3rd) was the to teach students how to build a circuit, analyse its properties, and recognize the difference between practical and theoretical outcomes.

1) Pre-class preparation

The students were given a short introductory briefing three days before the in-class activity course, providing them with necessary guidance and practical information concerning the method of flipped classroom. They were also told to "watch out" for a relevant announcement. They were then invited through an automated e-class application to attend a seminar on "Load Lines" which would be organized as a Flipped Classroom. The announcement, which was sent to them with a message, contained a link to a superscript called "Preparation Guide: Loading Lines Upside Down". Links on the hypertext led to on-line material, uploaded to Dropbox. The on-line material consists of a number of short videos. Only free software was used to prepare the on-line material. There is also a series of readings of texts in Greek. The total duration of all the videos was about 15 minutes. Considering that some students would like to watch the videos again and spend about 10 minutes reading the texts and answering the quiz and assessment, the students were given an overall assessment of about 40 minutes.

The on-line material was divided into four sections. The first section was about basic concepts on load lines and the necessary mathematics and aimed at providing a brief and comprehensive view of the various forms of load lines. The second and third sections were, respectively, about the properties of load lines in a common-emitter (CE) and common-collector (CC) transistor circuit while the fourth and last section was about power efficiency. After each of the first two sections, the students answered a small number of questions, in a quiz related to the knowledge provided in the immediately preceding section. Quizzes were used for two purposes; on one hand, they can induce immediate "activation" of the recently acquired knowledge and, therefore promote its consolidation [20], [21] and on the other hand, they can provide feedback to the teacher about the points of the on-line material that remained vague for the students giving him/her the opportunity to clarify them in the classroom [22]. Quizzes were created using the Blank-Quiz template of Google Forms®. The off-class preparation and the on-line material were evaluated by the students (at the end of the procedure) via a questionnaire. The questions of this questionnaire were questions with a linear-scale response. The students had also the opportunity to write a short paragraph, expressing in this way some views. The assessment form was filled by the eighty nine percent (89%) of the participating students.

According to the students' answers, the off-class preparation was a positive experience given that in the question "How was the overall experience of the off-class preparation, with the on-line material", 72% of the participating students answered "Excellent" and 28% answered "Very Good". Also, as it seems the preparation was not time consuming. To the question: "How long it took you to get prepared, with the on-line material, in relation to the estimated duration?", 53% of the participating students answered "As Expected", 17% answered "Less Than Expected", 16% answered "Much Less Than Expected" and 14% answered "More Than Expected".

2) In-class activities

In-class activities began with a discussion aiming at the review of the on-line material. In general, organized discussions and debates facilitate the exchange of peer-to-peer knowledge enhance interact with the content of the course and allow the concepts of the courses to become more substantial, the hypotheses and perspectives of the students to be tested and explored. During the debates or discussions, students form groups of two or more members and, after each question, are given the opportunity to discuss within their group and come up with a common answer announced by one of the members as team representative. With a series of questions asked by the instructor, students had the opportunity to retrieve and demonstrate the basic principles of load lines. Particular attention was paid to the points identified in the online quiz and questionnaire as more vague or obscure. Such structured and discreetly guided discussions can help the instructor assess students' understanding while also facilitating the development of team spirit. The students, adopting a more active attitude than usual, soon felt more relaxed and confident and after that began to enjoy the process.

The time was considered appropriate for the following class activities based on the concept of Active Learning whose merits are indicated in numerous papers [23]-[26]. We consider the excitement created by this methodology [27] as its greatest advantage. We have chosen to use Experiential Learning between various approaches of Active learning. In Experiential Learning activities, students learn through immersive, hands-on learning experiences. These learning experiences have some important pedagogical benefits that have been well documented in the relative literature. So, it is obvious the efficacy of simulation environments and modelling in enhancing learning [28]. Experiential learning activities can take a number of forms, including role playing, experimentation demonstrations, labs, computer simulations, competitions etc.

The evaluation of in-class activities took place during the last part of the course. Students had the opportunity, during the discussion, to express their views on Flipped Classroom. These views were very positive in their vast majority.

To the question: "How difficult did you find the in-class activities?" 69% of the participating students answered "Not at all", 25% answered "Just a bit" and 6% answered "A little". To the question: "Do you think that in-class activities have helped you to improve the level of understanding of the lesson you achieved during off-class preparation?" 73% of the participating students answered "A lot" and 27% answered "Very much".

