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Implementing Student Centered Teaching Methodology in Electrical and Computer Engineering Courses

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Abstract

Many new faculties struggle on becoming effective instructors. Teaching undergraduate and graduate Electrical and Computer Engineering courses poses its own challenge since most of the concepts are complex and abstract. Students often find some of the lecture slides hard to understand. To make things worse, some students are afraid to ask questions even if they do not understand the material since they think if they ask questions, they will be considered stupid. How to teach something that is difficult to understand and how to effectively engage with students? In this paper, we present our own learning on how to become more effective instructors.

The purpose of this paper is to share the Student Centered Teaching Methodology (SCTM) that we developed, implemented, and assessed in the Electrical and Computer Engineering undergraduate and graduate courses. We found this methodology effective in improving students' learning experience. We want to share the SCTM to help new faculty and experienced faculty to become more effective instructors.

The SCTM has five key components, and they are:

E - Easy-to-Understand: We develop course material that translates complex and abstract ECE concepts into something easy to understand. We deliver lecture speech using real life analogies and examples to help students make the connections on why they are learning what they are learning and how it is relevant.

E - Engaging: We proactively engage with students throughout the term by doing frequent check-ins with students on how they are doing in class.

E - Examples: We developed many worked examples to provide students chances to practice and solidify their learning. This inductive learning process proved to be very effective.

A - Accommodate: We accommodate students of diverse backgrounds and instill DEI into our teaching practice. For example, we hold extra office hours on weekends for students who work full time during the week and can only come to office hours on weekends.

F - Feedback: We seek real-time students' feedbacks on our teaching throughout the term and make adjustment to our teaching to improve students' learning experience.

We have found that SCTM worked well to help students' learning experience across a diverse student population, and they promoted DEI. The effectiveness of these SCTM is quantitatively examined by assessing the students' satisfaction with the learning process and their exam scores for courses with and without these practices implemented. We believe that our implementation of SCTM is effective and can be replicated elsewhere.

1. Introduction and Motivation

Many new faculty members struggle to become effective instructors. Teaching undergraduate and graduate Electrical and Computer Engineering courses poses its own challenge since most of the concepts are complex and abstract. Students often find some of the lecture slides difficult to understand. To make things worse, some students are afraid to ask questions even if they do not understand the content since they think if they ask questions, they will be looked down upon and considered unintelligent. So how can we teach something that is complex and abstract? How can we effectively engage with students?

In this paper, we present our lessons learned from classroom practice and teaching experience on how to become more effective instructors. The goal for this paper is to share the Student Centered Teaching Methodology (SCTM) that we developed, implemented, and assessed in the Electrical and Computer Engineering undergraduate and graduate courses. Our working definition of Student Centered Teaching includes not only active teaching in class but also other components, such as providing students with multiple examples of varying complexity to scaffold their learning, meeting student needs when and where they need help, and using structured student feedback for identifying problem areas and quickly fixing them. The novelty and effectiveness of this approach lies in its totality, not in its individual components, as explained below. We found this methodology effective in improving students' learning experience and we believe that it can be implemented by instructors teaching similar courses.

Prior works in active learning and student centric teaching were documented in, e.g., [1] - [16]. The effectiveness of the student-centered active learning pedagogy was reported in [1]. Active learning increases student performance in science, engineering and mathematics [2]. Active learning strategies for college courses were discussed in [3], including pause procedures during lectures, group discussions, clickers, peer reviews and games. Student-centric learning requires students to take ownership of their learning and places emphasis on students' interests, abilities and learning styles [4]. Research has shown that the implementation of a problem-based active learning model had positively affected students' academic achievements and their attitudes towards science courses [5]. Prince in [6] reviewed the effectiveness of active learning, and identified the common forms of active learning most relevant for engineering faculty. The study found support for all forms of active learning examined. Student centric curriculum design and implementation was discussed in business management & IT education in [9] and can be applied to other subject including engineering education. In [10], a student-centered approach coupled with the full integration of lecture and laboratory formats and hands-on activity based-instruction showed clear cognitive and attitudinal gains in students. Chapman in [17] provided educators with recommendations for developing and presenting an effective and worthwhile lecture. A 5-step Paper-Based model was discussed in [18] to foster students' participation in large lectures.

Cognitive theories describe three phases of the learning process from attention to comprehension to integration [19]. The first two phases of learning create a short-term memory for new information. Davis described a simple approach to maximize the first two phases of learning to get the students' attention and tell the students what to pay attention to and do not overload the system in [20]. These strategies address the initial classroom learning environment and can help a lecturer communicate material effectively. Reis in [21] added one more strategy that takes into account the final phase of learning to give students the opportunity to review and apply lecture material and provided a list of quick and easy ideas on how to create memorable lectures.

We expand the work in [20] and [21] by providing detailed and easy to understand lecture notes to help students better interpret the lecture material, especially when studying on their own. However, our SCTM is not focused on just a single element of active teaching covered in [1] - [21], but on the totality of the teaching approach covering various aspects of students' learning both in and out of class. The SCTM we implemented has five key components and they are: **E** for Easy-to-Understand; **E** for Engaging**;** **E** for Examples; **A** for Accommodate and **F** for Feedback. All instructors have to be selective – both in course content as well as instructional techniques they use. The reason we selected these five components in the SCTM is because they fit our instructional approach which is still based on face-to-face lectures, and they seemed to fit our very diverse student body. They are also backed by research findings and have been refined based on student feedback. Section 2 gives an overview of the five key components of the SCTM and explains what they are. Section 3 provides some detailed implementation examples of SCTM. Section 4 discusses the assessment of SCTM effectiveness. Section 5 concludes and summarizes our findings.

2. Student Centered Teaching Methodology (SCTM)

2.1 E - Easy-to-Understand

The first component of the SCTM is to develop easy-to-understand lecture slides. We developed course material that translates complex and abstract ECE concepts into something easier to understand. We delivered the lecture using familiar analogies and examples to help students make the connections to why they are learning what they are learning and how it is relevant.

To scaffold student learning, we have developed easy-to-understand lecture slides and detailed notes section of PowerPoint slides. For complex and abstract concepts that are difficult to understand, we put clear explanations in the notes section of the PowerPoint slides. The notes section of the PowerPoint slides typically includes:

1) Cross-reference information to the textbook page number, Chapter and Section number, Example number;

2) Detailed explanation on concepts that are not easy to understand and detailed formula derivations that are not described in the textbook;

3) Summary of the essential content of the slide.

