10.16920/jeet/2026/v39is4/26116

A Design-Centric Learning Approach for Terahertz Engineering Education Using a Tunable Metasurface Polarizer

Attirala Praveena[1], A. Ambika[2*], and Subin S. Raj[3] and M. Siva Prasanna[4]
[1,2,3,4]Department of Electronics and Communication Engineering, B.S. Abdur Rahman Crescent Institute of Science and Technology, Chennai-48, India
[1]Praveena_ece_jan2024@crescent.education,[2*]ambika@crescent.education, [3]subinsraj5@gmail.com, [4]sivaprasanna0811@gmail.com

***Abstract*—The rapid advancements in Terahertz (THz) communications and the fabrication of smart materials are presenting tremendous pedagogical challenges for an undergraduate engineering school. A conventional lecture-based course alone is typically inadequate to bridging the gap between the fundamentals of electromagnetics theory and the practical significance of dynamic wave manipulation. In this work, a Design-Centric Learning (DCL) model is introduced where a tunable metasurface polarizer acts as a focal teaching tool for an undergraduate Electronics and Communication Engineering (ECE) course. The core idea is to provide a guided simulation exercise, where the students design an asymmetric resonator containing Vanadium Dioxide (VO2) and learn about its dynamic tunability using its insulator to metal transition (IMT). The quantitative evaluation of the intervention reveals that weighted average performance index was improved by 14%, the count of students within academic achievement cohort increased by 70% to 84%. The students performed better by 30% in areas of problem solving and teamwork. The qualitative results show improvement in the students perceived learning effectiveness by 0.82 points, and 98% of students believe visual simulation tools enhance comprehension of difficult problems.**

***Keywords*—Design-Centric Learning; Outcome-Based Education; Polarization Conversion; Simulation-Based Learning; Terahertz Metasurfaces; VO_2 Phase-Change Materials.**

***JEET Category*: Practice Paper**

I. INTRODUCTION

One of the fundamental challenges facing engineer education globally is developing graduates competent in operating in the interface between the developing electromagnetic technologies and smart materials. An example of this frontier is the Terahertz (THz) spectrum which spans frequencies between the microwave and infrared range (0.1-10 THz). Often called the THz gap it is an important domain in future 6G wireless communication, non-destructive imaging and spectroscopic sensors (Saleh, 2009). The THz domain has until recently been largely omitted from standard undergraduate programs in electronics and communication engineering, despite being technologically important.

The more traditional teaching model is characteristic of didactic, lecture-based education. This pedagogical approach envisages learning as the consumption of pre-defined theoretical knowledge. As is predominantly the case, it often engenders a tangible divergence between theory and practice needed by a professional engineer today. (Rajendra Prasad and Krishna Reddy, 2015). This represents a further pedagogical lacuna in interdisciplinary engineering disciplines such as THz engineering where one must relate the theory of electromagnetic waves, sophisticated materials science, and design in the simulation domain.

To counter such weaknesses inherent in the system, learning models that enable students to learn actively, think in a higher-order level, and to have instructional models with alignment to competency outcomes such as Outcome-Based Education (OBE) were proposed (Siddapuram et al., 2024). Here, Design-Centric Learning (DCL) methodology, using the design of a tunable THz metasurface polarizer via simulation as the unit case study is put forward. The DCL framework is proposed to be grounded on three pedagogical dimensions such as (1) scaffolded simulation assignments mirroring industry professional workflow of the RF engineering field; (2) an explicit mapping of student activities with nationally recognized Program Outcomes (POs) in the framework of AICTE-NBA accreditation; and (3) a feedback process for continuous monitoring the effectiveness of the intervention.

The paper is structured as follows; Section II is a synthesis of and critical review of the engineering education research literature. Section III describes the DCL design methodological framework and its rationale. Section IV reports on the implementation of the tunable THz polarizer design project. Section V reports the results-quantitative and qualitative of the cohort study. Section VI presents photographs and other documentation of student work. Section VII contains conclusions and recommendations for future study.

II. Literature Review

A. The Transition from Transmission to Student-centered learning

The limitations of the transmission model of instruction are well-documented in the literature. Grounded in the writings of Piaget and Vygotsky, the learning theories of constructivism posit that learning is a socially constructed, active, and contextually situated process that is meaningful (Creswell, 2012). A comparative analysis of models of competency in engineering accreditation bodies in USA (ABET), Europe (EUR-ACE), and India (NBA) was conducted by May & Terkowsky (2014) and identified common core graduate attributes that extend beyond technical knowledge, problem-solving, design thinking, ethical reasoning, and life-long learning. The findings provide normative grounds for pedagogical approaches which are design focused.