IV. EVALUATION

The effectiveness of a teaching approach, learning method course module or curriculum, cannot be easily evaluated. Factors such as differences in students' learning styles, background as well as interest in the subject cause significant obstacles [29]-[35].

Apart from the specific evaluation actions explained above, students were given two sets of questions, one regarding lesson's content (aiming at evaluating the effect on students' comprehension of the load-line concept and its application to the CE transistor amplifier) and one regarding the students' attitude.

A. Question on the Lesson's Content

1. Regarding the diode circuit of Fig. 2, what is the physical meaning of the load line as compared to the physical meaning of the diode characteristic?
2. Regarding the diode circuit of Fig. 2, what is the algebraic equivalent of the quiescent point Q?
3. Why is the AC load line in the CE circuit not parallel to the DC load line (as it is in the resistor or the diode circuit)?
4. How are the AC load line and the position of the quiescent point associated with the compliance concept?
5. What is the meaning of saturation-dependent and cutoff-dependent compliance?

TABLE I: STUDENTS' PERFORMANCE REGARDING QUESTIONS ON THE LESSON'S CONTENT

Answer / Question	Write answer	Wrong answer	No answer
1	65%	20%	15%
2	61%	19%	20%
3	72%	16%	12%
4	69%	10%	21%
5	66%	15%	19%

B. Question on the Students' Attitude

1. The pre-class activities.
   A. Made it easier for me to understand the concept and use of the load line.
   B. Made no difference.
   C. Were rather confusing.
2. The in-class activity using the flipped-classroom approach
   A. made it easier for me to understand the concept and use of the load line.
   B. made no difference.
   C. was inferior to the conventional approach.
3. The fact that the AC load line is an overall rather than a "pure" AC line
   A. was clear to me from the beginning.
   B. was made clear to me after the analysis of section 2.
   C. is still not clear to me.
4. The physical meaning of the quiescent point Q as an intersection between the DC and the AC lines
   A. was clear to me from the beginning.
   B. was made clear to me after the analysis of section 2.
   C. is still not clear to me.
5. The association of the load line equation with the algebra of the typical y = a – bx form
   A. was not a problem for me and gave me a better perspective of how the load line has to be handled.
   B. made the calculations more difficult but it gave me a better perspective of how the load line has to be handled.
   C. made the calculations more difficult and I prefer not to use it.

Students' answers are shown in Table II.

TABLE II: STUDENTS' ANSWERS REGARDING ATTITUDE TOWARDS LESSON

Answer / Question	A	B	C
1	75%	20%	5%
2	81%	19%	0%
3	7%	86%	7%
4	9%	87%	4%
5	46%	44%	10%

Our findings seem to verify that the students in order to enhance their understanding and improve learning outcome, they need to be actively involved in the learning process. This suggests that conventional lecturing needs to be substituted (at least partially) with modes of teaching that encourage students' participation such as the blended learning or the flipped-classroom approach. Regarding transistor circuits, which present a higher degree of difficulty compared to simple resistor or diode circuits, students need to construct their knowledge based on their own quantitative observations.

V. CONCLUSION

The aim of this work was to present the concept and applications of the load line in a unified and mathematically straightforward manner and, at the same time, employ the blended-learning and "flipping-the-classroom" approach in order to enhance students' understanding and learning outcomes. Judging from the students' response, their active participation together with pre-class preparation and use of simple mathematics facilitated comprehension of the general concepts and notions behind load lines and helped students understanding similarities and differences between the various application cases. Among others, significant improvement was observed regarding use of the load line of transistor circuits that had been a source and misconceptions for several students. Moreover, students seem to strongly prefer the described mode of instruction as compared to conventional forms of teaching.

The flipped-classroom method (together with clarity and simplicity in the calculations involved) could be used in other topics of basic electronics such as the evaluation of power efficiency of transistor circuits (where it was observed that students often fail to see the general idea and the associated assumptions, approximations and limitations). Another topic could be the electronic feedback concept (where students often fail to associate general block diagrams with the approximations involved) as well as the Thevenin/Norton equivalents of amplifier circuits.

Conflict of Interest

Authors declare that they do not have any conflict of interest.

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