The main point and novelty of the PowerPoint notes section is in focusing on the essential content so that we provide students with the most efficient way to study. This saves students a lot of time reading through the thick textbook. By focusing on the essentials, we are also achieving better students learning outcomes. We found this method very effective for both undergraduate and graduate students. One may expect that the level of understanding and analytical skills are higher for senior and graduate level students than for lower level undergraduate students. We have found, however, that even for senior and graduate level students, many still encounter difficulties in understanding some of the complex and abstract course material. This is in large part due to their diverse backgrounds and their inability to connect present material with their prior knowledge. One way to make this connection is to simplify the content and then add detailed explanations in the notes section of the PowerPoint slides. For example, the textbook and lecture slides may show the equation derivation in one or two steps, omitting many intermediate steps. Our notes section explains clearly these intermediate steps and helps students understand the intricate concepts. Students from all of our classes gave us overwhelmingly positive feedback regarding the notes section of the PowerPoint slides and said the notes help them to more thoroughly understand the concepts.

2.2 E - Engaging

We proactively engage with students by doing frequent check-ins on how they are doing in class and if they have any questions on the course material. Studies have shown that Question-driven Problem-based Learning is an inquiry-based approach which promotes student-centered learning in the classroom, e.g., [22]. In the middle of a lecture, we pause and ask students if they have any questions after we go through a concept, and we do this regularly. By doing frequent check-ins, students are encouraged to ask questions. Often 1 or 2 students ask questions, and that leads to other students asking more follow-up questions. So, we have a deeper discussion on the concept in class. To get over students' reluctance to ask questions, sometimes we do anonymous Zoom polling questions to the class to check if students understand the concepts. This gives students the sense of ownership of their education and lets students know their instructors care about their learning experience. As expected, since the implementation of SCTM we have observed a significant increase in the number of questions students asked. This is a direct result of our intentional approach of implementing the "E – Engaging" component of SCTM.

2.3 E - Examples

We developed worked-through examples beyond what is available in textbooks to provide students chances to practice and solidify their learning. This inductive learning process is known to be effective. We usually release the example problems first, giving students a chance to reflect and apply concepts learnt in class to the problem, then hold classroom discussion and step-by-step problem solving sessions, before releasing the solutions. We received positive feedback from students that the examples are helpful to their learning and they often ask for more examples. This approach is supported by studies that have shown that Problem-Based Learning can help students perform better in class, e.g., [23].

2.4 A - Accommodate

Our university is urban university with vibrant high-tech industry in the surrounding area. Many of our undergraduate students work while studying, commute to university, and are on average older than more traditional students. Among graduate students we have a very large international contingent. Domestic students tend to be working at local industry and studying part-time and significant fraction are post-baccalaureate students. Therefore, we must accommodate students of diverse technical, social, economic and ethnic backgrounds and instill DEI into our teaching practice. For students who are working parents, we offer weekend office hours since some of them are not available to come to weekday office hour. We make assignment due dates to be on weekends to accommodate their schedule. For students who contracted COVID-19 or have other health problems, we are flexible in the assignment due dates so that students have nothing to worry about but to focus on health recovery. For students that have anxiety and other learning disabilities, we adjust exam time and duration to accommodate their needs. We also provide supplementary lecture recordings to class. Studies have shown lecture recordings can support significant increases in academic performance in students with specific learning difficulties including dyslexia [24]. While it is difficult to quantify the effects of these interventions, we believe that their cumulative effect on student success is very positive.

2.5 F – Feedback

We seek real-time student feedback throughout the term and adjust our teaching to improve students' learning experience. Every week at the start of the class, we remind students to provide us feedback by email, or talking to us before or after the lecture or during the class break or coming to our office hour to talk to us. We ask students if the lecture speed is too fast or too slow. Right after the midterm exam, we do an anonymous course survey to identify areas to improve for the second half of the term. We remind students not to wait until the end of the term to give us feedback since that would be too late to impact their learning. It has been reported that student evaluation is very important and plays a significant role in the quality assurance process for course success [25].

In the next section, we will provide several examples of how these techniques have been implemented.

3. Implementation Examples of Student Centered Teaching Methodology

In this section, we provide implementation examples on Easy-to-Understand, Examples and Feedback elements of the SCTM applied to ECE courses.

3.1 Implementation Example I: Providing Easy-to-Understand Lecture Notes

For all of our lecture slides, we provide not only the PowerPoint slides but also the detailed notes section of the slides. The notes section thoroughly explains some of the intricate concepts in the lecture slides that are difficult to understand. We will show a sample notes we developed for the Digital Integrated Circuit Design I course.

This course is a senior/graduate level ECE course. It is a condensed course, covering lots of new material that is built on the knowledge from pre-requisite courses. There are many circuit theories, derivations and calculations involved and students need to integrate what they learned from the pre-requisite courses in logic circuits, electric circuit analysis and electronics, and then expand that knowledge further. Graduate students may have taken the pre-requisite courses many years ago and may need to refresh their prior knowledge. Expanding knowledge from another course is not automatic. As instructors, we cannot repeat the whole pre-requisite courses, but we can bring out the essential concepts to re-engage students. We use a textbook and accompanying slides [26].

In our approach, we identify essential prerequisite topics that students struggle with and look for ways to remind them of what they know already and explain the problems succinctly. To this end, we added detailed lecture notes in the notes section of the PowerPoint slides to help explain some complex concepts which involve expanding the knowledge from prerequisite course.

Figure 1 shows page 33 of one of the lecture slides [27] on DC & Transient Response. It shows both the main lecture slide in the upper portion of Figure 1 and the notes section that we added in the lower portion of Figure 1. The notes section includes the following information:

