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PIVOTeeING: A Flipped Approach in a Postgraduate Solid State Devices Course

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Abstract: Design and implementation of flipped courses is a challenge as it involves many elements. Flipped approaches, though well-suited for engineering courses, have not been implemented and reported as much as K-12. A review of the various meta-studies also points out that due to the presence of complex activities in flipped approach instructors need support for the design, implementation and evaluation of flipped classrooms. In this paper, we describe the design, implementation and evaluation of a flipped approach for a postgraduate Electrical Engineering course - Solid State Devices. The instructors and educational researchers from our institute worked in a partnership framework for the flipped approach - Problem solvIng Via instructOr mediaTed peer learING (PIVOTeeING). Since it was an exploratory cycle in the Design Based Implementation Research (DBIR) framework, various learner affect and performance parameters were explored. The results show that, for more than 65% of the time, learners were engaged with the content and more than 60% of learners attained satisfactory levels in an end-semester exam on a new concept not specifically addressed in class. The implementation was also carefully examined to present practice-based guidelines for implementation of flipped classroom in the electrical engineering domain via the participatory design framework.

Keywords: flipped classroom, participatory design, solid state devices

1. Introduction

A common strategy being implemented in current courses is the flipped classroom, where learners are introduced to course content outside of classroom and provided with deeper engagement opportunities within the class. The flipped classroom design is equivalent to the design of a system consisting of different moving parts (Talbert, 2017). The core elements of this flipped design are: (i) content exposure prior to class, (ii) mechanism to assess out-of-class learning, (iii) higher-level cognitive activities in-class (Brame, 2013). The design rationale behind converting any course to flipped format is to utilize the class-time for engaging learners in higher order cognitive activities (Velegol, Zappe & Mahoney, 2015).

The implementation of the flipped approach has predominantly been reported in K-12 education, for example, a meta-review on flipped classroom revealed that 90% studies (of about 759 original studies reported from 1995 to 2015) were in the K-12 setting (O'Flaherty & Philips, 2015). However, this pedagogical approach is gaining popularity in higher education as well. 164 flipped studies in engineering were reported from 2000-2015. (Karabulut-Ilgu et al., 2017). Flipped learning appears to be well suited for engineering education as it "combines learning theories once thought to be incompatible—active, problem-based learning activities founded upon a constructivist ideology and instructional lectures derived from direct instruction methods founded upon behaviorist principles" (Bishop & Verleger, 2013). In this paper we describe the course design, implementation and evaluation of a flipped classroom PIVOTeeING (Problem solvIng Via instructOr mediaTed peer learING), for the course 'Solid State Device' for the post-graduate program in Electrical Engineering at IIT Bombay.

The following recurring recommendations emerge from various meta-reviews of the flipped classroom: (Karabulut-Ilgu et al., 2017; O'Flaherty and Philips, 2015; Kim et al, 2014; Howitt, Christine and Pegrum, 2015; Lo et al., 2017)

i. Flipped approach needs more careful implementation and reporting to understand how and which of its elements contribute to learning
ii. Flipped course practioners need support to create learning sequences, use of technology in learning intervention
iii. Flipped courses need to be evaluated for student learning effectiveness for which the practitioners need help in design, implementation and evaluation.

Instructors need support for implementing the above recommendations. At the same time, research is required to explain the working of a flipped approach in a way that informs the practice. One strategy that has been recommended to address these goals is a collaboration between educational researchers and practitioners (Peneul et al, 2015). The researcher's role is to translate their work on learning to interventions implementable by instructors and conduct educational evaluation, while the practitioner implements the learning interventions in continuously evolving environments. This collaboration will ensure that the research builds closely from practice and would be relevant to the implementation. The practitioners would deepen and enhance their own practice by engaging in the research process. A research-practice partnership towards the design, implementation and evaluation of flipped approach could systematically provide answers to the questions arising from the meta-reviews.

