Peer instruction - Implementation and assessment of learning

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***Abstract* — This research experience report provides an overview of research work conducted on how the peer instructional constructive methodology enhances the student's critical thinking skills from lower order to higher order based on the learning taxonomies like Blooms revised taxonomy (BT). The research design adopted is quasi-experimental, two equivalent groups, post-test, same-topic design. In this report we mainly highlight, how the assessment of students cognitive levels of thinking was carried out at different levels. We report on how the cognitive level of the assessment aligns with that of the learning outcomes (LOs) of the selected topics were carried. The cognitive levels of the LOs were estimated the following the ABCD model. We analyse and identify whether the LOs are aligned with cognitive levels of assessment questions (aligned with Bloom's Taxonomy action verbs), wherein, the multiple choice-questions and problem solving method were used to assess lower and higher order thinking skills of students respectively. The perception survey of students was carried out to understand their perceptions of learning and engagement to further triangulate the teaching-learning process.**

Keywords: **Peer Instruction, learning objective, cognitive levels, ABCD model, Blooms Taxonomy, Assessment**

I. INTRODUCTION

Traditional lecturing, a one-sided teacher-centric lecturing of the curriculum contents, has been predominantly dominated in the higher education over millennium and continues to have strong advocates [1-2]. It has been considered as an easy method by several instructors, as a significant amount of syllabus could be disseminated to a large group of students. However, there is crucial requirement to transcend from the teacher-centric traditional methodology into the student-centered instructional strategies that would actively engage the students [3]. Higher educational reforms strongly emphasis on the systematic implementation of an evidence based active – learning instructional methodologies in STEM (science, technology, engineering, mathematics) courses to promote the student-centric collaborative learning environments in the academics as well as to address problem related to an effective learning and engagement of students (4). Recently, Freeman et al. [5] did a comprehensive meta-analysis of 225 studies on undergraduate STEM education, wherein, they have showed evidences that the students in classes with traditional lecturing were 1.5 times more likely to fail than that of the students in classes taught with active learning. Further their data indicate that (i) active learning increases in achievement hold across all of the STEM disciplines and occur in all class sizes, course types, and course levels and (ii) active learning is particularly beneficial in small classes. Harlow et al. [6] have revealed the importance aspects of students behavior and attitude toward the physics learning. Furthermore, the authors have reported that the behaviors, attitudes, beliefs and expectations of the students would be positively altered with an active teaching-learning strategies. Researchers have suggested to do critical discussions on the difficult concepts or the problems during the in-class activity and to give brief writing assignments and tests to the students based on the self-covered topics [5-6]. It has been found that active learning improved students content achievement even when the content is reduced. Research had proved that the reduced lecture time and reduced lecture information density enhances learning. Hence, lesser lecture time in the classroom and lower density content should not lead to lower expectations of the students or instructor. According to the constructivist teaching learning theory, the active learning methods encompasses several research based pedagogical strategies that are designed to engage the students in higher order thinking such as analyzing and reflecting on experiences, reasoning out or justifying the concept based on the prior knowledge, thus going beyond passive listening, memorizing or copying of lecture notes or [7-9]. Wide range of interactive-based teaching learning approaches and models have been developed and reported elsewhere such as collaborative learning methods like peer-led team learning [7], reciprocal teaching [8], peer tutoring [9], peer instruction [10], cooperative problem solving [11], flipped classroom [12], inquiry based learning [13], etc. All these methods show that learning can be improved through interactive methods, thus helping students gain a deeper understanding of what they are learning in STEM (science, technology, engineering, and mathematics) courses.

One of the active learning methods, the peer instruction (PI) is an interactive student centered instructional strategy that engages students through a structured questioning process done as a formative feedback [14]. The basic goals of PI method are to exploit student interaction to enhance their understanding of concepts and to learn from each other. Furthermore, during the PI strategy, the students gets collaboratively engaged in constructing knowledge along with peers, which help students develop more advanced critical thinking skills that can never be achieved in traditional lecturing. The PI method initially developed by the

