Designing and Evaluating a Flipped Digital Circuits Course

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***Abstract*—The progression of pedagogical blueprints in engineering education has led to the advocacy of innovative slants targeted at intensifying learner's engagement, comprehension and performance. One such strategy is the Flipped Classroom Model (FCM), which upends didactic approach/formal teaching methods by rendering instructional theme outside of class and making use of classroom time for interactive, active/collaborative learning, and application-based activities. Although flipped mode of learning is widely embraced, evidence unique to Digital Circuits course remains limited. This paper presents the design, implementation and evaluation of a flipped Digital Circuits course with a mixed strategies design involving pre-class micro content, in-class problem-based activities & post-class unification tasks. It encompasses a comprehensive review of existing literature, outlines the course design process, assesses learner's performance and perceptions, and discusses the implications for engineering education. The quantitative analysis collated DFW grades, distribution of grades over two academic years, whereas quantitative data is gathered from learner's perceptions. The results show substantial improvement in attainment of high grades, pass rate & student motivation, supported by the in-class activities. The education with entertainment named as Edutainment is the element given as a response by majority of the learners in feedback for flipped classroom model provides evidence for enjoyable epiphany.**

***Keywords*— Flipped Classroom Model (FCM), Digital Circuits, Didactic approach, Edutainment, Active/Collaborative Learning**

***ICTIEE* Track— Innovative Pedagogies and Active Learning**
ICTIEE Sub-Track— Use of Technology in Teaching and Learning

I. INTRODUCTION

In the transient landscape of engineering education, formal teaching methods are increasingly being supplemented or superseded by learner centric strategies that spotlight active/ collaborative learning, engagement and satisfaction. The digital circuits course, a fundamental and core component in electronics and communication engineering program, presents unique challenges due to its complex and abstract concepts and the necessity for collaborative problem solving and hands-on experience. To direct the study on designing and evaluating a flipped digital circuits course, the main research question was formulated as: "How does a structured FCM based digital circuits course influence conceptual understanding, in-class learner engagement, problem solving ability and learning experience compared to traditional lecture-based model?"

The research objectives (RO) are presented as:

RO1: To design a structured FCM framework tailored to digital circuits course including pre-class learning handouts, in-class problem solving tasks & post class assessments.

RO2: To evaluate the quantitative impact of FCM on DFW rating, distribution of grades and performance of students.

RO3: To examine learner perceptions regarding the flipped format, learning handouts, and instructional design through qualitative feedback.

RO4: To compare learning outcomes between FCM and traditional lecture-based model.

The flipped classroom model reapportions the delivery of content to pre-class activities, regularly through video lectures or handout(reading assignment), thereby making the class time to be effectively used for interactive sessions by providing case studies for learners to exchange their views/ideas, problem solving exercises and collaborative projects. The FCM offers a promising substitute by shifting passive learning to active engagement there by making the learners initially introduced to the content prior to the class and concentrate on deep understanding of the content during the class time, where they will get support and feedback from the instructor/facilitator and peers. This signifies that the activities intriguing higher levels of Bloom's taxonomy for the cognitive domain such as applying, analyzing and evaluating are performed in the class, making the lower-level cognitive tasks moved out of the class time (Ruan, L, 2023). The table I specifies the comparison of traditional/instructional teaching and FCM. The key reason for the engineering educators shows much interest in flipped classroom is due to preserving the content delivery through online videos and usage of handouts. The learners have the flexibility to hold, rewind and review the video content, makes them engage with the handout independently. Once the learners come to the class they are equipped with hands-on work or solving problems in individual or in a team benefiting them by virtue of learn by doing. FCM changes the attention and allocation of instructor time towards learners. Conventionally, the instructor engages with the one who pose questions, but this FCM makes it possible to focus on who don't pose the questions and equips attention to "*silent smarters*", referring to focusing on whom the most need help from the instructor rather than the most confident learners which quantify the philosophy or spirit behind flip.

TABLE I
COMPARISON OF TRADITIONAL/INSTRUCTIONAL TEACHING AND FCM

Teaching Style	In-class	Out-of-class
Traditional/ Instructional Teaching	• Passive learning (listen to lectures) • Individual activity • Lower forms of cognitive work	• Problem solving after class • Individual activity • Higher level cognitive load
FCM	• Problem solving during class • Group activity (support from instructors and peers) • Higher forms of cognitive work	• Watch video lectures or reading handout (prior to class) • Individual activity • Lower-level cognitive load

The major purpose of this paper is to analyze and show the effectiveness in flipping forty percent of the digital circuits course content. The table II specifies the comparison between formal teaching and flipped classroom in map with blooms taxonomy levels.