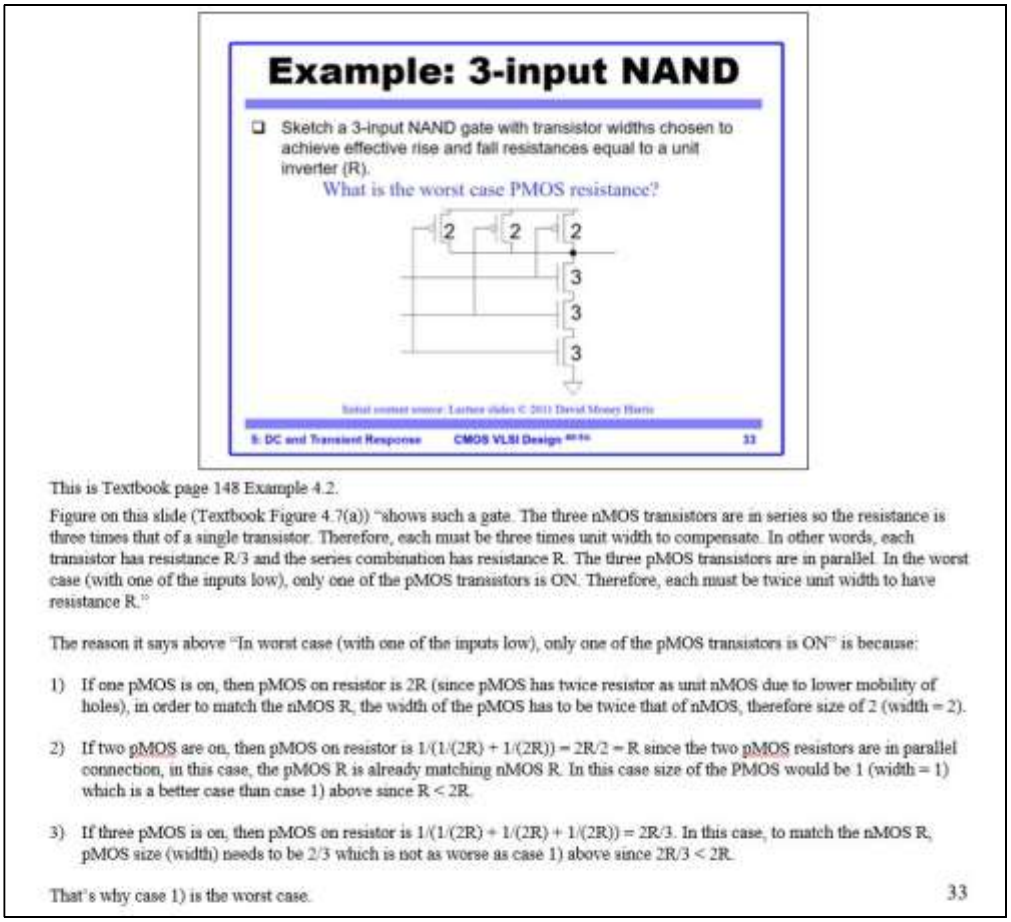
1. Cross-reference to the textbook page number, section number, example number.
2. Key excerpt from the textbook.
3. Detailed explanation on why for a 3-Input NAND gate, the worst case pull-up resistance occurs when only one of the three PMOS is on. This involves expanding the knowledge from circuit analysis prerequisite course.

The cross-reference to the textbook provides students an additional resource in case students want to dive deeper into the material. The detailed explanation helps clear questions students may have for the slide. The goal of providing the detailed notes section is to enable students to understand the lecture concepts without reading the textbook, therefore saving students time and increasing students' learning efficiency. We do not cover all the notes section in the class, and we are not trying to replace students taking their own notes. However, even students who take their own notes will still encounter questions on some concepts, and our lecture notes can provide the additional resource to help them understand and save them time from reading the full textbook text. The notes section only covers the essential part of the textbook. As long as the students understand our lecture slide and notes content, they may need to consult the textbook only occasionally.

Such detailed lecture notes are also helpful for any faculty who pick up a new course to teach and can help instructors deliver lectures more effectively. Developing the notes section of the lecture slide is a time consuming task, but well worth it. Because of the overwhelmingly positive feedback from students, we now implement notes sections in all the courses we teach.

3.2 Implementation Example II: Developing Easy-to-Understand Lecture Slides

Advanced Computer Architecture I is an advanced graduate level course. There is no textbook for this course because there is no single textbook that can keep up with all the latest development in this area. The course uses twenty research papers. Students learn from these research papers and some of the papers are presented in a way not easily digestible and have lots of jargon. Our observation is that the concepts are abstract, students find some of the papers very difficult to understand, and they cannot connect their prior experience and knowledge to the course content. One such difficult topic is the Two-Level Adaptive Branch Prediction [28]. To help students understand this branch predictor better, we use familiar analogy and introduce smaller concepts, then build up the large and complex concepts step-by-step, followed by examples, as explained next.



This is Textbook page 148 Example 4.2.

Figure on this slide (Textbook Figure 4.7(a)) "shows such a gate. The three nMOS transistors are in series so the resistance is three times that of a single transistor. Therefore, each must be three times unit width to compensate. In other words, each transistor has resistance R/3 and the series combination has resistance R. The three pMOS transistors are in parallel. In the worst case (with one of the inputs low), only one of the pMOS transistors is ON. Therefore, each must be twice unit width to have resistance R."

The reason it says above "In worst case (with one of the inputs low), only one of the pMOS transistors is ON" is because:

1) If one pMOS is on, then pMOS on resistor is 2R (since pMOS has twice resistor as unit nMOS due to lower mobility of holes), in order to match the nMOS R, the width of the pMOS has to be twice that of nMOS, therefore size of 2 (width = 2).

2) If two pMOS are on, then pMOS on resistor is 1/(1/(2R) + 1/(2R)) = 2R/2 = R since the two pMOS resistors are in parallel connection, in this case, the pMOS R is already matching nMOS R. In this case size of the PMOS would be 1 (width = 1) which is a better case than case 1) above since R < 2R.

3) If three pMOS is on, then pMOS on resistor is 1/(1/(2R) + 1/(2R) + 1/(2R)) = 2R/3. In this case, to match the nMOS R, pMOS size (width) needs to be 2/3 which is not as worse as case 1) above since 2R/3 < 2R.

That's why case 1) is the worst case. 33

Figure 1: Expanded lecture slides notes for Digital IC Design I: Lecture Slide 5 Page 33

Before the class, students are asked to read the research paper [28], but many students still do not understand how this branch predictor works. In class, we follow it up with further discussion of this topic. Figure 2 shows two lecture slides that we present to class. The left slide in Figure 2 introduces the concept of pattern recognition and asks students, given a pattern of 11110 repeating many times, what would be predicted as the next digit after 1111. Here, 1 stands for branch to be taken and 0 stands for branch to be not taken. Then we repeat the same process which involve a different pattern 00001. The right slide in Figure 2 introduces the Two Level Adaptive Branch Prediction concept of Branch History Register (BHR) or per-address Branch History Table (BHT) and Pattern History Table (PHT) [28]. By linking pattern recognition that students are familiar with to the branch prediction concept of BHR, BHT and PHT, students understand better how this branch predictor works. We have found that after introducing these two slides to the class, students' understanding is much improved. This shows that using everyday analogies relatable to students is effective in scaffolding students' understanding when introducing complex ECE concepts.