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Harvard physicist Eric Mazur [10] is implemented in the following sequence: First, the students vote individually on the correct answers for the given multiple-choice questions (MCQs) using a classroom response system called “clickers”. If the percentage of correct answers are less, then the teacher allows the students to discuss the questions with their peers for about 2 to 3 min; they then vote individually again on the same questions. The sequence generally ends with a whole-class discussion in which the instructor provides explanations about the concepts. Although this is the most generally recommended way of using the PI method as suggested by Mazur, PI has been slightly modified by different instructors. Dancy and Henderson [15] have revealed that only less than 12.8 % of the instructors implement the PI strategy as it was originally designed by Eric Mazur [10]. Whereas, high level of modifications is currently being made by the instructors due to the external constraints encountered, while attempting to integrate these research based instructional strategies in the classroom structure. However, report by Andrews et al. [16] showed that any modification of evidence-based instructional practices has been associated with reduced learning gains. Recently Nuri et al.[17] have reported additional perspective of PI based on the statistical meta-analysis to determine the effectiveness of analyzing as well as reflecting skills of PI as compared to traditional lecture method based on culture of countries. They have referred to number of studies which depicted that PI is most effective in enhancing skills in collectivist and individualist countries as compared to those countries which encourage individual learning.

There have been several reports evaluating the efficacy of PI as an instructional strategy in the various disciplines such as natural sciences including chemistry, biology and physics, medical sciences [18-20]. All these reports suggest that the collaborative learning environment in PI enables to promote a deeper learning of concepts of fundamental sciences as well as student retention, perception of learning, engagement, etc. However, to our knowledge, limited studies have been reported on using the PI implementation to achieve the critical thinking skills in basic science courses for an undergraduate engineering curriculum [18]. Furthermore, it is reported [20] that the quality of good learning should be followed by a good assessment strategy as well, because the information from the assessment is useful for improving the quality of learning and an appropriate assessment method of learning [20]. Thus, the present study aims to determine the development of students critical thinking skills [21] through the implementation of peer instructional strategy and the critical thinking assessment instrument in the basic engineering physics course. The following are the research questions addressed: whether the implementation of PI instructional strategy promote (i) the learning effectiveness in an engineering physics course of the undergraduate engineering students and (ii) enhances the student’s critical thinking skills from lower order to higher order based on the Blooms revised taxonomy (BT).

II. RESEARCH DESIGN

(a) Course Format and participants

This study was conducted in an engineering physics course (EPH101) of the first year undergraduate engineering B.Tech program at GITAM (deemed to be university), Hyderabad. Two different 1st year B.Tech sections with the specialization (major) in the electronics & communication and computer science & engineering were considered as an experimental group (EG) and control group (CG) respectively. EPH 101 course has totally five modules. The study was conducted in first two modules of wave optics namely, interference and polarization of light. These topics have numerous engineering applications. It gives scope for the students to apply and integrate their thinking skills by way of group activity, problem solving and discussions with peers. The total number of students in each CG and EG sections were N = 66.

(b) Research design

The research design adopted here is quasi-experimental design. The research was conducted on two equivalent groups: control and experimental group, post-test, same-topic research design. The EG was taught with the PI strategy along with the flipped classroom method, while the CG was taught with traditional lecturing with no PI. The effectiveness of PI intervention was measured by comparing the post-test marks of both EG & CG taught with these two different instructional strategies. The effectiveness of the PI intervention is measured by comparing the post-test marks of both CG & EG taught with these two different instructional strategies. Same instructor taught the course for both the groups. The teaching content, text books and learning materials were same for both the groups. Duration of each class was 50 minutes. Care was taken to strictly maintain same number of classes (total number of PI hours = 14) taught for the selected topics for both the group to avoid extra teaching. Sufficient and relevant instructional materials were provided for both the groups. Both the groups have an access to online GITAM moodle (glearn) with their own user login (student’s PIN numbers) and password, in order to attempt the assessment test.

(c) Proposed methodology

The proposed methodology has been divided into following steps:

- Step 1: Writing a learning objective and outcomes as per Audience-Behavior-Condition and Degree (ABCD) model [19,20,21].
- Step 2: Mapping of keyword present in “Behavior” part of learning outcome with that of the revised Bloom’s taxonomy’s table of action verb.
- Step-3: Implementation of quasi-experimental research design.

- Step-4: Creation of the assessments test items, each one aligned with that of learning outcomes.
- Step-5: Data collection and analysis of student learning effectiveness.