Thus, the other goal of this paper is to discuss the interactions between the researcher team and the practitioners (which included a faculty instructor and 3 TAs). Based on our participative evaluation design, we present the outcomes of this flipped implementation in the form of observations of in-class engagement, learners' perception and learners' end semester scores. We have tried to reflect post-facto how we worked and what all can be improved in-terms of the flipped approach design as well as the collaboration. Based on the collaborative effort we have come up with guidelines at different levels and in terms of different aspects to be considered while taking a flipped approach to a course. As with any educational strategy, reports on evidence based flipped classroom practices will contribute towards a theoretical framework that may be able to answer the 'why' and 'how' questions about the strategy. Such research-based practices would benefit the primary stakeholders in the classroom - instructor as well as learners.

2. Related Work

2.1 Flipped Classroom

A flipped classroom has been defined as a combination of interactive group learning activities in the classroom, and computer-based instruction outside the class (Bishop & Verleger, 2013). This approach differs from the traditional approach, where most of the instruction is delivered in class and most of the learning activities are given to the students outside the class. While the traditional approach has historically been effective in disseminating large amounts of course content to a large audience, there is mounting evidence this approach does not necessarily promote a high level of learning or retention of knowledge (Borrego & Bernhard, 2011). Most of the in-class time is spent by the student listening to the instructor and taking notes. Instructors do spend time in higher order thinking activities like problem solving, discussions etc during class, but this can be done only after relevant content has been covered. Traditional lectures are not self-paced, and many students require more time to understand a particular concept. Flipping the classroom can mitigate the above difficulties to a large extent. Students engage with the basic concepts outside class at their own pace. Hence a lot of in-class time can be devoted to higher order thinking activities. Difficulties and misconceptions can also be addressed by the instructor in-class.

Studies reporting the flipped classroom approach are on the rise in the past few years (Giannakos et al, 2014). The flipped classroom approach has been used in school-level, undergraduate as well as graduate courses, covering a wide range of disciplines like Biology, Physics, Architecture, Computer Science, Electrical engineering, Mechanical Engineering, Clinical Nursing, Management, Pharmacy, English speaking, History, Mathematics and Sociology (Giannakos et al, 2014; O'Flaherty & Philips, 2015).

Most studies measure the learning gains and students' perception of the flipped classroom approach. Findings of a meta-study (O'Flaherty & Philips, 2015) suggest that the flipped classroom approach shows increased academic performance compared with historical controls. However, very few studies evaluated increase in students' higher order thinking skills, such as problem solving, inquiry and critical thinking. There is also limited published evidence on long term student learning outcomes. In another meta-study (Giannakos et al, 2014), the authors report that more than half of the studies analyzed suggest that students have positive attitudes toward the flipped classroom approach. Students especially liked that they could learn independently and at their own pace. The authors suggest that the active learning component of flipped classroom enabled students to remain at higher order levels of the Bloom's Taxonomy for longer durations of time, and hence students perceive that the quality of learning is better.

There are certain reported critiques of the flipped approach as well. The in-class component requires students be actively engaged and hence more accountable. This more active role is difficult for some students to adjust to (Bormann, 2014). In one of the studies (Mason, Shuman & Cook, 2013), based on student feedback, the authors conclude that this format might not work in a course with many new concepts because students would struggle to identify where to apply the various new concepts and equations. Also, students disliked video lectures and claimed that recorded lectures are not appropriate for more difficult course material (Giannakos et al, 2014). The flipped classroom approach may not be applicable to all subjects and also depends on the willingness of learners to adapt to the new format. The meta-study by O'Flaherty and Philips (2015) also states existing studies do not have robust evidence to show that the flipped classroom approach is more effective than conventional teaching methods.

2.2 Participative Design

Course instructors and educational researchers are members of different but related communities of practice (Goos, 2014). The members of the community working in isolation may not result in improvement of the practice. It becomes essential that they work together. While working together might seem as the solution, the relationship needs to be based on a partnership collaboration model. Participative design is the approach of design characterized by stakeholder involvement (Spinuzzi, 2005). Participative design draws on various research methods such as ethnographic observations, protocol analysis, interviews, and analysis of artifacts. These methods are used iteratively to construct the design, which is emerging. The design is then implemented on field after which the results are co-interpreted by the designer-researchers and the users of the design. Participative design is based on partnership with the stakeholders which needs to be iteratively conducted

There exists different models of researcher-practitioner partnership, in which practitioners: (i) either participate in research as objects of inquiry or (ii) work alongside researchers engaging in form of inquiry. In this paper we were working on designing a flipped approach towards the teaching-learning of post graduate electrical engineering course Solid State Devices, hence we look at the researcher-practitioner partnership engaging in a form of inquiry. PIVOTeeING started with design by the practitioner after which for the implementation and evaluation the practitioner partnered with the researcher. The aim of the evaluation is to feed back into the design.

