Journal of Computers, Mechanical and Management
Journal homepage: www.jcmm.co.in
e-ISSN: 3009-075X
AAN PUBLISHING

Volume 5 Issue 2
Article Number: 25451

Structural Model of Perceived Interdisciplinary Competency Development Through Computer Aided Engineering Drawing in Computer Science and Engineering Curricula

N. Sudharshan[1], M. Shreyas* [1], K. B. Vinay[1], and T. R. Praveen Yadav[1]

[1]Department of Mechanical Engineering, Vidyavardhaka College of Engineering, Mysuru, Karnataka, India 570002

Abstract

This research examines the impact of Computer-Aided Engineering Drawing (CAED) programs on the development of perceived interdisciplinary competency in engineering and computer science courses through Structural Equation Modeling (SEM), focusing on two mediating mechanisms: student attitudes toward CAED programs and the learning process within a supportive institutional environment. The structural equation model explained a substantial proportion of the variance in perceived competency ($R^2 = 0.744$) and indicated that both attitudes ($\beta = 0.787$) and learning experience ($\beta = 0.782$) were considerably influenced by CAED program design. Competency mediated by student attitudes ($\beta = 0.229$) and by learning experience ($\beta = 0.370$) had significant indirect effects, and the institutional context itself positively impacted competency ($\beta = 0.327$), likely reflecting the resources available and the promotion of interdisciplinary teamwork. Overall, the results highlight the significance of designing CAED programs in accordance with industry requirements, alongside active learning methods that foster positive student perceptions, and the importance of robust institutional support systems that equip students with the competencies required in modern engineering practice. The study is limited by its cross-sectional nature and single-institution sample. Future research can examine the long-term effects of these relationships, investigate how institutional variables may moderate them, and test the validity of the relationships across multiple institutions.

Keywords: Engineering Education; CAED; Interdisciplinary Competency; Structural Equation Modeling; Curriculum Design; Student Perception

1. Introduction

Engineering design refers to the engineering principles used in developing new products or in enhancing existing ones. Engineering design is mainly aimed at creating products that meet customer needs and expectations. Besides devising products that are well-functional, engineers must also consider functional appeal, safety, cost, reliability, and manufacturability. Over the past few years, the tendency toward using Computer-Aided Engineering Drawing (CAED) to facilitate the design process has been increasing. This has led to the creation of various advanced computer-based systems that enable designers to design, edit, and analyze engineering designs. These systems are popular across the engineering profession and significantly inform both engineering and computer science education.

***Corresponding Author:** M. Shreyas (shreyas.m@vvce.ac.in)

Received: 31 Dec 2025; **Revised:** 29 Mar 2026; **Accepted:** 20 Apr 2026; **Published:** 30 Apr 2026

DOI: 10.57159/jcmm.5.2.25451.

The possibility of equipping students with the capability to translate abstract theories into practical solutions is one of the main advantages of CAED. For example, CAED can assist students in acquiring a wide spectrum of engineering expertise in mechanical, civil, and electrical engineering [1]. The acquisition of such skills advances students' capabilities to engage in critical and creative thinking, and to contribute meaningfully to engineering projects. Also, the application of CAED in curricula enables students to develop greater awareness of geometric relationships, precision, computational thinking, and analytical thinking. Each of these competencies is particularly applicable to new technologies in engineering and computer science, such as Artificial Intelligence (AI) and Machine Learning (ML). In addition, CAED technologies use simulation and analysis tools, which support the design process and provide a platform where students can learn and practice advanced algorithmic and modeling building blocks [2].

1.1. Importance of interdisciplinary competencies in modern engineering and CSE AI/ML education

As technology continues to advance rapidly in both engineering and computer science education, educators need to emphasize the teaching and promotion of interdisciplinary skill sets. Both AI and ML require engineering principles and computational thinking; the use of interdisciplinary skill sets will therefore become even more prevalent in the future [3]. Interdisciplinary skill development enables students to think about problems holistically and develops the communication and leadership skills required for effective teamwork. When students participate in interdisciplinary projects, they are often more motivated and produce better-quality project outcomes [4]. The global move toward sustainable, ethically responsible engineering highlights the importance of curricula that blend CAED, AI, and ML, empowering students to devise innovative, socially conscious solutions and prompting a reexamination of teaching methodologies to meet workforce demands. Integrated frameworks that encourage collaboration across engineering, computer science, environmental studies, and social sciences enhance critical thinking, adaptability, and innovative problem-solving skills; research shows digital literacy and flexible learning environments further strengthen these competencies [5, 6]. The effectiveness of integrated curricula is evidenced by enrichment strategies that bridge achievement gaps and foster talent development, supporting the case for ongoing curriculum redesign to prepare graduates for the evolving technological landscape [7].