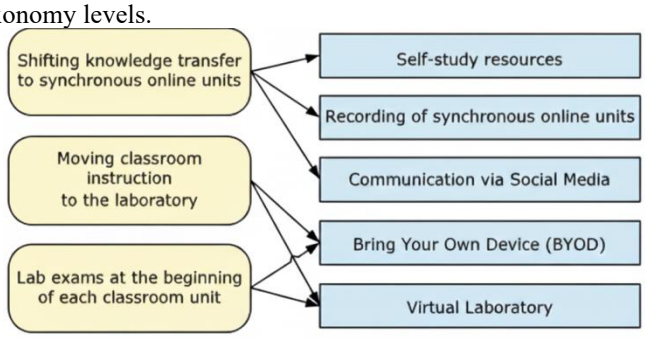

Fig.1. Transfiguration move towards an FCM

This study makes use of ASSURE instructional design model shown in figure 1, is a systematic framework designed in order to achieve the goal of producing effective teaching and learning. ***(ASSURE:*** ***A****nalyze learners,* ***S****tate objectives,* ***S****elect methods/media/materials,* ***U****tilize media/materials,* ***R****equire learner participation,* ***E****valuate & revise*).

TABLE II
COMPARISON OF FORMAL TEACHING AND FLIPPED CLASSROOM IN MAP WITH BLOOMS TAXONOMY

Blooms Taxonomy level (Level of learning)	Formal classroom	Flipped classroom
Remembering	face-to-face lecture	Watch video lectures or reading handouts independently
Understanding	Teacher to student discussion (Question and Answer)	Active/collaborative learning, reflection, peer to peer discussion
Analyzing	Solving problems as home work	In class activities such as problem solving through group discussion
Applying, Evaluating, Creating	Homework or Nothing	Collaborative projects, presentations, evaluations by peer &instructor

This model helped to effective plan and implement flipped classroom learning to improve student involvement in learning, comprehension and satisfaction. This paper describes the flipped classroom model that is implemented for Digital Circuits course of Electronics and Communication Engineering (ECE) department for II Year B.Tech students at Anurag University. The structure of the paper is as follows: Section II discusses the background knowledge and research of FCM. Section III describes the design and implementation of flipped classroom approach in a digital circuits course. Section IV discusses the evaluation norms and results of the work. Finally, Section V specifies the conclusion.

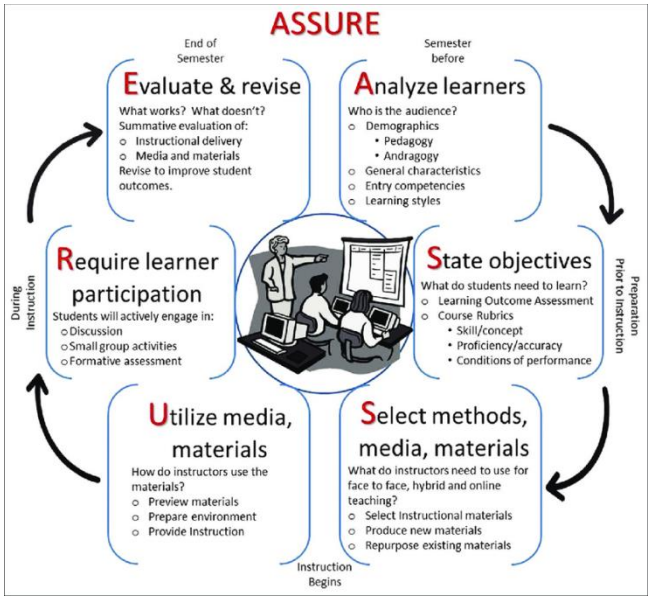

Fig. 2. ASSURE Instructional Design Model

II. BACKGROUND KNOWLEDGE AND RESEARCH

The flipped class room has progressed as a technology assisted pedagogy rooted from the principles of constructivist & active learning. Technology plays an important role in improving student engagement and comprehension (Wang and Zhu 2019).