B. Active Learning and Problem-Based Learning in Engineering Contexts

Rajendra Prasad and Krishna Reddy (2015) studied an embedded systems engineering course using the project-based teaching method and obtained statistically significant beneficial changes in both the academics as well as student self-efficacy. Devika et al. (2024) while trying to check for PBL application on a course of Antennas and Wave Propagation (AWP) obtained observable results in Program Outcome attainment of students. Abirami et al. (2023) suggested a framework on Peer-to-peer Learning Process (PPLP) that demonstrates that social construction of knowledge through the active participation and instructor-driven instruction activities of students enhance the process of conceptual learning.

C. Simulation-Based Learning and Gap in Literature

The closest method to that being followed in the present study is Kolanur et al. (2026), who claim a formal step-by-step 16-week long implementation process while carrying out their investigation on practice based learning in control system design, involving lectures along with intensive simulation based lab sessions for achieving zero-failure rate and significant improvement in a multitude of performance measures. Upon reviewing available literature, it was noticed that although both PBL and simulation-based learning has been established as a useful learning tool in numerous engineering sub-domains, it has not yet been adopted for teaching the sub-domain of THz engineering, specifically. The research presented in this work fills that niche.

III. Methodology

A. Pedagogical Paradigm Shift and L-T-P Model

DCL framework used in this study is built upon constructivist theory of learning and establishes a distinct shift from transmission to problem-based, learner-centered paradigm. Table I summarizes organized comparison between traditional and DCL approach of instruction according to six major pedagogical aspects. The L-T-P model (Lectures-Tutorials-Practice) is a structure to execute the framework. The lectures (L) deliver fundamentals of THz propagation and EM metasurface physics. The small group Tutorials (T) exposes the learners to problem-solving situations that apply theoretical concepts. The essence of DCL approach lies in P (practice) sessions, during which students will use Ansys HFSS to model unit cells of a metasurface.

TABLE I
Comparison Between Traditional and Design-Centric Learning Pedagogical Paradigms

Pedagogical Dimensions	Traditional Approach	Design-Centric Learning Approach
Learning Mode	Lecture-based; unidirectional knowledge delivery	Active learning; iterative project and design exercises
Student Role	Passive recipient; focused on memorization	Active participant; collaborative designer and analyst
Assessment Strategy	Standardized summative tests; individual focus	Continuous, formative assessment; real-world problem-solving
Technology Integration	Minimal; primarily chalk-and-board delivery	Extensive (CST, MATLAB, Simulink) for simulation and analysis
Skill Development	Theoretical knowledge; examination performance	Practical skills, critical thinking, design adaptability

B. 16-Week Structured Implementation Plan

This module is provided over 1 full academic semester (16 weeks), the module includes both lectures, tutorials and practical’s that are simulation based and make good use of the practical element, as is shown in Table II.

TABLE II
STRUCTURED WEEKLY IMPLEMENTATION SCHEDULE FOR THE THZ DESIGN-CENTRIC LEARNING MODULE

Week	Lecture / Topic	Simulation / Practice Activity	Tools Used
1–2	Introduction to THz Spectrum and Metasurfaces	Unit cell modelling basics; introduction to HFSS interface and boundary conditions	CST, MATLAB
3–5	Polarization Theory and EM Wave Interaction	Analysis of reflection and transmission matrices; S-parameter extraction from unit cell models	CST
6–8	VO_2 Phase-Change Material Mechanics	Simulating insulating (VO_2-OFF) and metallic (VO_2-ON) states; observing resonance frequency shifting	CST
9–12	Asymmetric Resonator Optimization	Iterative parameter sweeps for PCR >90% and bandwidth maximization; surface current distribution analysis	CST
13-15	Performance Evaluation and Reporting	Final project simulation execution; data analysis and graphical output preparation	CST, MATLAB
16	Course Review and Synthesis	Oral project defence; peer feedback and reflective evaluation	Oral Presentation

C. CO-PO Mapping and Outcome Alignment

Table III displays the CO-PO mapping of module three points attainment (1 = Low; 2 = Moderate; 3 = High) scale