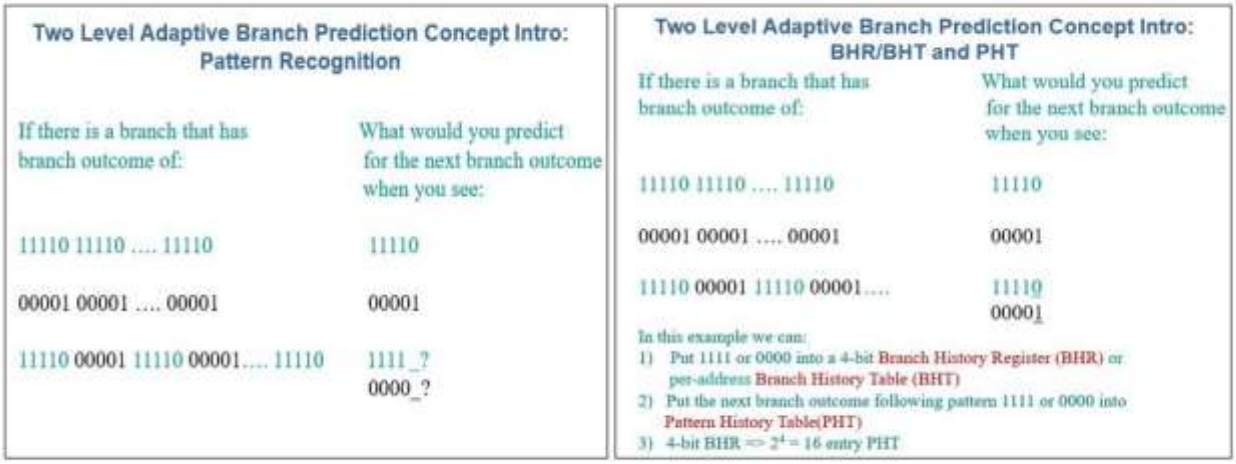


Figure 2. Two Level Adaptive Branch Prediction Concept Introduction

3.3 Implementation Example III: Providing Worked-Through Example

In this section, we show a worked-through example of the Two-Level Adaptive Branch Prediction discussed in Section 3.2 that we provided to the class. Figure 3 shows such an example with a branch having repeating pattern of outcomes TTTTN TTTTN …. This branch outcome sequence is repeated millions of times. Consider a Two-Level Adaptive Branch Predictor "P1" which uses 2-bit of per-address history in the Branch History Table (BHT) and 1-bit state machine in the Pattern History Table (PHT). The next task is to calculate the prediction accuracy of "P1". Figure 3 illustrates step-by-step procedures on how to calculate the branch prediction accuracy, as described below.

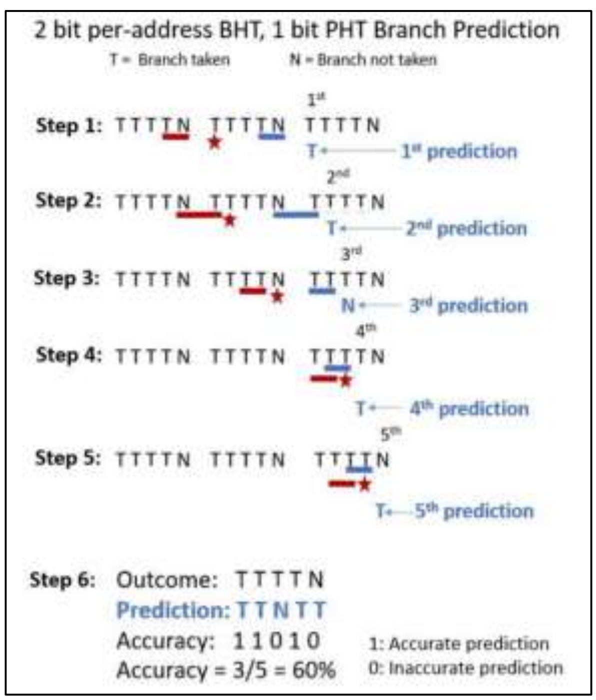


Figure 3. Two Level Adaptive Branch Prediction Example

Step 1:

a) To predict the first pattern (marked with 1st above it in Figure 3), we need to find out what the previous 2 branch patterns are before this pattern since 2-bit of per-address history is used in BHT. The previous 2 patterns are TN which is underlined with blue line, where T stands for Branch taken, N stands for Branch not taken.

b) Since 1-bit state machine is used in PHT, we need to find out the branch outcome after the previous occurrence of TN, which is underlined in red color. The branch outcome after that previous occurrence of TN is T, which is marked with a red star.

c) Because the previous time when TN happened, the pattern followed is T, therefore, this time we will predict T and the prediction T is written in blue color at the top of Figure 3.

Step 2: Using the same method as described in Step 1, the 2nd prediction is T.

Step 3-5: Using the same method as described in Step 1, the 3rd, 4th and 5th prediction is N, T, T.

Step 6: Calculate the branch prediction accuracy to be 60% because 3 out of 5 pattern are correctly predicted.

We solve this example step-by-step using document camera and different color of pens to highlight the last and current occurrence of the branch pattern and their subsequent next branch pattern. This process helps students to use pattern recognition to predict the branch outcome. Such detailed process of solving example problem helps students connect all pieces of this complex branch predictor together to solidify their knowledge.

As a practical matter and based on students' feedback, document camera works better in displaying the problem solving steps than white board since white board has reflection and cannot be viewed well from all angles by students sitting at different seats in the classroom.

3.4 Implementation Example IV: Seeking Student Feedback

For all the courses we teach, in the very first lecture, we ask students what they think makes a good instructor. We write down students' feedback and pledge to be a good instructor for the class. Right after the midterm exam, we ask students to fill out an anonymous mid-term feedback form. We emphasize to students that their feedback can help us adjust our teaching to improve their learning experiences, rather than the end-of-term student evaluation feedback, which only benefits future students. The three questions we ask students on the mid-term feedback form are:

1. What is one thing that is working really well for you about how this class is structured that we definitely do not want to get rid of in future course offerings?
2. What is one thing that you really wish could change about this class that would help you learn better?
3. Is there anything else that the professor should know?

After we collect students' mid-term feedback, we identify a list of things we can implement and adjust in our teaching for the second half of the term to improve students' learning experience and go over this list with students in class. We also identify a list of things we will implement for future course offerings and a list of things we will not implement and explain to students why. For example, we have included more interactive problem solving sessions and more Q&A sessions in class. On the other hand, when students requested us to get rid of writing lab report, we explained to them that being able to write good lab report is part of the learning and it is an essential skill at workplace, therefore we cannot remove the lab report requirement.