3. Design and Implementation of PIVOTeeING

PIVOTeeING – Problem solvIng Via instructOr mediaTed peer learING - was designed for the course – Solid State and Devices. This is a compulsory (elective) course for the Master's (Ph.D.) program in the Microelectronics specialization within Electrical Engineering. It is expected that after going through the course student would be able to (i) judiciously choose devices for a design, (ii) verify device behavior experimentally, (iii) analyze different devices with different compositions, (iv) tweak existing device structure and composition to obtain a desirable behavior and (v) create a new device with certain specific desirable characteristics and behavior. At a broad level the design of PIVOTeeING is based on the general flipped classroom guidelines (Brame, 2013). For the in-class activities the instructor chose the active learning strategy of Peer-Instruction (Mazur, 1997).

The instructor had developed a set of learning objectives to achieve the course outcomes. The learners would need to solve solid state devices problem by reasoning: (i) mathematically, (ii) conceptually, (iiii) diagrammatically and (iv) connect the three of them. These objectives were crucial to the design of flipped approach as the in-class activities were designed based on these objectives. Similar to many flipped models, PIVOTeeING design also had pre-class, in-class and post-class elements. The pre-class element was asynchronous which would enable the learner to learn content in their own pace. During the class, students were involved in problem solving with peers, mediated by the instructor. At this phase they were also encouraged to view multiple representation (MR) such as mathematical equation and the corresponding band diagram. Fig. 1 explains the design in detail.

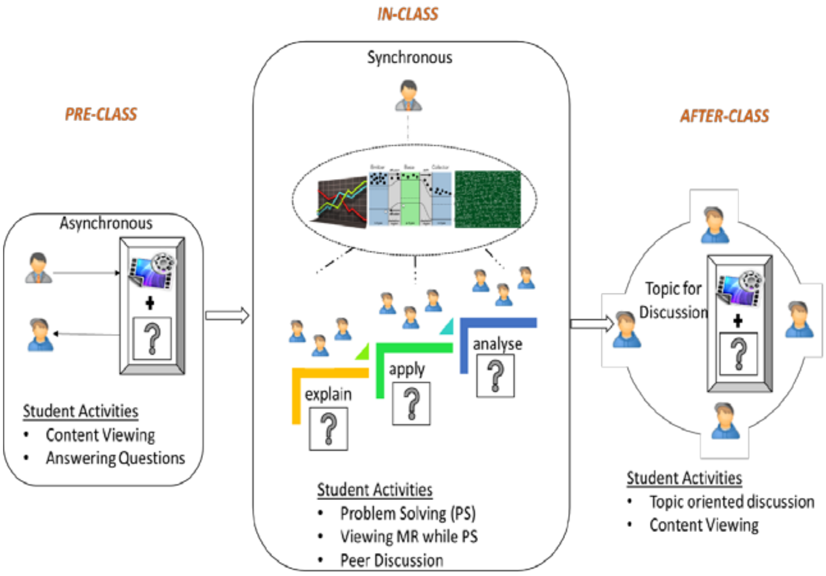

Figure 1. PIVOTeeING (Problem solvIng Via instructOr mediaTed peer learING): A flipped approach

3.1 Course Materials

For the pre-class phase, the instructor had prepared screen casts with audio narration. The presentations were uploaded on Moodle learning management system. All courses in our institute are run on Moodle, so the learners had experience using the platform. At the end of presentation, the instructor posed a problem, which the learners were required to solve before they came to class. All pre-class materials were made available on Moodle as well. Any course related announcements, in terms of quizzes or assignment submissions were also made on Moodle.