Research zeniths the framework of online platforms, engaged tasks, gamification & spirit of collaboration in amplifying the conceptual understanding. Flipped classroom, a vibrant and collaborative learning platform is the major component of technology integration in engineering education. Numerous studies on FCM have been published related to various academic fields which includes: analysis of the tools and technologies used to support teaching and learning, identifying the pedagogical tasks/activities in order to improve the effectiveness of flipped classrooms and addressing the challenges faced during the phase of design and implementation of flipped classrooms in engineering education and how to overcome them. The literature review is performed focused on the following points:

a) The various technologies or tools that are used in the FCM which supports teaching and learning. (Table III)
b) The various pedagogical activities that make the FCM more effective. (Table IV)
c) The impact of FCM on learner's achievement, interaction and motivation. (Table V)
d) The various challenges of practicing FCM.

Even though the technological tools are important in the FCM practice, the instructor should focus without ignoring the factors which directly influences the learner's effective/productive learning such as learner's interaction, motivation, and engagement. The teaching strategy of instructor must be in a flow, such that it will always be in synchronous with the learning styles of the learners.

TABLE III

VARIOUS TECHNOLOGIES OR TOOLS USED IN FCM

Source/Reference (Author, Year)	Technologies or Tools
Ng and Lo (2022), Sevillano-Monje et al. (2022), Zhao et al. (2021), Davies (2013), Wang and Zhu (2019),	YouTube, Screen cast, Echo360 classroom Capture, Camtasia Studio, MyIT Lab videos and software simulation
Torio (2019), Sevillano-Monje et al. (2022), Mortaza Mardiha et al. (2023), Roach (2014), Hung (2015)	Clickers, Web Quest, Kahoot, Edpuzzle, Instant response, Microsoft PowerPoint, Blogs and Wikis
Mortaza Mardiha et al. (2023), Ng and Lo (2022), Kim et al. (2014), McLaughlin et al. (2013)	Moodle, Blackboard LMS, Google Docs, Integrated Learning Accelerator Modules (ILAM), Drop box, Big Blue Button, Google hangout

TABLE IV
VARIOUS PEDAGOGICAL ACTIVITIES USED IN FCM

Source/Reference (Author, Year)	Pedagogical activities
Zou et al. (2020), Mortaza Mardiha et al. (2023), Ng and Lo (2022), Sevillano-Monje et al. (2022), Zhao et al. (2020), Wang and Zhu (2019), Li and Li (2022), Khan and Abdou (2021), Yildiz, E et al.(2022), Reddy, P. L et al. (2025)	Gamification competitions, Quizzes, problem solving exercises, discussions among peers, worksheet exercises, half solved problems, mind map construction, 3-2-1 reflection sheet (3 key learning's, 2 questions and 1 application), fill up the blanks, match the following exercises, simulation-based problem solving, Jumbled code, Odd one out of the choices given for a question, problem solving through group discussion.

The various challenges encountered in practicing of flipped classroom approach specified by various authors includes spending more time on writing content/video making so as to motivate the learners to read the handout or to watch the video lecture, lack of technological resources by the instructor and learners, lack of guidance for learners out of the class, adoption of FCM.

TABLE V
IMPACT OF FCM ON LEARNER'S ACHIEVEMENT, INTERACTION AND MOTIVATION

Source/Reference (Author, Year)	Impact of FCM
Enfield (2013), Talley and Scherer (2013), Pulluri, H. (2025)	*Learners Achievement:* Productive in helping learners to learn the content of learning, Mind map construction of concepts by the learners by critically analyzing the facts behind the laws, Improvement in grades compared to previous semester without FCM approach.
Mortaza Mardiha et al. (2023), Ng and Lo (2022), Reddy, P. L et al. (2025)	*Learners Interaction:* Collaborative spirit shows by the learners in problem solving through group discussion, interactive learning, Engaging in discussions, building a learning ecosystem to exchange thoughts to solve problems and networking in and out of the class.
Kim et al. (2014), Davies et al.(2013)	*Learners Motivation:* Self-exploring of the concepts other than the learning materials provided by the instructor, expressing views on solving the problems by the learners without any fear or favor, Independent learning motivated to work/learn at their own pace.