III. IMPLEMENTATION

(a) Framing the learning outcomes and identifying the cognitive levels as per Blooms Taxonomy-Revised

The selected contents to be taught were divided into several sub-topics. For all the selected sub-topics that were taught, specific, well-defined learning outcome (LO) statements were generated. Learning outcomes (LO) are the measureable statement(s) of the knowledge, skills, attitudes, and values that students are intended to acquire after the successful completion of the course. Hence, utmost care was taken to write LOs precisely and completely without any ambiguity and having only one measureable action verb. These LO acts as a guideline for selecting or designing the instructional materials, course content, and teaching methodology. Further, the cognitive level alignment between the LOs statements and the assessment questions were checked. By cognitive level we refer to the six identified levels within the cognitive domain as per Bloom [22,25], which ranges from the simple recall or recognition of facts, as the lowest level, through increasingly more complex and abstract mental levels, to the highest order which is classified as creating or synthesis. Mastering lower cognitive levels is a prerequisite before the students are able to move to higher cognitive levels. Before implementation, alignment of the learning outcomes, instructional contents and assessments in a sequential order of cognitive skills were done. Furthermore, it also facilitated the instructors to easily check whether the specific LOs have been achieved by the students.

In order to verify that the instructors validated all the learning outcomes using the audience-behavior-condition-degree (ABCD) model [22-24]. The last three components that help instructors to understand the intent when writing an LOs are performance, conditions and criterion. The performance component in an objective always states what a learner is expected to be able to do. Conditions component describes the conditions under which a student is able to perform or execute the given task. And criterion component clarifies how well the student must perform the task, in order for the performance to be acceptable. When framing the LOs, check has been performed whether the complexity level of each of the LO statement starts from the lowest and moves up to the higher order of thinking skills. To do this the keyword (action verb) present in the "behavior" part of LO was mapped with Bloom's Taxonomy revised (BT) table of action verb [25,23, 24]. This helped us to identify the cognitive level of action verb used in LO statement. Generally, BT keywords are used to specify the cognitive level for a given question or learning objective. However, there are reports [22, 27] strongly emphasizing that only keywords in LOs may not always accurately predict the actual cognitive level required to solve the problem.

(b) Conducting PI in an engineering physics course

Before the start of the lecture, the LOs were explained to both CG and EG, in order to specify them what skill they were expected to learn or to be able to do at the end of the teaching. The PI research design required the EG to prepare the lecture contents via the flipped classroom method, wherein the students go through the conceptual contents in the form of recorded screencast and the you-tube animated videos or directed reading of specific topics that were released in the glearn moodle, to acquire the basic knowledge prior to the in-class PI activity. To test if all the students had gone through the flipped content or not, the moodle access activity report were checked and the instructor would randomly ask a student to give his/her solutions based on flipped content. Adopting flipped classroom allowed the instructor more class time to organize collaborative-student-centered learning activities such as the PI. During in-class PI implementation, the instructor engaged the students by asking several higher order multiple choice questions, encouraged an active peer/peer discussion. Further, the instructor took a regular feedback on peer learning process, clarified any doubts to effectively enhance their critical thinking skills and by assisting the students to present their results to the class for review by the instructors and peers. For CG, same set of instructional contents were taught by using the traditional lecturing without any PI activity.

During the in-class lecturing, the instructor taught the contents using the blackboard, PPT slides, you-tube animated videos, while the students will observe individually. Instructor poses questions and provides sample problems to solve to an individual student. Students solves the problem individually without any peer intervention. Later, any conceptual doubts are clarified by way of one to one interaction between instructor and individual students. As opposed to PI methodology, traditional lecturing was confined to individual student's thinking and understanding Generally, the students are observed to remain passive during the classroom lecturing. It has been reported that engagement of low performers is a major challenge in these active learning methods [4-7]. In an effort to improve the engagement levels of the low-performers during PI, the students were grouped with the good performers, such that they get involved actively during the in-class PI activity. Throughout the semester, the low performing students were frequently reminded about the PI strategies and its importance to achieve success in the subject. Aimed to keep them focused on an effective discussion with their peers, the low performers were encouraged to understand the simpler problems first before attempting the higher order problems of complex concepts. The instructor repeatedly intervened and assisted the discussions of such groups until an improvement in engagement of low performers were observed.

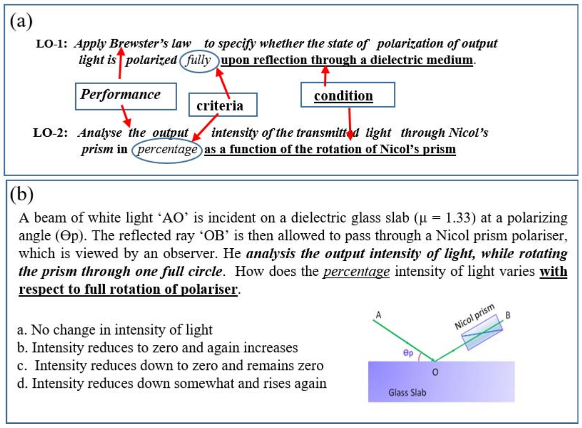

Figure. 1: (a) Learning outcomes statements written as per Bloom's Taxonomy action verbs of APPLY cognitive level and validated with ABCD model [26-28]. (b) Multiple choice questions based test item that assesses the lower-order thinking skills (LO-1 and LO-2).