4. SCTM Effectiveness Assessment

The effectiveness of SCTM is quantitatively examined by assessing the students' satisfaction with the learning process and their exam scores for courses with and without these practices implemented. We used three independent data sources to achieve that. First, we developed a post-course student survey to assess students' satisfaction with the SCTM practices. Second, we also used the end of term instructor course evaluation data to verify students' satisfaction with the learning process for courses with and without these SCTM practices. Lastly, we used exam scores to verify the effectiveness of SCTM implementation.

4.1 Student Survey

In order to assess the effectiveness of the SCTM, we designed Post-Course Student Survey to probe students' satisfaction with the learning process for courses with these SCTM practices. The survey was collected for the Fall Term 2021 Digital IC Design 1 (DIC-I) and Advanced Computer Architecture I (ACA-I) courses. The survey questions are listed below and it contains two components: A) perceived effectiveness of SCTM instructional techniques used in the class, and B) assessing student self-efficacy, i.e., the perception of their own abilities to perform certain tasks. The survey was modeled after survey developed in [29].

Student survey questions for Part A) include:

A) Effectiveness of instructional techniques

Scale: Complete waste of time (1), Not helpful (2), Neutral (3), Somewhat helpful (4), Very helpful (5)

1. Providing PPT lecture slides notes
2. Providing formula sheet
3. Use of Zoom polling
4. Providing accessible course material
5. Help provided by instructor in office hour and email
6. Seek feedback to improve teaching
7. Frequent check-ins by instructor

Table 1. Student survey questions for *Part B) regarding self-efficacy*

Student Survey Questions for Part B) *("I am confident that I can …")*	
Scale: Strongly disagree (1), Disagree (2), Neutral (3), Agree (4), Strongly Agree (5)	
Digital IC Design I (DIC-I)	**Advanced Computer Architecture I (ACA-I)**
8. Estimate circuit delay	8. Explain superscalar pipeline architecture
9. Analyze PMOS & NMOS IV	9. Evaluate performance
10. Calculate effort delay	10. Branch prediction
11. Compute probability & activity factors	11. Distinguish trace cache from iCache
12. Design combinational & sequential logic	12. Compare pros & cons of register buffering methods
13. Model wire as pi-model	13. Predict memory dependence
14. Apply CMOS circuit quality metrics	14. Evaluate cache performance
15. Explain timing & gate sizing trade-offs	15. Compare pros & cons of SMT models
16. Estimate power	16. Identity performance, power & battery life feature

Figures 4 - 7 show the survey results. For DIC-I, 39 students responded to the survey while the total number of students in the course is 69. For ACA-I, 22 students responded to the survey while the total number of students in the class is 50. We will strive to improve the relatively low response rates so that our sample size becomes larger, which would give us more confidence in our conclusions.

Data from the survey regarding the effectiveness of SCTM are presented in Figure 4, where average scores for each question are presented. The average rating range for DIC-I is 4.51 – 4.90 and the average rating range for ACA-I is 4.14 – 5.00 out of the full scale of 5. The data shows students from both classes think positively on the effectiveness of the SCTM practices.

One thing to point out is that the rating of "Use of Zoom polling" was the lowest. Based on the mid-quarter students' feedback, we added the use of Zoom polling to let student answer questions during the lecture. Students said their attention span was not more than 20 minutes. By interchanging activities such as Zoom polling sessions and lecturing sessions during the two-hour long class, the intent is to keep students engaged. Surprisingly, the survey data consistently show some students think this method is less useful compared to other SCTM practices. By examining the histogram data of the survey question of "Use of Zoom polling" in Figure 5, we found that between 10% and 20% of students rated this item below 4. We suspect that this is caused by the time needed for the class majority to complete each polling question. This may be too long for some students who can answer the questions quickly, resulting in relatively lower rating for this item. In the future, we will try to make short, more focused questions and shorten the time for students to answer questions. This issue requires further analysis and if this intervention proves to be effective, it will illustrate an interesting and novel application of the survey data analysis. Based on these survey results, students seem to think that the SCTM practice is helpful and effective.

Figures 6 and 7 show the DIC-I and ACA-I survey results regarding student self-efficacy respectively, and the average scores for each question are presented. We are trying to probe at all levels of cognitive learning of Bloom's taxonomy [30]. Student self-efficacy rating is 4.15 – 4.64 for DIC-I and 4.36 – 4.82 for ACA-I. For DIC-I, the lowest rating is 4.15 and it corresponds to the capability of power estimation; the highest rating is 4.64 and it corresponds to the ability to estimate circuit delay. For ACA-I, the lowest rating is 4.36 and it corresponds to the capability of comparing pros & cons of register buffering methods for precise interrupt for the superscalar processor architecture; the highest rating is 4.82 and it corresponds to the ability to evaluate impact of various parameters to performance and the ability to identify performance & power/battery life feature. We think the reason for the lowest rating items is because we did not provide many examples for students to work on in those areas while for the highest rating items, we did. This further demonstrates that providing examples for students to exercise helps students' learning experience and solidifies their knowledge. These data are useful and can shed light on what areas to focus on in future course offerings to improve students' learning. We will continue to monitor how all of these items develop over time.

4.2 Course Evaluation

The second set of data to evaluate the effectiveness of SCTM is the end of term course evaluations. We will show the Computer Architecture course evaluation for the Winter Term 2018, Winter Term 2019 and Spring Term 2021 taught by one of the co-authors of this paper. The reason we show this course evaluation comparison is because Winter Term 2018 was the first time one of the co-authors taught this course and most of the SCTM practice were not implemented. For the Winter Term 2019 course, some SCTM components were implemented. For the Spring Term 2021 course, all SCTM components were implemented. Figure 8 and Figure 9 show the average student evaluation scores for instructor-related items and course-related items respectively. Full scale of the rating is 5. Course enrollment is 49 for the Winter Term 2018, 56 for the Winter Term 2019, and 65 for the Spring Term 2021. The total number of students who submitted the course evaluation is 34 for the Winter Term 2018, 44 for the Winter Term 2019 and 32 for the Spring Term 2021. The course delivery mode is remote synchronous for the Spring Term 2021 and in-person for the earlier offerings. We think that the lower number students who submitted the course evaluation for the Spring Term 2021 is due to the remote delivery mode.