III. COURSE MECHANICS AND METHODOLOGY

The flipped classroom teaching model is used in a bachelor's level course during the fall 2024. The study was conducted with 72 second year B.Tech students enrolled in the *Digital Circuits* course during the academic year 2024-25 and it is offered as a professional core course in ECE program at Anurag University. Comparative data from previous cohort (N=72, Academic Year 2023-24) taught under a traditional lecture model. The learning objectives of the course are related to design and analyze various combinational circuits, sequential circuits, finite state machines and its Verilog representation. The course evaluation is done via Continuous Internal Evaluation (CIE) for 30 Marks, Assignments for 20 Marks and Semester End Examination (SEE) for 50 Marks. The course contains 40 lectures among which 10 were organized in flipped classroom model. The connectivity concepts are flipped so as to make the students to work individually out of the class and come to the class hours to work collaboratively on the assignments. The flavor of FCM that is implemented in the class is based on the spirit of *knowledge transfer*, which is carried through usage of various technologies and tools, supplemented by online discussion forums and *deepening of knowledge* rooted through making use of class instruction focusing on the application perspective of the already self-learned topic. The spirit behind making use of FCM as a part of teaching and learning for this course is based on the definition given by the Flipped Learning Network (FLN), which conveys that FCM replaces the direct delivery of content to a team space by creating an individual learning space, making the team space transformed into a dynamic, collaborative learning ecosystem where the instructor serves as a facilitator making the learners apply the concepts and engage inventively in the subject professional.

The FCM for the mentioned course is carried out in three phases.

First Phase (Pre-class):

Knowledge Acquisition: Provide learners with handouts or videos to engage with prior to the class which are accessed by the learners through the Learning Management System (LMS) of Anurag University by name AUPULSE.

Second Phase (In-class):

Active & Collaborative Learning: Connect the out-of-class learning to in-class tasks. The in-class norm should be steadfast to problem-solving, skill development, active learning, collaborative learning, networking between what has formerly been learned.

Third Phase (Post-class):

Consolidation: Tasks or resources that congeal what has been learned previously and/or extra scope to practice or expand knowledge. The formative assessment on both the individual & team learning gains

The first phase focuses on the selection of the concept/topic to be flipped, clearly specifying the learning objective and providing of learning materials (handouts, short online video lectures). The second phase focuses on the conduct of in class activities & the third phase assessing the learning spirit of the learners. The success rate of FCM purely depends on the design and delivery of the classroom activities.

Regarding first phase of FCM design and implementation, the suitability of the topic to be flipped is chosen based on *connectivity*, which means that a major topic in the course dealt by the instructor in a direct delivery norm, has many interconnecting sub topics, those are flipped so as to make the

students to work individually out of the class with a little prior knowledge and come to the class hours to work collaboratively on the assignments which are dealt in an application norm of the self-learning topics. This obviously brings attention and relevance of what they are supposed to learn at a self-space rather than in a group space. The relevant handout of the topic(s) will be provided by the instructor stating the learning objective and the videos of the topic. In spite of the assertion that "flipped class is not entirely about the videos," it is necessary and vital to provide a source of means for learners to get the coequal of traditional lectures out of the class for the purpose of making the class time utilized for active and collaborative learning. Regarding second phase of FCM design and implementation, various in-class activities/assignments are picked based on the topic/content which is flipped which suits to enhance the spirit of interaction and engagement among the learners. The few such are Problem Solving through Group Discussion (PSGD), mind map construction of the topic, 3-2-1 reflection sheet (specifying 3 key learning's, 2 questions and 1 application of the flipped topic), Jumbled code, Odd one out of the choices given for a question, half solved problems, worksheet exercises etc. Regarding third phase of FCM design and implementation, the assessment for few in-class activities/assignments needs to be done based on framing the rubrics with specific criteria to be assessing the learning spirit of both the individual and team performances. A space for making the learners to think beyond the topic in an application perspective needs to be done by the instructor by briefing a real-world scenario to relate the topic learned through flipped mode which deepens the knowledge & makes the learners to enhance critical thinking skills.

Instructional Design

The FCM intervention followed the ASSURE model.

1. Pre-class: Learning handouts, short lecture videos and guiding questions
2. In-class: Problem solving through group discussion, peer instruction, poll quizzes and reflections.
3. Post-class: Consolidation exercises and rubric based evaluation

Validation Metrics & Statistical Analysis

1. DFW rate comparison across cohorts
2. Grade band analysis (A/B/C vs D/F/W)
3. Qualitative thematic review of feedback

The equivalence of content, stability in assessment and cohort preparedness were critically examined. The format of questions and rubrics for evaluation were made identical over the years to minimize bias.

The one such implemented scenario of FCM at Anurag University in the department of Electronics and Communication Engineering program is shown below:

Topic/Concept Minimization of Switching functions using Karnaugh (K) Maps.

Students have already learnt how to represent the switching functions either in SOP or POS using K-Maps. With the current concept, students will be able to apply the same on how to simplify Boolean expression by grouping the min terms or max terms & realize the same using logic gates. This quantifies the suitability of flipped mode.

Learning Objective

At the end of the class/session, the students can be able to:

Simplify a Boolean Expression represented either in Sum of Product (SOP) or Product of Sum (POS) using K-Maps & realize the same using logic gates.