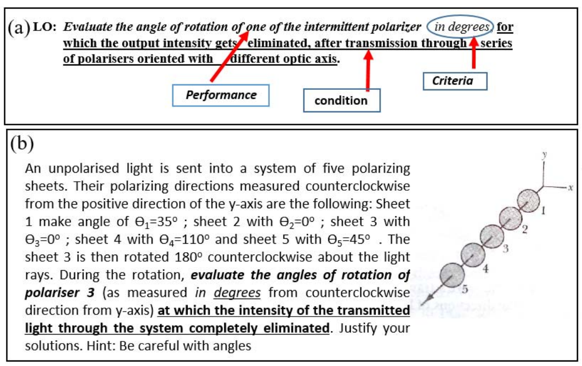

Figure 2: (a) (a) LO statements written as per BT's action verbs of evaluate - cognitive level and validated with ABCD model [26-28]. (b) Problem solving skill test item that assesses the higher-order thinking skills of LO.

(c) Creating assessments aligned with learning outcomes

Assessment of the student's conceptual understanding were carried out at different cognitive levels of complexity starting from the lower order thinking (LOT) to higher order thinking (HOT) skills. Both LOT and HOT skill assessment items were set at an increasing cognitive levels of knowledge and skill in accordance with the revised Bloom's taxonomy [25]. To assess the LOT skills, three different multiple choice question (MCQ) based tests were designed, each test for remember, understand and apply cognitive levels (no of test items = 10; duration of test = 30 minutes). The test was administered and graded through the online MOODLE. During the validation of questionnaire, each of the test item was checked for clarity of statement, completeness of data or representations in diagrams. Check has been performed to see whether each of the assessment test items designed also aligns with that of the cognitive level of corresponding LOs. Different category of test items was designed, with increasing difficulty levels as a measuring factor.

Figure.1 shows the cognitive level alignment between the learning outcomes (LO-1 and LO-2) with respect to one of the LOT skills test questions. The MCQ test item shown was administered to assess the apply cognitive level of students as per the revised Blooms Taxonomy (Revised). Figure. 1 (a) shows that the LO statement being validated with respect to performance-condition-criteria model [26-28]. As per the MCQ test item in Fig 1b, the learner needs to first apply Brewster's law (assessment as aligned with LO-1) for light incident upon a dielectric medium, wherein, he needs to ensure the state the polarisation upon reflection at polarising angle. Further he/she had to analyze the intensity variations upon a full rotation of Nicol's prism (assessment as aligned with LO-2). Here, the students are expected to apply what they learned about the working of Nicol Prism as a polariser. Thus, with the apply-level cognitive skill test, the instructor could assess the student's ability of applying conceptual knowledge to a certain scenario. To assess the higher-order cognitive skills (HOT) like analyze and evaluate levels, descriptive problems solving skill test (in-class) was administered.

Figure.2a shows the validation of LO statement as per performance-criteria-conditions [4-6]. We can see that how one of the problem solving skill (PSS) test question (to assess evaluate cognitive level) has been aligned with that of the LO stated in figure 2.a. To solve the problem in figure 2b, the learner is expected to first use Malus law in optics to a more complex situation, wherein, the light being transmitted through series of polarisers each oriented with different optic axis. Then, estimate the rotation angles of one of the intermittent polariser, using the definite criteria, for which the output intensity through it gets eliminated completely. Furthermore, the students need to provide an appropriate justification for their solution. Thus, the HOT skill tests assessed the student's ability to solve complex problems utilizing the given data and to compare, contrast or justify their solutions by blending their basic knowledge. However, due to limitation in assessment design, the highest cognitive level of Blooms Taxonomy (Create level) could not be assessed in present study. The field experts reviewed the validity of both the LOT and HOT skill test questionnaire as stated above. Then, it was pilot tested on some randomly selected students. Relevant modifications on the test questionnaire were subsequently made based on the suggestions concerning the duration of the test, clarity and difficulty levels of the questionnaire.