For the in-class activities, the instructor implemented a series of active learning and collaborative strategies. The most common activity was Peer Instruction (Mazur, 1997) in which the instructor posed a conceptual multiple choice question and students had to vote and re-vote after peer discussion. The questions started from explain level in Bloom's taxonomy and moved towards higher levels. An example of a question in Peer Instruction activity is:

"*The potential profile across a device is shown in the above graph. The total space charge inside the device is: a) Positive, b) Zero, c) Negative, d) Cannot be determined from the given information*"

At times, activities such as Think-Pair-Share were implemented, for questions that required deeper and longer reasoning. The instructor mediated the discussion and provided hints and additional information as required. All activities entailed learners to perform actions based on the learning objectives (Section 3). The instructor also posed an open-ended question at the end of class for the learners to explore post-class.

3.2 Interaction between Instructor and Researchers

The course instructor designed and implemented the flipped approach. The instructor had previously watched online lectures from the Educational Technology department in our institute, regarding active learning pedagogies. The videos had guidelines for practioners to implement the active learning pedagogies such as Think-Pair-Share and Peer Instruction. Based on the guidelines the instructor along with the course Teaching Assistants prepared a multiple-choice question bank for the whole course. The options for each multiple choice question were carefully designed to explore all the solution paths and scenarios. The instructor created peer instruction activity for the learners based on the questions.

While the instructor implemented the flipped design in-class, the research team performed in-class observations to capture the learner engagement during the activities. The research team used a previously validated observation protocol (Kothiyal et al, 2013) to observe in-class learner engagement. The observation protocol had a list of engaged on-task, engaged off-task and completely disengaged behaviors. A team of five researchers were present in-class for observations. Each of the researcher observed 10 randomly picked students throughout for 2 classes.

The instructor had also prepared formative quizzes to understand the performance of learners. The formative quizzes were administered for 30 minutes after class. While evaluating the quizzes, the research team initially found that learners were not in line with the expected solution. In the words of the instructor – "It appears that the quizzes were far too tough". The detailed analysis of the quizzes revealed that they did not provide explicit mechanisms for learners to apply what they had practiced in class. So the research team suggested alignment of quiz questions to activities in class, especially for activities at the Analyze and Evaluate levels. The instructor adopted the suggestions during preparation of the end-semester exam, which was then evaluated by the instructor, TAs and the research team.

4. Research Methodology

PIVOTeeING was a collaboration of partnership between the two communities of practice (Electrical Engineering educators and Educational Technology researchers) existing within our institute. The teams partnered to systematically design, implement and evaluate the flipped approach. We worked in the framework of Design Based Implementation Research (DBIR). DBIR applies design-based perspectives and methods to address and study problems of implementation (Fishman et al, 2013). The core principles of DBIR are: (1) a focus on persistent problems of practice from multiple stakeholders' perspectives; (2) a commitment to iterative, collaborative design; (3) a concern with developing theory and knowledge related to both classroom learning and implementation through systematic inquiry; and (4) a concern with developing capacity for sustaining change in systems. This paper reports the first cycle of the DBIR implementation.

4.1 Research Questions

We took an explorative approach to examine various aspects of the effect of the flipped classroom. Since learners are the primary stakeholders we first examined the impact on the learners such as affect and learning outcome. The RQs related to the learners are:

RQ1: How did the implementation of PIVOTeeING impact learners' affective parameters such as engagement and perception?

1.1. How engaged are the learners during in-class activities?
1.2. What is the learner perception about various design elements of the course?

RQ2: How did the learners perform in the end semester exam with respect to the learning objectives?

The other goal of this paper is to evaluate the design of PIVOTeeING and provide guidelines to the practitioners via a researcher- practitioner partnership. The RQ related to this objective are:

RQ3: What changes are required for the design, implementation and evaluation of PIVOTeeING flipped approach?

4.2 Participants

The class consisted of a total of 58 students. Among these students there were 2 cohorts, the postgraduate and doctoral students. Among the 58 students only 36 agreed to participate in the study. However, only 32 of the 36 students appeared for the end semester examination. All of the students were from the electrical engineering background with a basic exposure to solid state device course.