Learning Material

The students are advised to go through the handout prepared by the instructor & observe on how to simplify a Boolean function using K-Maps. Page 2 quantifies the minimization process using K-map & Pages 3 to 6 quantifies the representations and grouping mechanisms in K-map.

https://drive.google.com/file/d/1LYaQ9zcqGB2KqeLK-Jq5cqajC0I_qDfC/view?usp=sharing

The students are advised to go through the video lecture: https://youtu.be/V9PTbe9cz7o?si=erI3IWlR86KD6biB

At 9:40 time stamp, the introduction to K-Map is covered. At 17:45 time stamp, the representation of K-Maps is specified both in SOP & POS forms. At 23:00 time stamp, how the grouping of terms needs to be done in order to simplify a Boolean expression is clearly stated with examples.

A discussion forum is opened for the students through WhatsApp group to clarify doubts on the concept before the flipped class.

Instructions for in-class activity

The duration of the class is 55 minutes & the in-class activities are performed as follows:

1. Initially, a mini quiz (Individual activity- 2 Minutes) will be conducted to bring attention & confidence among the students to do team activity.
2. A micro lecture (5 Minutes) by any one student will be planned to specify the concept at glance.
3. Choice will be given to students for in-class activities, which really allows the learners to play their strengths of learning. The students can choose either a set of questions to solve (4 problems) based on both SOP & POS forms to simply using K-maps & realize the same using logic gates. The set of questions include half solved problems, LHS=RHS prove based problems, linking based questions, test case-based questions or can write a small report on the topics learnt clearly explaining the procedure with examples. (Reddy, P. L, 2025) (20 minutes)
4. While the in-class activities are under execution, the instructor moves around the class and communicates with the students if necessary.
5. Feedback is taken from the students through a Google form regarding the flipped mode dealing of class (1Minute).
6. The feedback questionnaire includes:
   a) Have you enjoyed the flipped classroom attire?
   b) Did the pre-class, in-class and post-class things are aligned to enhance your learning spirit & deepening knowledge of the concept?
   c) Is the learning material & videos useful for the clear understanding of the concept?
   d) Do you feel to have such strategy of approach for other courses?
   e) Any other information.
7. A buffer of 7 minutes is allocated for cover up any deviations in class activities. The assessment of the same will be

evaluated team wise for 10 Marks based on the rubrics sheet shown in table VI. (20 Minutes)

TABLE VI
RUBRICS FOR ASSESSING THE IN-CLASS ACTIVITY

Criteria	Exemplary (5M)	Satisfactory (3M)	Needs Improvement (1M)
Analysis of the problem (5M)	The problem is clearly stated & proper k-map is used to solve the Boolean function	The problem is clearly stated & fails to group the terms using K-map	The problem is not clearly stated and fails to solve the same using K-map.
Realization of the circuit using logic gates (5M)	Simplified Boolean function is well realized.	Simplified Boolean function is partially realized.	Simplified Boolean function is not well realized.

IV. RESULTS AND DISCUSSIONS

Both the qualitative and quantitative assessment strategies were considered in this FCM. The theme of quantitative assessment incorporates a collation of final grades in the flipped version of the class to average grading of class and pass rates in prior offerings of the same course in traditional norm. The average pass rate and improvement is shown in table VII.

TABLE VII
AVERAGE PASS RATE AND IMPROVEMENT

Course Name & Code	Traditional classroom Academic Year: (2023-2024)	Flipped classroom Academic Year: (2024-2025)	Improvement
Digital Circuits (A54006)	No. of students Passed: 50 69.4%	No. of students Passed: 58 80.6%	11.2%

The DFW and Non-DFW grades are used as a metrics to specify the efficacy of FCM mode of instruction delivery to traditional mode of instruction delivery. DFW grades indicate the poor performance or non-completion of the course, where as Non-DFW grades indicate the successful completion of the course.