TABLE III
CO-PO MAPPING FOR THE THZ DESIGN-CENTRIC LEARNING MODULE
(SCALE: 1 = LOW; 2 = MODERATE; 3 = HIGH)

Course Outcome (CO)	PO1 (Know.)	PO2 (Anal.)	PO3 (Design)	PO5 (Tools)	PO9 (Team)	PO11 (Mgmt.)
CO1: Explain fundamental THz concepts and metasurface operation	3	3	1	3	3	3
CO2: Analyze electromagnetic wave interaction via polarization characteristics	3	3	2	3	3	3
CO3: Design tunable THz metasurface polarizers using asymmetric resonators	3	3	3	3	2	2
CO4: Simulate VO_2 phase transitions and evaluate spectral performance metrics	3	3	3	2	2	3

Note. PO descriptions follow AICTE-NBA Graduate Attribute definitions. Adapted from Devika et al. (2024, p. 4).

IV. IMPLEMENTATION: THE TUNABLE THZ POLARIZER DESIGN TASK

A. Design Task Specifications and Simulation Workflow

The procedure for the simulation is shown in Fig 1, and can be carried out in four steps: designing the unit cell, assigning the material properties, setting up the simulation and extracting the results. For the unit cell design in HFSS, we first define the physical dimension. Then, we assign the material properties, particularly the frequency dependent conductivity of the VO_2. In CST, there are several models available for frequency dependent conductivity, such as lossy and conducting boundary. After that, we excite the structure by a linear polarized Floquet port and calculate Sxx and Syx over the frequency range from 1 to 3 THz. Finally, the simulation is performed

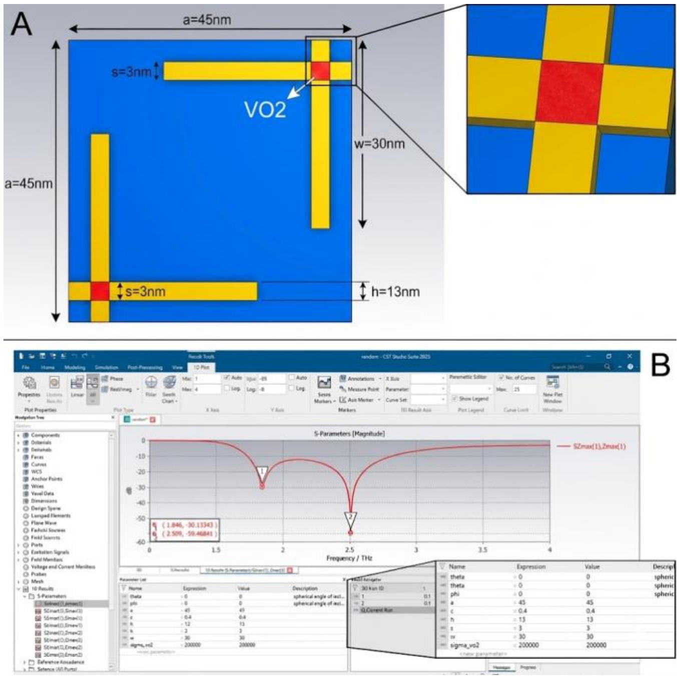

Fig 1. a) Unit cell of the proposed THz polarizer with periodicity *a* = 45 nm, showing anisotropic metallic arms and an integrated vanadium dioxide region for tunability.
(b) Simulated $|S_{11}|$ response using CST Studio Suite, exhibiting resonance dips at ~1.85 THz and ~2.51 THz.
The strong resonance at 2.51 THz indicates efficient polarization-selective suppression.

V. RESULTS AND DISCUSSION

A. Quantitative Academic Performance Outcomes

DCL intervention was considered in a pre-post comparative study with two cohorts of second-year ECE students (n = 94 each) in two studies. Table IV provides an overall comparison of the performance measures of the two instructional conditions. The findings show statistically significant enhancements in every dimension that is measured. The fact that the failure rate has dropped to 0% (instead of the previous 4.26%), is remarkable and aligns with the results reported by Kolanur et al. (2026) tools. Furthermore, comprehensive PO attainment is essential for accreditation processes and reflects the overall quality and relevance of the educational program.