4.3 Instruments

4.3.1 Observation Protocol

The in-class activities of PIVOTeeING aimed at learners working at higher order levels in Bloom's taxonomy. The assumption here is that by doing so the learners would be actively engaged with the content of the course for most of the time in-class. To measure the in-class engagement, we used the real-time observation protocol for learner engagement behaviours by Kothiyal et al (2013). Since the instrument was already validated in previous studies, we checked the reliability of the observations. The research team had five observers. All of the observers picked a set of same 10 students in the class and performed observations throughout the class. The team observed each student for 10 seconds. In the first round of observations, there was only 36% agreeability, as there was no synchronization in the observation timing. For the next round, the team synchronized the observation timing by reducing the observation timing to 5 seconds and recording only the dominant behavior. After the second round of observations there was agreement of 81%.

4.3.2 Rubrics for End-semester Exam

The end semester exam had 3 questions which were evaluated at two levels. The first round of evaluation was done by the TAs. The second round of solution analysis was done by the research team. This evaluation was more fine-grained and the intention was to look at how much learners were able to achieve the learning objectives (Section 3). A six criteria rubric with 3 scales was developed by the research team. These criteria were: C1 – Application of appropriate concepts of semiconductor devices, C2 – Identification of mathematical construct to solve the problem, C3 – Appropriate linkage between semiconductor concepts and mathematical constructs, C4 & C5 – construction of relevant diagrams, C6 – Linkage between concept, mathematical concept and diagram to devise solution.

The rubric was checked for content validity by checking alignment with the learning objectives and in-class activities. To ensure reliability of scoring using the rubric, two iterations of independent evaluation was done for 6 student answers. Cohen's Kappa was calculated for each criteria in the rubric: $kappa_1$= 0.66, $kappa_2$= 1.0, $kappa_3$= 1.0, $kappa_4$=1.0, $kappa_5$= 1.0, $kappa_6$= 0.64.

4.4 Data Analysis

The data analysis involved use of mixed methods. To answer RQ 1.1, quantitative methods such as aggregating the behaviors and scores was used. RQs 1.2 and 3 were answered using thematic analysis of two focus interviews. Focus group interviews were conducted for two cohorts of learners - one being post graduate students and the other being PhD students. The interviews were transcribed and two researchers independently coded the transcripts to elicit themes. The transcripts were analyzed using the guidelines provided by Clarke and Braun (Clarke and Braun, 2014). After the initial coding, the researchers compared their codes and categories, thereby refining them considerably in the process. The discussion also helped in reviewing the emergent themes. Fig. 5 (Section 5.2) summarizes the main themes, sub-themes and categories that emerged from the focus group interview data. Table 1 summarizes for each RQ (Section 4.2), the data sources, instruments and data analysis methods used.

Table 1: Research Questions - Method – Analysis

RQs	Data Source	Instrument	Data Analysis
RQ1.1	In-class student behaviors	Observation protocol	Analyze engaged behaviors, aggregate the behaviors and compare engaged and non-engaged behaviors
RQ1.2	Transcript of focus group interview (FGI) with 2 cohorts of learners	-	Thematic analysis of the FGI transcript
RQ2	End semester exam answers	End semester evaluation rubric	Rubric based evaluation
RQ3	End semester exam answers and transcript of FGI		Rubric based evaluation and thematic analysis of the FGI transcript

5. Results

5.1 Student in-class Engagement

The student engagement overall in class is presented in Fig. 2. From the engagement behaviour distribution, we see that apart from 15% of reading instructor presentation, the students are actively engaged with the content. Fig. 3 presents the engagement across the activities in one class. From the bar graph we see that for more than 65% of the class time (90 mins) learners were engaged with the content.