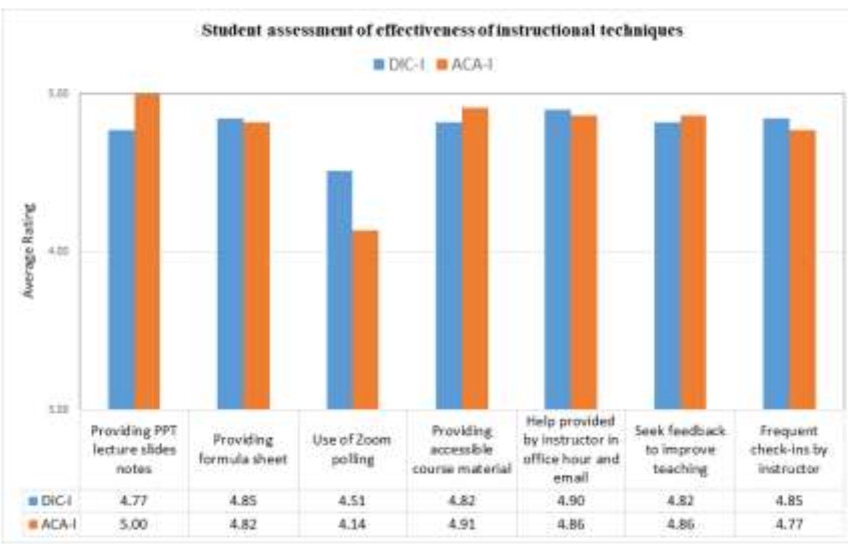


Figure 4. SCTM instructional techniques effectiveness as determined by the end-of-term survey

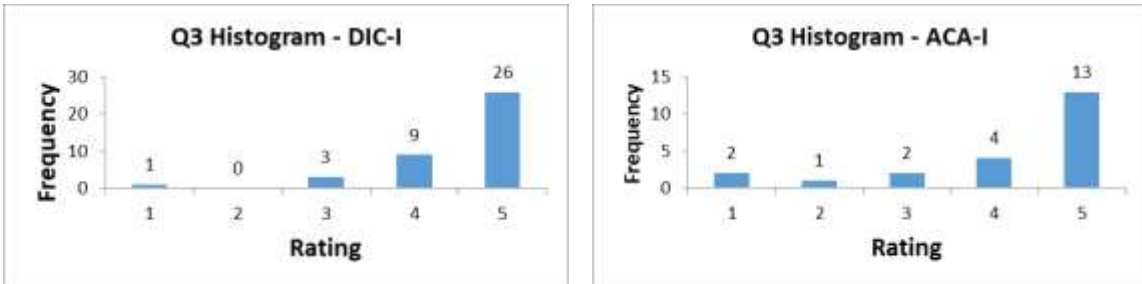


Figure 5. Histogram: Use of Zoom polling

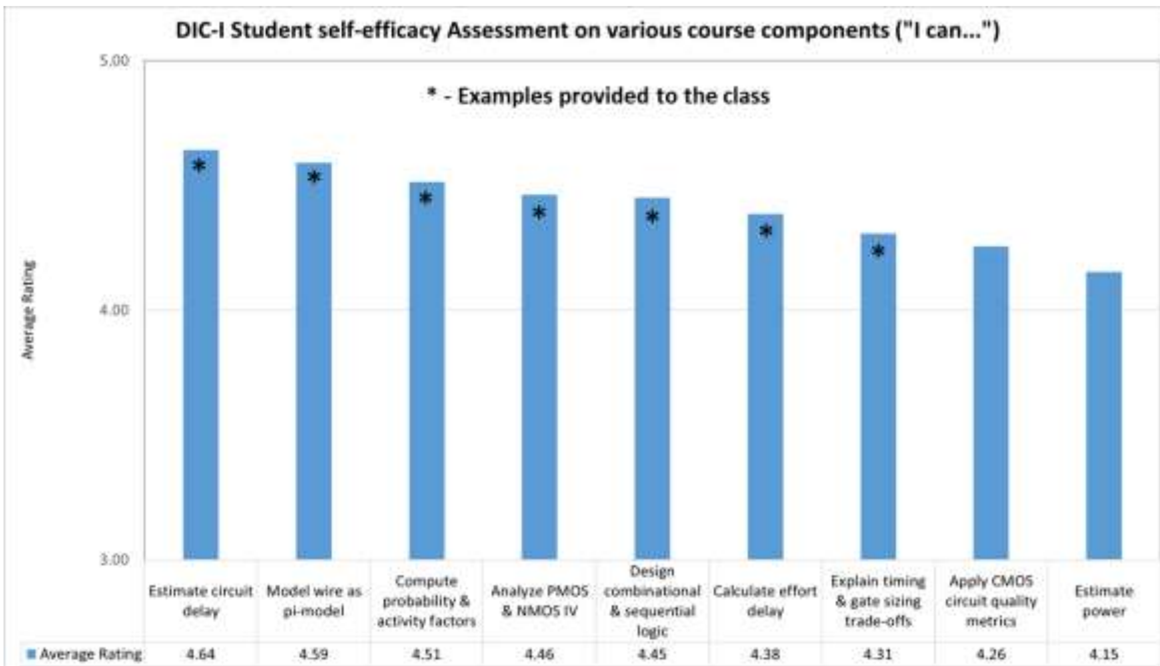


Figure 6. Student self-efficacy as determined by the end-of-term survey for DIC-I

Figure 8 shows a steady improvement on instructor related evaluation items. Instructor Overall rating improved 31% from 2.79 in Winter Term 2018 to 4.35 in the Spring Term 2021. After reviewing the course evaluation in 2018, instructor looked for ways to improve the course. One of the student feedback items was that the homework was too difficult. Instructor then developed practice examples incorporating students' feedback. In the Winter Term 2019, instructor implemented the Examples and Engaging components of the SCTM to the course and the overall rating improved across the board. In the Spring Term 2021, instructor further added detailed notes section for the PowerPoint lecture slides and implemented all key components of SCTM and overall rating improved further. We think these improved scores reflect the changes of implementing SCTM practices.

Similarly, Figure 9 shows a steady improvement of course related evaluation items. Overall average rating of all course-related items improved from 66% for Winter Term 2018 to 87% for Spring Term 2021, a 21% improvement. We think this further indicates the SCTM practice seems to work in improving students' learning experience.