TABLE VIII
DFW AND NON-DFW GRADE COMPARISON

Grade	Traditional classroom Academic Year: (2023-2024)	Traditional classroom Academic Year: (2023-2024) %	Flipped classroom Academic Year: (2024-2025)	Flipped classroom Academic Year: (2024-2025) %
A	10	13.89	16	22.22
B	18	25	22	30.56
C	22	30.56	20	27.78
D	8	11.11	6	8.33
F	8	11.11	4	5.56
W	6	8.33	4	5.56

From the table VIII of results, the following are the conclusions:

1. Traditional classroom:
DFW Grades (D+F+W): 22 student's → 30.6%
Non-DFW Grades (A+B+C): 50 student's → 69.4%
2. Flipped classroom:
DFW Grades (D+F+W): 14 student's → 19.4%
Non-DFW Grades (A+B+C): 58 student's → 80.6%
3. FCM approach reduced the DFW rate from 30.6% to 19.4%, while increasing higher grades (A & B).
4. Differences are strongest in A (13.89% → 22.2%) and F (11.11% → 5.56%)

TABLE IX
FEEDBACK RESPONSES FROM THE STUDENTS

Questions	Agree	Neutral	Disagree
Have you enjoyed the flipped classroom attire?	94%	6%	-
Did the pre-class, in-class and post-class things are aligned to enhance your learning spirit & deepening knowledge of the concept?	72%	17%	11%
Is the learning material & videos are useful for the clear understanding of the concept?	92%	8%	-
Do you feel to have such strategy of approach for other courses?	52%	38%	10%

Quantitative findings

a) DFW rate reduced from 30.6% to 19.4%
b) Increase in A/B grades indicates improvement in higher order competency.
c) Pass rate rose by 11.2%, specifying performance gains under FCM

Quantitative findings

Learners appreciated the clarity of pre-class learning handouts, the collaborative spirit of in-class activities and boosted confidence in understanding & applying concepts.

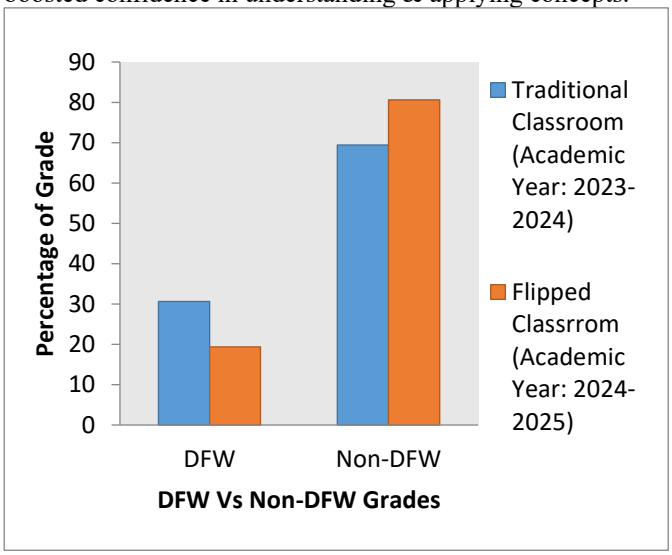

Fig. 3. DFW and Non-DFW grades comparison with Traditional classroom and FCM

FCM in Digital Circuits lowered the DFW rate shows a clear improvement in student success and more students achieved A and B grades, while failures and withdrawals dropped notably. This shows that active learning strategies in a flipped class benefit both performance and retention. Overall, the flipped approach appears more effective than traditional classroom instruction. The qualitative assessment is done by sharing a Google form questionnaire shared to get the perceptions of the learners regarding the FCM approach, shown in table IX. The learners have expressed few constraints regarding increasing the class duration for flipped classroom, so as to make them feel ample time given for solving the problems, more weight of marks to be allocated for this approach so as to appreciate the cognitive load taking by the learners, integration of lab &

theory session for the smooth conduct of simulation-based assignments. Findings align with the principles of constructivist learning, where pre-class exposure supports cognitive readiness & in-class activities promoted knowledge construction. The integration of reflection and peer interaction strengthened metacognitive awareness. These results suggest that FCM can substantially enhance the depth of learning in core courses like digital circuits. The limitations are: single institution study limits generalizability, cohorts may differ in preparedness despite safeguards and long-term retention was not measured.

CONCLUSION

The flipped classroom model offers a promising approaching to enhance transfiguration education. With a proper plan of design & implementing the strategies outlined in the methodology, instructors can create a more interactive, engaging and motivate spirit of both personalized and collaborative learning flavors for the learners. Despite challenges, the potential benefits of FCM approach make it a worthwhile initiative. The spirit of the FCM approach lies on 5E's- Engagement, Exploration, Explanation, Elaboration and Evaluation leading to an interactive based systems thinking flavor for learners to look at the dimensions of engineering in multiple ways. Both quantitative and qualitative results in view of FCM are very encouraging. Future work can incorporate simulations, effective discussion forum creation with technological tools, multi course FCM adoption, adaptive learning and deeper analytics can further reinforce its impact.

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