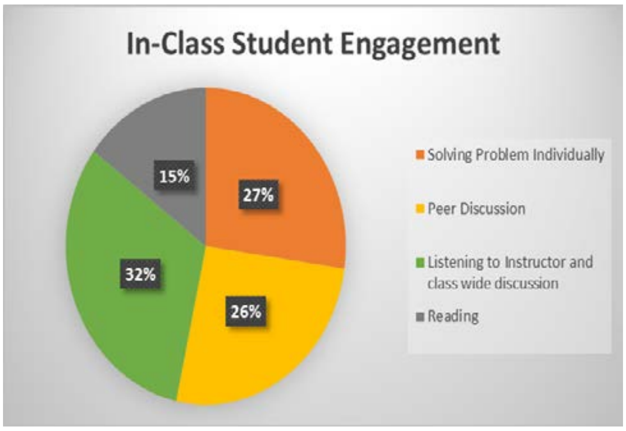

Figure 2. Overall In-class Engagement

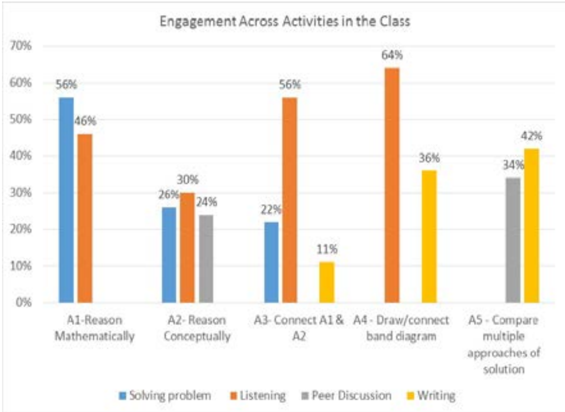

Figure 3. In-class engagement across activities

5.2 Student Perception of Course Material and Learning Strategy

Analysis of the two focus group interviews reveal 2 major themes with 6 key sub-themes. The student related themes covers sub themes such as student needs, challenges and how they learn (Fig. 4). The other major theme was related to the course which covers sub-themes of perception about course content, benefits of course format and problems in course format (Fig. 5).

5.3 Achievement of Learning Objectives

Using the rubric, the end semester answers were evaluated (N=26). The end semester exam had three questions based on different devices Junction field-effect transistor -JFET (Q1), N metal-oxide-semiconductor field-effect transistor - NMOSFET (Q2) and PNP Bipolar Transistor (Q3). Q1 and Q2 had scaffolds (references to in-class activities) to answer the question whereas Q3 did not have any scaffolds. The rubric criteria applicable to all questions were C1, C2, C3 and C6. C4 and C5 were only applicable to Q2. Fig. 6 compares applicable criteria (C1, C2, C3, and C6) across the three questions. It is seen that across the criteria C1 and C2 the learners have performed well in Q1 (device JFET). It is to be pointed out that JFET as a device was not separately discussed in class. However, when students had to answer questions related to this device in the end semester exam, they had to synthesize from multiple concepts covered in class. In the answers for Q2 with regards to the criteria C4 and C5, only 15% (4) have performed well in both.