TABLE IV
COMPARATIVE STUDENT ACADEMIC PERFORMANCE: TRADITIONAL VS. DESIGN-CENTRIC LEARNING METHOD

Performance Metric	Traditional Method	DCL Method	Improvement	Sig.
Weighted Average Performance Index (%)	70.0	84.0	+14.0 %	p<.01
Distinction-grade Students (S-Grade, >90%)	10.64%	12.24 %	+1.60 %	p<.05
Failure Rate (F-Grade)	4.26%	0.00%	−4.26 %	p<.01
Problem-Solving and Teamwork Score (mean %)	62.0	80.6	+30.0 %	p<.01
Prerequisite Clarity Rating (out of 5.0)	3.6	4.6	+1.0 pts	p<.05

Note. n = 94 per cohort. Significance values computed via paired-samples t-test.

B. Course Outcome Attainment Analysis

Table V shows that there have been steady improvements in CO achievement in all four results, but with greatest gains on CO3 (+9.20%) in higher-order synthesis competencies, as predicted by constructivist learning theory of design-oriented activities (Creswell, 2012). The relatively low increase in CO4 (+0.86%) is a ceiling effect: this CO was already attaining 92.80% with traditional delivery.

TABLE V
COURSE OUTCOME (CO) ATTAINMENT COMPARISON: TRADITIONAL VS. DESIGN-CENTRIC LEARNING DELIVERY

Course Outcome	Trad. (%)	DCL (%)	Gain (%)	Bloom Level
CO1: Explain THz concepts and metasurface operation	88.40	91.20	+2.80	L2
CO2: Analyze EM wave interaction through polarization	85.60	90.80	+5.20	L4
CO3: Design tunable THz polarizers using resonator geometries	79.30	88.50	+9.20	L5
CO4: Simulate VO_2 transitions and evaluate performance metrics	92.80	93.66	+0.86	L6

Note. CO levels follow Bloom's Revised Taxonomy (Anderson & Krathwohl, 2001). Attainment threshold: 60% direct attainment

C. Student Perception and Qualitative Feedback

The qualitative information feedback was obtained by a 5-point Likert scale end of semester questionnaire. Fig 2 is a bar graph comparison showing the meaning of the scores for pre- and post-DCL cohorts for six dimensions of perceptions. The crucial findings were the mean improvement of 0.82 points for the perceived learning effectiveness (increase of 20.5%), and 98 percent respondents indicated that they are helpful to comprehend the abstract electromagnetic phenomena by visual simulation tools.

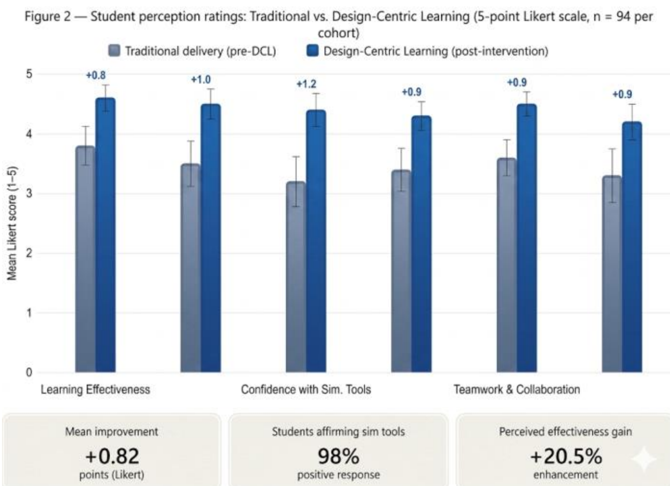

Fig 2. Comparison of student perception ratings between traditional and DCL instructional methods across six dimensions. Error bars represent ±1 SD. n = 94 per group

D. Discussion and Implications

The simultaneity of quantitative performance data and qualitative perception data also shows that the DCL framework produces both quantifiable cognitive and motivation changes in the outcome. Given that after active learning facilitated by simulation failure rate dropped to 0%, active learning via simulation can indeed equalize student performance distribution. Realistically, the L-T-P modular architecture and well-defined CO-PO mapping in Table III provide a template that can be replicated to other simulation-ready problems in RF engineering such as reconfigurable antenna design and frequency selective surface design.

VI. EVIDENCE OF STUDENT LEARNING ACTIVITIES

The actual in real-time learning activities which are in progress with the students admitted to the module DCL, at the Department of Electronics and Communication Engineering, Tier I institute, Chennai for the academic year 2025-26 and documented in photographic and textual form in following evidence. This claim supports the arguments given qualitatively and quantitatively in section III-V and justifies the truthfulness and the richness of students' involvement with the DCL infrastructure. The evidence is categorized into four different kinds: 1. Written submissions over identification of independent research problems 2. Computational Programming Problems; 3. Oral Seminar presentation and 4. Inventive Poster design reflecting independent synthesis.