TABLE- I: Post-test scores of CG and EG for lower-order thinking MCQ test. [M-mean (out of 10); SD-standard deviation; V-variance]

Cognitive level	CG-Post Test			EG-Post Test			statistical data	
	M	SD	V	M	SD	V	F	P
Remember	7.16	1.94	3.7	7.82	1.5	2.2	4.0	0.04
Understand	5.33	1.74	3.0	6.70	2.4	5.7	10.7	0.00
Apply	4.32	2.06	4.2	6.09	2.6	6.6	28.1	0.00

TABLE- II Analysis of the post-test scores of CG and EG for HOT problem solving skill test using the rubrics (as adapted from ref [28])

Cognitive level	Problem solving rubric criteria as adapted from ref [5]	Control group - post test			Experimental group - post test			Statistical value	
		Mean (out of 5)	Std. Dev.	Variance	Mean (out of 5)	Std. Dev.	Variance	F	P-value
Analyse	Useful description (UD)	0.88	0.67	0.45	1.88	1.5	2.25	44.02	0.000
	Physics approach (PA)	2.95	1.37	1.89	3.80	1.40	1.96	22.98	0.000
	Specific application of physics (SP)	2.35	1.31	1.71	3.19	1.41	1.98	23.49	0.000
	Mathematical.procedures (MP)	1.93	1.27	1.62	2.72	1.46	2.14	20.67	0.000
	Logical Progression (LP)	0.72	0.95	0.91	1.61	1.49	2.24	30.91	0.000
Evaluate	Useful description (UD)	0.81	0.97	0.94	1.94	1.5	2.64	43.35	0.000
	Physics Approach (PA)	2.38	1.76	3.11	3.13	2.03	4.13	9.78	0.0019
	Specific application of physics (SP)	1.9	1.57	2.47	2.73	1.94	3.77	13.71	0.000
	Mathematical.procedures (MP)	1.35	1.26	1.61	2.39	1.81	3.27	26.70	0.000
	Logical Progression (LP)	0.45	0.84	0.70	1.36	1.46	2.13	35.47	0.00

III. DISCUSSION

(a) Data collection and analysis of student learning effectiveness

Online moodle was used as a technological tool for providing LOT MCQs test assessments, allowing data collection and analysis via online. Moodle also acted as an effective tool for the instructors to follow-up these out-of-class assignments to insure that every student has completed the task, which greatly reduces the amount of hand grading. The research data thus collected from the MCQ and PSS tests were analysed for estimating the learning effectiveness with and without PI. The HOT skill test solutions were evaluated using the rubric (adapted from ref [28]) by another faculty member to avoid any kind of any unconcious bias. The rubric provided in the Ref [28] identifies five general problem-solving criteria as refered in Table-II. The authors of [28] had reported the evidence for validity, reliability and utility of the instrument. Students received a small amount of credit (marks) for attempting the test, whether or not the answers were correct.

Same test duration and questionnaire were designed and administered for both the CG and EG students. Analysis of variance (ANOVA) was used to compare the test results and also to evaluate the effect of PI on the post-test means (Table I & II). The comparative analysis between the mean post-test scores of the LOT cognitive skill tests (remember, understand and apply levels) for both the CG and EG showed no substantial differences and a p-value ~ 0.04 (Table-I). Whereas, analysis of the HOT test showed significant differences in the mean post-test scores with p value < 0.001 for all the rubric-criteria (Table-II). Our study indicated that as compared to the LOT skill test, the PI had facilitated the EG students to improve their performance in the HOT based problem solving skill test. The EG students solved problems systematically with the better cognitive strategies as well as the logical progression. Whereas, the CG had difficulty in organizing the given information from the problem statement into an appropriate and useful data ($F = 43.35$; $p < 0.001$ for UD) and a logical progression ($F = 35.47$; $p < 0.00$ for LP) [Table-II]. Further, CG solved most of the higher-order problems incompletely without much of a conceptual clarity. Our results revealed that compared to traditional lecturing, the PI implementation has dominantly enhanced the HOT skills than the LOT skills as well as engagement and motivational levels.

(b) Student's perception survey analysis

The student perception survey was collected via online to address our research question (Table III and IV). The survey questionnaire had 4 Likert scale questions with 5 points: Strongly disgree /disagree /Neutral /agree /Strongly agree. The frequency distribution of the Likert scale options selected by students were number 1 to 5 and mean value (out of 5) was calculated. Paired T-test analysis was used. Perception survey about cognitive level alignment of LOs and assessment test items were taken. Both CG and EG agreed that there LOs-Instructional contents-assessment were aligned. Comparison between the mean marks (out of 5) about various perceptions about the knowledge and confidence levels gained due to PI and traditional lecturing showed significant different P-value for most of survey questions.