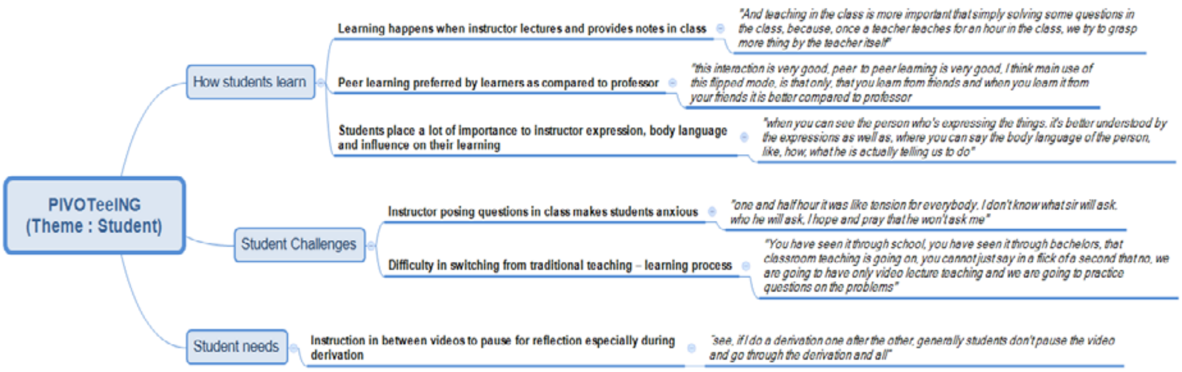

Figure 4. Student related themes from FGI

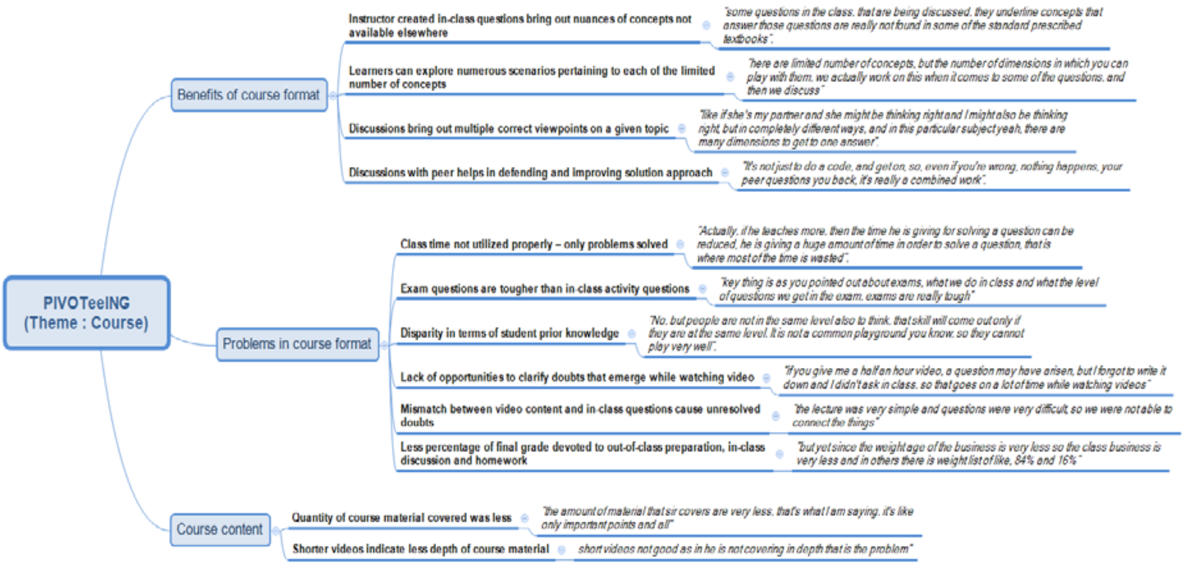

Figure 5. Course related themes from FGI

6. Discussion and Conclusion

Research questions pertaining to engagement (RQ1.1) are answered by the pie-chart depicting 'overall student engagement' and bar graph of 'engagement behaviors across activities' (Figs. 3 and 4). The students were engaged with the content more than 65 % of the class time. From the two charts we see that across the activities, students were mostly engaged in solving problem/questions individually and listening. Since most of the dominant behaviors were of writing and listening, in-class questions could include more scaffolds for peer discussion for focused discussion.

With regards to learner performance (RQ2), more than 60% of learners were able to achieve target level of concept identification and satisfactory level of mathematical construct recall for solution in the context of JFET and NMOSFET than PNP Bipolar transistor. 50 % of learners are able to achieve satisfactory level of establishing link of mathematical construct and concept for JFET. This result may indicate transfer of learning, as JFET as a concept was not explicitly handled in class. Additionally the question with JFET and NMOSFET had scaffolds (reference to in-class activities) to answer the question whereas the PNP Bipolar transistor question did not have scaffolds. This seems to indicate that if the questions had sufficient scaffolds learners are able to apply their learning to an unknown concept. So PIVOTeeING has been able to achieve near transfer.

The design of PIVOTeeING included elements of course format, course material and evaluation. The themes related to student perception (RQ1.2) that emerged in the analysis of focus group interviews corresponded to these elements. Students perceived that while the problem solving approach and Peer Instruction activity were useful in exposing them to concepts with multiple viewpoints, they would like to have a largely lecture driven format. The reasons for this preference seem to stem from the deeply embedded bias for the traditional teaching format with a visible reluctance to embrace a new pedagogical format. Lack of opportunities for doubt clarification and mismatch between out-of-class and in-class activity seems to have added to student discomfort with the format. The unavailability of opportunities to bridge out-of-class and in-class content led to the student belief that short videos lacked depth. Students also felt that there was a disproportionately lesser allocation of marks for class quiz, homework and discussions, considering the effort that went towards them.

The themes of student needs, problems in course format, course content, how student learn, and student challenges, bring out the discomfort of the students about the different aspects of the PIVOTeeING method. Based on this, we have come up with guidelines (Table 2) to be applied for design and implementation of PIVOTeeING flipped approach. These guidelines will be carefully included in the design of PIVOTeeING for the second cycle of DBIR.