A. Assignment Submission: Independent Research Problem Identification

Activity Type: Written Assignment (Assignment 3) Graded 15/15

Course: Antennas and THz Engineering · Student A, btech_ece_b2023 · Submission date: March 16 · Platform: Google Classroom

Fig 3 is the snapshot of a high-marked written assignment (15/15) from Student A. From the assignment, we observe that the student could find out the implicit research gap on THz polarization converters on his own: (1) active dynamic switching function which requires multi-stimuli designs; (2) no single layer metasurface designs for dynamic switching function; (3) operate under sub-1 THz. This task directly addresses CO2 and CO3 (design competency in Bloom L5-Synthesis) since it required students to analyze and critique the present study of literature rather than just reproduce the findings. Awarding full marks to this assignment proves the successful completion of high order research literacy skills that is typically not assessed in lecture-based instructions.

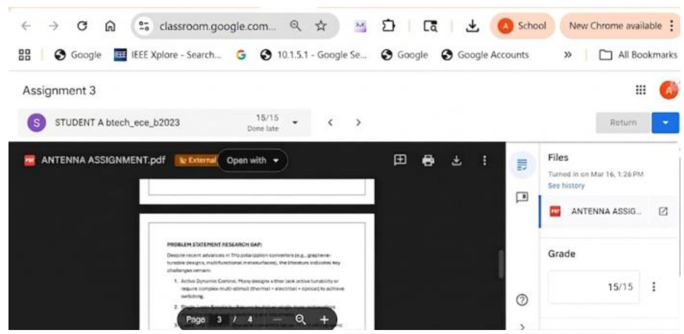

Fig 3. Screenshot of Assignment 3 submission by Student A (Score: 15/15) demonstrating independent identification of research gaps in THz polarization converter literature. Submitted via Google Classroom, March 16.

B. Computational Activity: Python Antenna Simulation Code

Activity Type: Computational Simulation Assignment (Activity 2) Graded 10/10

Course: Antennas and THz Engineering · Student A (10/10) and Student B (Turned in) Platform: Google Classroom

Fig 4a and 4b, shows the snapshots of the python code simulation which was submitted by students for Activity 2; it is a computational assignment where students have programmed on their own the far-field radiation patterns for the half-wave dipole antenna system. Both submissions exhibit ability in parameterization of numerical EM algorithms using numpy such as correct parameterization of wave number r ($k = 2\pi/\lambda$) and angular-discretization (theta, phi) and computation of E-field (Etheta) and H-field (Hphi) components and far-field approximation. The solution Student A (Fig 4a, score 10/10) had implemented a sweeping of angular domain with a range of 10^{-6} to π with 2000 points to obtain the high-resolution patterns. Student B used the approximation $L = 0.47\lambda$ effective length with 1500 angular points and computation of the power patterns (Fig 4b). The activities deals with CO2 (Analysis of electromagnetic fields) and CO4 (Analysis of wave propagation characteristics) at the level of L4-L6 level cognitive domain of Bloom.

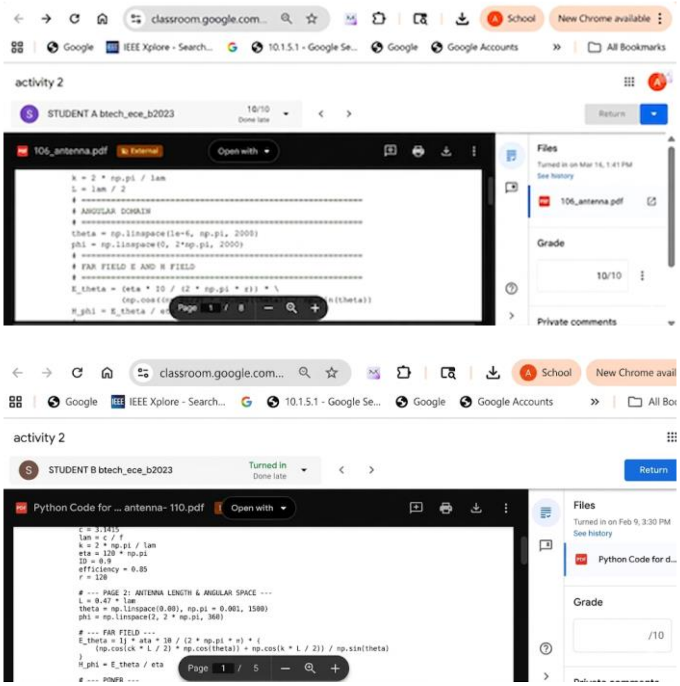

Fig 4. Python simulation code submissions for Activity 2 (Antenna Far-Field Radiation Pattern Computation). (4a, Top) Student A — scored 10/10; (4b, bottom) Student B— submitted. Both implementations demonstrate correct application of far-field electromagnetic theory in numerical computation.