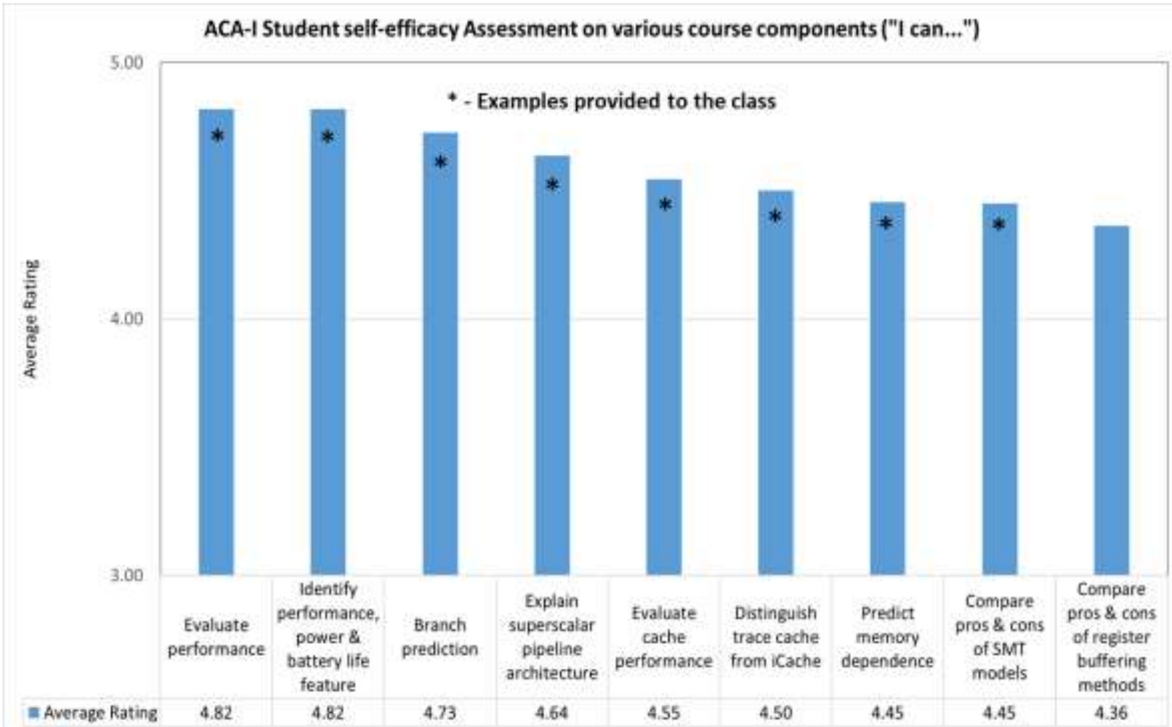


Figure 7. Student self-efficacy as determined by the end-of-term survey for ACA-I

We also want to acknowledge that there are many confounding factors that prevent the firm conclusion that these results are due to our implementation of any specific approach. For example, just getting more familiar with the material instructor is teaching would lead to better teaching and therefore better evaluations. We are also aware of the current controversies surrounding the validity and effectiveness of student ratings of instruction (student teaching evaluations). However, we still believe that this data can at the very least provide a starting point for analysis and forming a hypothesis. In addition, SCTM techniques are based on research findings and suggested best practices. We will continue to monitor how these items develop over time for future course offerings.

4.3 Summative Student Assessment Data

The third set of data to evaluate the effectiveness of SCTM comes from exam results. We have compared the class average of the final exam score of the Computer Architecture courses of the Winter Term 2019 vs. Spring Term 2021. The course contents were the same and exams were similar in terms of difficulty level and the types of questions. In the Winter Term 2019 class, we only implemented a subset of SCTM. In the Spring Term 2021, we implemented all five key components of SCTM. The class average of the final exam score was improved by 5 points out of 100 points which would normally translate into one half of the full grade level improvement. This is one more indication that the SCTM practice improves students' learning experience.

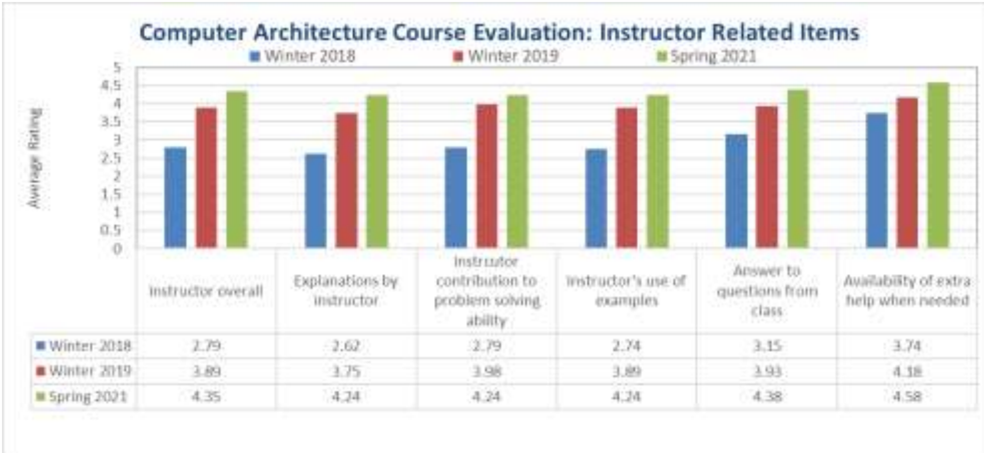


Figure 8. Computer Architecture Course Evaluation: Instructor Related Items

Figure 9. Computer Architecture Course Evaluation: Course Related Items

5. Conclusion

In this paper, we shared our approach to the Student Centered Teaching Methodology (SCTM) across upper-division undergraduate and graduate ECE courses. The SCTM has five key components, and they are: 1) delivering Easy-to-Understand lecture material and detailed notes section of the PowerPoint lecture slides; 2) proactively engaging with students by doing frequent check-ins; 3) providing examples; 4) providing accommodation to students with diverse needs and 5) seeking real-time feedback from students throughout the term. The novelty is in the totality of the approach, not in its separate components. None of the prior works we examined so far discussed how to effectively develop and package lecture slides material to enhance students' learning experience and maximize their learning outcome. Delivering the detailed notes section for the PowerPoint lecture slides enables students to learn efficiently. Detailed notes are also helpful for faculty who teach a new course. We have found that using every-day and familiar analogies relatable to students is effective in introducing complex ECE concepts.

The SCTM is a holistic approach treating students as active participants in their own learning process. We found the SCTM worked well to help students' learning. The effectiveness of the SCTM was quantitatively examined by the student post-course survey, course evaluation and final exam data. Based on the positive results from three different sets of data, we believe that our implementation of SCTM is effective. We also think that it is generally applicable and can be replicated elsewhere. We have also found that implementing SCTM during Covid-19 restrictions was relatively straightforward and students still benefited from this approach.

We plan to conduct student post-course surveys to all of our courses in the future. We will continuously monitor how these items develop over time and use them to keep improve and refining our teaching methods.

References

[1] J. Michael, "Where's the evidence that active learning works?", *Journal of Advances in Physiology Education,* vol. 30, pp. 159-167, 2006.