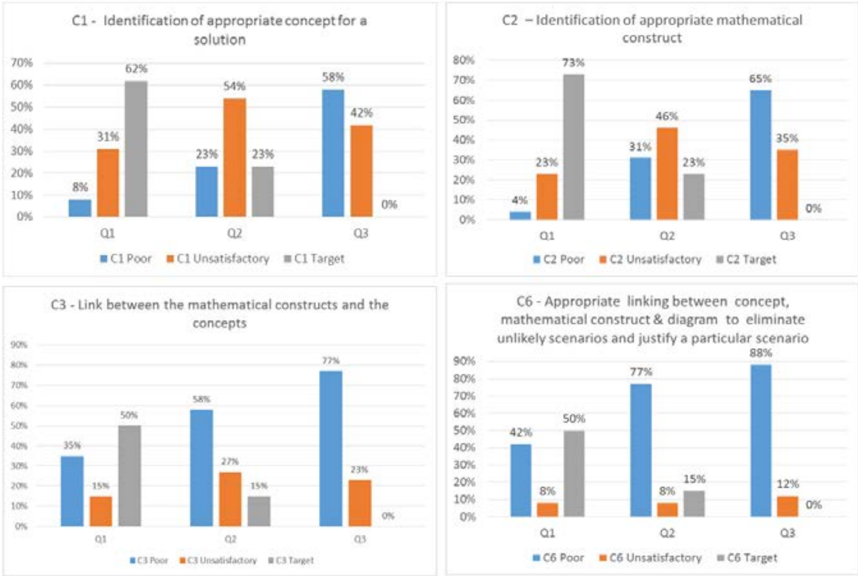

Figure 6. Comparison of Criteria C1, C2, C3 and C6 across the 3 questions

This study contains certain limitations. First, the RQ related to learning performance (RQ2) was a post-test only design. This design is known to be weak, and is at best indicative of the potential of the intervention. We were able to obtain such indications from the current study, however, a stronger research design is required to make claims of student performance from the PIVOTeeING flipped approach. Second, the observation protocol that was used to measure in-class student engagement (RQ1.1) needs to be refined. Since we adapted the instrument used in a different context (Kothiyal et al, 2014), it needs to be contextualized to certain activities specific in PIVOTeeING. For example, during in-class activities such as 'reading', we were not able to decode whether there is active engagement or not. Third, the implementation of the observation protocol was time and labor intensive, hence it limits scaling, especially in large classes. Since this first implementation was primarily an exploratory approach, we plan to use the insights from this cycle to systematically carry out an evaluation study in the next cycle. Third, there was a lack of measurement of learners' performance in pre-class. We gathered insight about the learners' video content viewing and learning time through a self-reported survey, but it does not directly indicate the pre-class learning performance.

Table 2: Guidelines for implementing PIVOTeeING flipped approach

Design Element	Guidelines for flipped approach
Pre –Class Activities	• Create videos carefully with appropriate reflection spots, learning by doing activities and self-assessment quizzes • Incorporate formative feedback to learners during the pre-class activities • Provide platform to let learners discuss the doubts/queries in the video • Moderate the discussion platform for learner's problems/misconceptions
Bridge Activities	• Create bridge activities in pre-class for learners to link to the in class activities • Summarize pre-class activities or conduct Q/A for pre-class activities • Create a focus question or problem on the class activities for post-class discussion • Provide platform to let learners discuss the focus question/problem post-class • Moderate the discussion for learner's problems/misconceptions

A contribution of this study is the implementation and evaluation of a flipped approach in post graduate engineering course using a participatory design approach. For practitioners who wish to implement a flipped approach, in addition to recommendations in Table 2, there are additional important recommendations related to affect: (i) get student buy-in, particularly for the non-traditional aspects of learning within a flipped class, (ii) seek training on aspects of implementation that you may not be familiar with– both technological (for ex creation of videos) and pedagogical (for ex conducting

PI) and (iii) be prepared to do two or more implementations before you start seeing results. Table 2 along with the affect related guidelines provide a practice based guideline for implementation of flipped classroom in electrical engineering domain via the participatory design framework. Finally further cycles' implementation and evaluation would lead to the development of a framework to guide a practitioner to systematically flip any course.

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