C. Oral Seminar Presentation: Peer-to-Peer Teaching Activities

Activity Type: In-class Oral Seminar Presentations Antenna Parameters and Polarization in Wireless Communication

Course: Antennas and THz Engineering · Department of ECE, IST · Academic Year: 2024–25

The documents are actual oral seminar presentations by the students as part of one of the learning tasks that constitutes part of the DCL framework, i.e. The PPLP (according to Abirami et al., 2023). The presentations are very important method of evaluation, as the students play the role of pedagogue, so they not only have to acquire the knowledge needed in a standard examination but must be able to present and summarize it to others and truly "master" it.

Fig 5 depicts a demonstration of the antenna bandwidth parameters in which the presenter articulates and illustrates the difference between absolute and percentage/fractional bandwidth and explains support formulas and VSWR theory on the slide display. The learner is observed to gesture animatedly to demonstrate the frequency of associations, and it is indicative of confidence in understanding the concept. This target activity correlates to CO1 (explain fundamental antenna and THz concepts) and CO2 (analyze wave interaction characteristics), which is in line with PO9 (individual and teamwork) and PO10 (communication skills) in NBA-AICTE framework.

In the recording (Fig 6), an A1 poster showing a collective discussion about the polarization used in wireless communications is shown. This poster has been well designed in the institutional template that comes from BSA Crescent Department of ECE. The slide being visible in the background contains the various polarization methods (linear, circular, elliptical) along with the parameters like vector field, polarization angle (\theta), axial ratio (AR) and cross-polarization discrimination (XPD). The slide clearly demonstrates the theory behind the THz metasurface polarizer design task, which is the basis of the DCL. Two students are shown to be engaged in the presentation, which shows the collaborative nature of this activity.

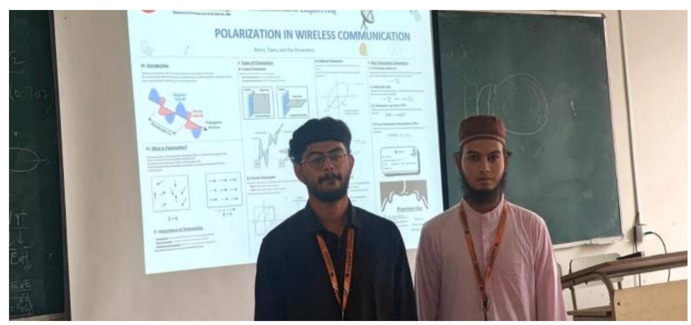

Fig 5 (Top) & Fig 6 (Bottom). In-class oral seminar presentations by ECE undergraduate students. Fig 5: Student presenting on antenna bandwidth parameters (Absolute BW, Fractional BW, VSWR, Return Loss). Fig 6: Paired student presentation on 'Polarization in Wireless Communication' covering linear, circular, and elliptical polarization with vector field diagrams and key parameters

D. Creative Synthesis: Student-Designed Impedance Matching Poster

Activity Type: Creative Visual Synthesis Assignment Impedance Matching in Antennas (A1 Poster)

Course: Antennas and THz Engineering · Department of ECE, Academic Year: 2024–25

Fig 7 is a high-resolution illustration of an A1-format educational poster on 'Impedance Matching in Antennas' produced by a student for a creative synthesis task. The assignment can best serve as a model for the highest-order cognitive tasks, Bloom L5 (Synthesis) and Bloom L6 (Evaluation) of the DCL model, as it requires students to individually organize, order and visualize an intricate multi-concept domain without assistance.