One of the perception survey question was posted to the students "Did the physics problems solving skill test promoted your HOT skills.?" were answered by both CG and EG. The percentage of EG students who strongly agreed were 46.3 % (37.1% for CG), agreed were 46 % (22.9 % for CG),7.7 % for Neutral (25.7 % for CG), 0 % for disagree (11.4 % for CG), 0 % for strongly disagree (2.9 % for CG). Whereas, for the question "did the MCQ test promoted your LOT skills?" the percentage of EG students who strongly agreed were 45.4 % (39.8% for CG), 39.8 % for "Agree" were (29.7 % for CG), 14.8 % for neutral (18.9 % for CG), 0 % for disagree (8.1 % for CG). This survey results suggested that the HOT skills of the EG students could be promoted better than the CG by way of problem solving skill test. However, the CG were not able to use the knowledge

Table -III: Perception Survey about alignment of cognitive levels of learning objectives-instructional contents and assessment test items.

Perception survey items	Control Group			Experimental Group			df	t Stat	t Critical	Significance P-value
	M	SD	V	M	SD	V				
Required learning materials for skill test were provided	4	1.1	1.23	4.21	0.91	0.86	57	-0.75	1.67	0.23
Learning materials provided and learning objectives were cognitively aligned	3.83	1.0	1.11	4.16	0.88	0.84	58	-1.26	1.67	0.106
Assessment test items-Instructional contents-LOs were cognitively aligned	3.91	1.0	1.13	4.24	0.76	0.61	57	-1.15	1.67	0.21
I could understand the text description, diagrammatical representations of test items clearly	3.91	1.1	1.37	4.21	0.69	0.52	57	-1.09	1.67	0.139
I did not face any difficulty to answer specifically due to the lack in clarity of questions or insufficient information in diagrams	3.77	1.2	1.47	4.08	0.76	0.60	57	-1.11	1.67	0.136

Table -IV: Perception Survey about the knowledge and confidence levels gained by control and experimental group. Mean marks are out of 5. (*p- value < 0.05)

Perception survey items	Control Group			Experimental Group			df	t Stat	t Critical	Significance P-value
	M	SD	V	M	SD	V				
I was confident enough to apply the physics concepts learnt to solve higher order problems.	3.51	1.24	1.62	4.42	0.56	0.34	59	-3.33	1.671	0.0007*
I could use the knowledge taught to solve lower-order questions in MCQs test	3.83	1.13	1.34	4.32	0.72	0.56	59	-1.85	1.671	0.034*
I could use the knowledge to solve higher-order problems in PSS test	3.79	1.08	1.19	4.458	0.571	0.346	56	-2.7	1.672	0.004*
MCQ test promoted my LOT skills.	3.88	1.16	1.415	4.31	0.72	0.543	59	-1.45	1.671	0.075
Problem-solving test promoted HOT skills.	3.8	1.12	1.24	4.36	0.62	0.418	57	-2.04	1.672	0.02*
Time duration was sufficient	3.33	1.33	1.85	4.04	1.07	1.21	59	-2.13	1.67	0.018*

gained and their confidence levels were also as low as compared to EG (significant value of $p < 0.05$). Further, CG were not able to complete the assessment test items within the stipulated time duration, as they were not able to easily link the concepts what they learnt. More importantly, our analysis suggested that the implementation of PI methodology has promoted the HOT skills of EG as compared to CG. This study could be further triangulated to that of lower order-MCQ and higher order problem solving skill test assessment results of CG and EG. This strengthens the positive effects of PI in enhancing the student learning effectiveness and thinking skills.

V. CONCLUSIONS

The present study is an attempt to provide an active learning environment for the undergraduate engineering students to develop problem-solving skills to enhance their thinking skills to higher cognitive levels. Our study infers that our students have acquired these kinds of attributes and skills, through active engagement to a measurable extent and they could reflect on the practice of learning through the perception surveys. Our studies showed EG students indicated a significant increase in both "confidence" and "skill" in problem solving as compared to CG. Moreover, the students enjoyed becoming part of the learning process through these new techniques of teaching.

Further extension of the study will be carried out by considering the experimental group and control group, wherein, the instructor plans to measure the students learning effectiveness and enhancement of thinking skills by adopting PI and comparing it with other active learning instructional approaches. Further assessment will be done by way of standardized pre-test and post-test research design to calculate learning gains, considering the possible effect due to several other confounding variables.

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