[2] S. Freeman, S.L. Eddy, M. McDonough, M.K. Smith, N. Okoroafor, H. Jordt, M. Wenderoth, "Active learning increases student performance in science, engineering, and mathematics", *Proceedings of the National Academy of Sciences of the United States of America,* vol. 111, no. 23, pp. 8410 – 8415, 2014.

[3] C.M. Patton, "Employing Active Learning Strategies to Become the Facilitator, Not the Authoritarian: A Literature Review", *Journal of Instructional Research,* vol. 4, pp. 134 – 141, 2015.

[4] K. Lathika, "Student Centered Learning", *International Journal of Current Research and Modern Education,* vol. I, Issue I, pp. 677 – 680, 2016.

[5] O. Akinoglu, R.O. Tandogan, "The Effects of Problem-Based Active Learning in Science Education on Students' Academic Achievement, Attitude and Concept Learning", *Eurasia Journal of Mathematics, Science & Technology Education,* pp. 71-81, 2007.

[6] M. Prince, "Does Active Learning Work? A Review of the Research", *Journal of Engineering Education,* pp. 223 – 231, 2004.

[7] S. Hartikainen, H. Rintala, L. Pylvas, P. Nokelainen, "The Concept of Active Learning and the Measurement of Learning Outcomes: A Review of Research in Engineering Higher Education", *Journal of Education Science,* 2019.

[8] J. Basavaiah, A.A. Anthony, C.M. Patil, "Transformation of engineering education through student-centric learning", *International Journal of Learning & Teaching, vol. 13, Issue 1,* pp. 32-41, 2021.

[9] S. Aithal, "Student Centric Curriculum Design and Implementation – Challenges Opportunities in Business Management IT Education". [Online]. Available: https://mpra.ub.uni-muenchen.de/74365/. [Accessed Dec. 17, 2021].

[10] M.T. Oliver-Hoyo, “Lessons Learned from The Implementation and Assessment of Student-Centered Methodologies”, *Journal of Technology and Science Education,* vol. 1, pp. 2-11, 2011.

[11] F.M. Rezende-Filho, L. Fonseca, V. Nunes-Souza, G. Guedes, L.A. Rabelo, “A student-centered approach for developing active learning: the construction of physical models as a teaching tool in medical physiology”, *BMC Medical Education,* vol. 14, no. 1, 2014.

[12] K.J. Nasr, C.D. Thomas, “Student-centered, Concept-embedded Problem-based Engineering Thermodynamics”, Int. *Journal Engineering Education,* vol. 30, no. 4, pp. 660 – 670, 2004.

[13] R.W. Maloy, I. LaRoche, “Student-Centered Teaching Methods in the History Classroom: Ideas, Issues, and Insights for New Teachers”, *Social Studies Research and Practice,* vol. 5, no. 2, pp. 46 – 61, 2010.

[14] R. Beichner, J.M. Saul, D.S. Abbott, J.J. Morse, D. L. Deardorff, R.J. Allain, S.W. Bonham, M. H. Dancy, J.S. Risley, “The Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) Project”. [Online]. Available: Main Title: (compadre.org). [Accessed Dec. 17, 2021].

[15] B. Khales, “The Impact of a Teacher Training Program on Mathematics Teaching Methodologies: Using Student-centered Learning”, *American Journal of Educational Research,* vol. 4, no. 14, pp. 992 – 998, 2016.

[16] G.B. Wright, “Student-Centered Learning in Higher Education”, *Int. Journal of Teaching and Learning in Higher Education*, vol. 23, no. 4, pp. 92-97, 2011.

[17] T. Chapman, “Waking up your lecture”, *Pediatric Radiology,* pp. 1388 – 1392, 2018.

[18] M. H. Aburahma, “Do not Lose Your Students in Large Lectures: A Five-Step Paper-Based Model to Foster Students’ Participation”, *Pharmacy Journal,* pp. 89 – 100, 2015.

[19] B. S. Fuhrmann, A. F. Grasha, *A Practical Handbook for College Teachers.* Boston: Little, Brown and Company, 1983.

[20] J.R. Davis, *Better Teaching, More Learning: Strategies for Success in Postsecondary Settings*, Phoenix, AZ, Oryx Press. ISBN 0-89774-813-1, 1993.

[21] Rick Reis, “How to Create Memorable Lectures, Tomorrow’s Teaching and Learning”, *Stanford Tomorrow’s Professor Posting,* [Online]. Available: How to Create Memorable Lectures | Tomorrow's Professor Postings (stanford.edu). [Accessed Mar. 10, 2022].

[22] C. Chin, L. Chia, “Problem-Based Learning: Using Students’ Questions to Drive Knowledge Construction”. *Wiley InterScience,* 2004. [Online]. Available: www.interscience.wiley.com. [Accessed Dec. 17, 2021].

[23] I. Bilgin, E. Senocak, M. Sozbilir, “The Effects of Problem-Based Learning Instruction on University Students’ Performance of Conceptual and Quantitative Problems in Gas concepts”, *Eurasia Journal of Mathematics, Science & Technology Education,* vol. 5, no. 2, pp. 153 – 165, 2009.

[24] K.P. Nightingale, V. Anderson, S. Onens, Q. Fazil, H. Davies, “Developing the inclusive curriculum: Is supplementary lecture recording an effective approach in supporting students with Specific Learning Difficulties (SpLDs)?”, *Computers & Education,* vol. 130, pp. 13 – 25, 2019.

[25] J. Leckey, N. Neill, “Quantifying Quality: the importance of student feedback”, *Quality in Higher Education,* vol. 7, no. 1, 2001.

[26] N.H.E. Weste, D.M. Harris, *CMOS VLSI DESIGN, A Circuit And Systems Perspective*, Addison-Wesley, 4th Edition, ISBN 10: 0-321-54774-8, 2019.

[27] Slides for N.H.E. Weste, D.M. Harris “CMOS VLSI Design DESIGN, A Circuit And Systems Perspective”. [Online]. Available: Weste & Harris, CMOS VLSI Design: A Circuits and Systems Perspective, 4th Edition | Resources (pearson.com). [Accessed Jan. 1, 2022].

[28] T. Yeh, Y.N. Patt, “Alternative Implementations of Two-Level Adaptive Branch Prediction”, *Proceedings the 19th Annual International Symposium on Computer Architecture,* pp. 124 – 134, 1992.

[29] B. Pejcinovic, P. Wong, “Evolution of an Introductory Electrical Engineering and Programming Course”, *ASEE Annual Conference & Exposition,* Columbus, Ohio, 2017.

[30] B.S. Bloom, M.D. Engelhart, E.J. Furst, W.H. Hill, D.R. Krathwohl. *Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook I: Cognitive domain,* New York, David Mckay Company, 1956.