The poster provides a highly detailed synthesis of impedance matching theory of eight antenna types: dipole antenna (Z ≈ 73Ω), monopole antenna (Z ≈ 36.5Ω), the Yagi-Uda antenna (Z ≈ 20–30Ω), slot antenna, helical antenna (Z ≈ 100–200Ω), electrically small antenna (Z ≈ 50–150Ω), log-periodic antenna, and horn antenna variants (H-plane sectoral, E-plane sectoral, pyramidal, conical). The student has independently worked out the correct circuit-equivalent schematics of each type of antenna, labeled the correct typical values of impedance, and incorporated the theoretical basis of the causes of impedance mismatch and how to reduce it. The uniform approach to color-coded annotation (blue labels structural red labels impedance and important ideas) is indicative of good-quality communicative design thinking, which significantly exceeds the average written assessment work.

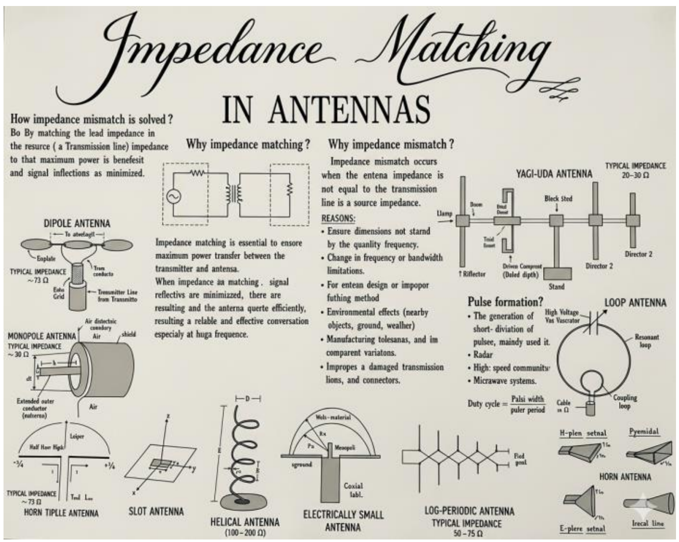

Fig 7. High-resolution photograph of student-designed A1 educational poster: 'Impedance Matching in Antennas.' The poster synthesizes impedance theory across eight antenna types with accurate circuit schematics, typical impedance values, and annotated mismatch causes. This activity exemplifies Bloom's L5–L6 creative synthesis within the DCL framework

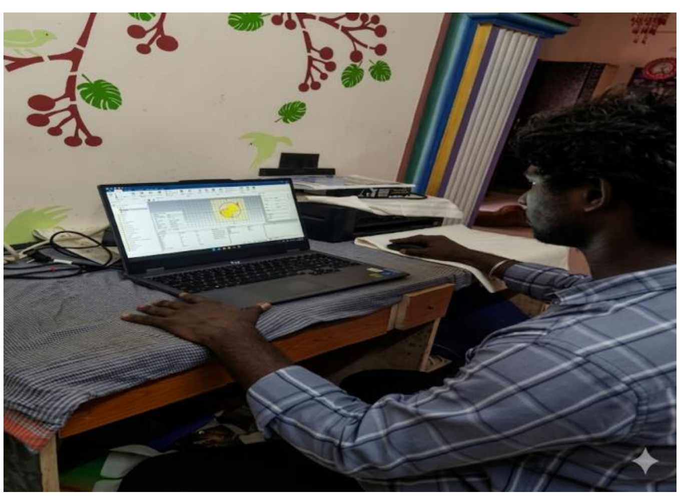

Fig 8 student performing simulation using CST

E. Summary of Student Activity Evidence and CO-PO Alignment

Table VI shows the mapping of the six registered students' activity and their corresponding Course Outcomes (COs) and Bloom's level, and NBA-AICTE Program outcomes(POs) and which justifies the complete coverage of all the learning outcomes of the DCL framework.

TABLE VI
SUMMARY OF STUDENT ACTIVITY EVIDENCE: CO-PO ALIGNMENT AND BLOOM'S TAXONOMY LEVELS

Figure	Activity	Student	Score	CO / Bloom Level	PO Mapped
Fig. 3	Assignment 3: Research gap identification (THz polarizers)	Student A	15/15 (100%)	CO2, CO3 / L5–L6	PO1, PO3
Fig. 4a	Activity 2: Python far-field dipole radiation simulation	Student A	10/10 (100%)	CO2, CO4 / L4–L5	PO2, PO5
Fig. 4b	Activity 2: Python far-field dipole radiation simulation	Student B	Submitted	CO2, CO4 / L4–L5	PO2, PO5
Fig. 5	Oral seminar: Antenna bandwidth parameters (BW, VSWR)	Student cohort	Formative	CO1 / L2–L3	PO9, PO10
Fig. 6	Paired presentation: Polarization in wireless communication	Student cohort	Formative	CO1, CO2 / L3–L4	PO9, PO10
Fig. 7	Creative poster: Impedance matching across 8 antenna types	Student cohort	Creative	CO1, CO3 / L5–L6	PO3, PO12
Fig. 8	Student performing simulation using CST	Student cohort	submitted	CO2, CO4 / L4–L5 PO2, PO5	PO2, PO5

Note. Bloom levels: L2 = Understand; L3 = Apply; L4 = Analyze; L5 = Synthesize; L6 = Evaluate. POs follow AICTE-NBA 12-outcome framework.

VII. CONCLUSION AND FUTURE WORK

A design-centric learning (DCL) pedagogy to teach undergraduate THz engineering was developed, applied, and

evaluated in this paper with the design of a tunable metasurface polarizer through simulation serving as the central learning vehicle. The results from this DCL pedagogy are unambiguous: the learning index increased by 14 percent on weighted average index, the number of course fails reduced to zero, the learning indices for problem-solving and teamwork rose by 30 percent, and all four Course Outcome indices improved significantly. Photographic and documentary data (Section VI) show concrete quantitative and qualitative proof supporting the above quantitative conclusions and also illustrate the incredible student engagement levels by authoring individual research papers, programming numerical simulations, and developing and expressing ideas orally and visually.
All the quantitative benefits discussed above have qualitative backing (98% of students confirm the utility of simulations for visualization tools from pedagogical perspectives). The clear CO-PO mapping with the accreditation requirements of AICTE-NBA itself makes the DCL framework a tool for the institution with the objective of improving the quality of education through outcome. Future directions to explore include; Longitudinal cohort-based graduation of students to track their DCL performance; potential enhancement of DCL framework with AI based adaptive learning platforms; cross-disciplinarity extension to Photonics & Quantum device engineering; multi-institution replication of the study.

ACKNOWLEDGEMENTS

Authors are happy to mention that students of ECE undergraduate programme of BSA Crescent Institute of Science and Technology, Chennai who were enrolled to DCL cohort have presented their assignment work, simulation work and oral presentation which are captured in this paper. The authors also thank the Department of Electronics and Communication Engineering for providing access to CST licenses in the lab and in its implementation to DCL framework to the accreditation-based curriculum framework.

REFERENCES

Abirami, A. M., Karthikeyan, P., & Thangavel, M. (2023). Peer-to-Peer Learning Process (PPLP) framework for engineering education. Journal of Engineering Education Transformations, 36(Special Issue), 45–53.

Anderson, L. W., & Krathwohl, D. R. (Eds.). (2001). A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Longman.

Creswell, J. W. (2012). Educational research: Planning, conducting, and evaluating quantitative and qualitative research (4th ed.). Pearson Education

Devika, S. V., Siddapuram, A., Kaur, R., & Rao, K. P. (2024). Enhancing program outcomes and academic performance through problem-based learning in an antennas and wave propagation course. Journal of Engineering Education Transformations, 37(3), 112–122.

Kolanur, C. B., Tapaskar, R. P., Meti, V. V., Giriyapur, A. C., & Karadagi, S. (2026). Practice-based learning in control systems design: A pedagogical framework for enhanced engineering education. Journal of Engineering Education Transformations, 39(3), 1–12.

May, D., & Terkowsky, C. (2014). What should they learn? A short comparison between different areas of competence and accreditation boards' criteria for engineering education. In Proceedings of the 2014 IEEE Global Engineering Education Conference (EDUCON) (pp. 1046–1050). IEEE. https://doi.org/10.1109/EDUCON.2014.6826252

Rajendra Prasad, M., & Krishna Reddy, D. (2015). Project based teaching methodology for embedded engineering education. Journal of Engineering Education Transformations, 28(2), 28–35.

Saleh, M. (2009). Challenges in engineering education: A view towards the future. In Proceedings of the 3rd International Conference on E-Learning in Industrial Electronics (ICELIE) (pp. 1–6). IEEE.

Siddapuram, A., Devika, S. V., & Bonkuri, M. A. (2024). Quality practices and accreditation in higher education institutions: A roadmap for excellence in engineering education. Journal of Engineering Education Transformations, 37(Special Issue 2), 78–89.