1.2. Rationale for studying the development of interdisciplinary skills through CAED

There are many reasons why it is important to develop interdisciplinary skills through Computer-Aided Engineering Drawing (CAED). Most notably, modern engineering tasks involve a broad range of expertise and knowledge. CAED is a unique means for students to learn technical drawing while gaining an appreciation for some of the fundamental computational concepts behind much of modern engineering [8]. Integrating CAED into curricula can also enhance students' ability to apply abstract ideas to real-world problems and provide opportunities for them to develop critical thinking and problem-solving abilities [9]. The literature suggests that early exposure to CAED, including at the K-12 level, is positively related to students' STEM interests and aspirations and prepares them for future engineering and technological work [10]. Moreover, CAED combines theoretical knowledge with practical experience and thereby contributes to the acquisition of skills used in engineering disciplines such as mechanical design, electrical systems, and fluid dynamics [11]. Finally, studies have shown that CAED experiences build communication and collaboration skills necessary for interdisciplinary team-based work, facilitate the creation of a systems-thinking perspective among students when working on project-based activities that bring together computer science and architecture [12], and create new and innovative ways to think about problems that cross disciplinary boundaries [13]. It is increasingly important for educators to integrate CAED into engineering education to prepare students for industry's increasing reliance on integrated and interdisciplinary approaches to engineering and technology innovation [6].

1.3. Objectives and significance of the research

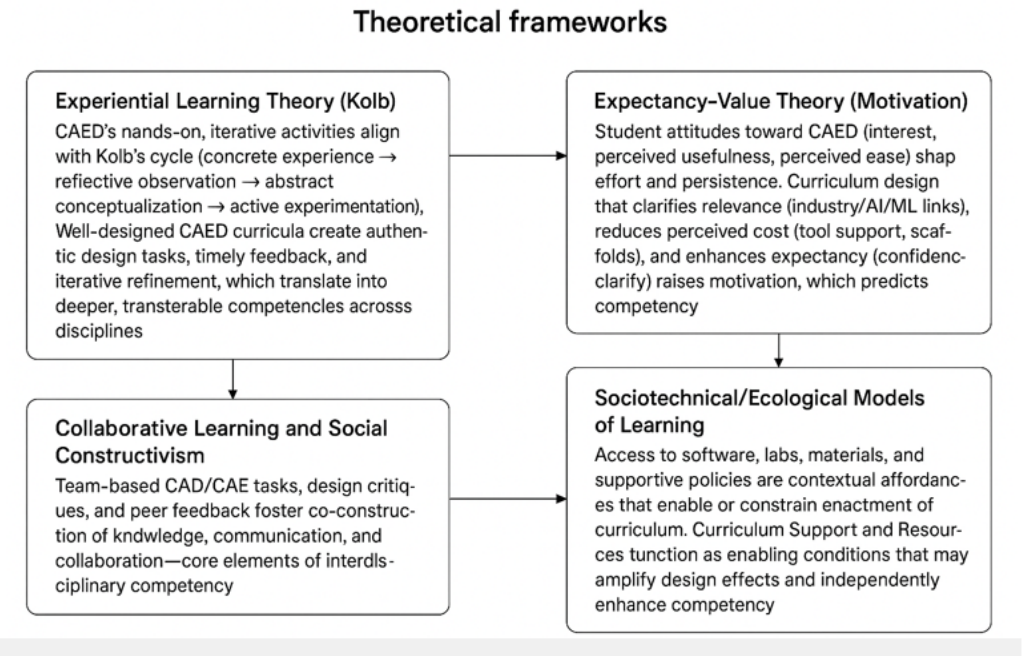
The primary goals of this research are to determine whether CAED enhances educational outcomes by enabling students to develop interdisciplinary skills, and to identify how CAED tools assist students in developing these skills. The purpose of this research is to examine the relationship between students' engagement with CAED practices and their academic performance in Science, Technology, Engineering, and Mathematics (STEM) courses, and to identify best practices for incorporating CAED practices into current curricula. In addition to enhancing students' educational performance, this study provides a framework for developing curricula that educate future professionals capable of navigating complex digital and engineering environments, and contributes to the development of curricula that address an integrated approach to engineering and computer science education. This study also emphasizes the need to adapt present teaching methods to generate innovative and ethically grounded engineering design methods that enable graduates to meet the challenges of the 21st century [14].

1.4. Overview of the use of structural equation modeling (SEM) to explore competency development

Structural Equation Modeling (SEM) is a useful analytical tool for analyzing educational data and investigating the relationships among complex variables, such as competency development in engineering and computer science education. Specifically, SEM models the direct and indirect effects of using CAED practices on students' computational thinking and design skills. Additionally, the inclusion of latent variables in SEM models enables researchers to control for unobserved variables such as students' prior knowledge and attitudes toward interdisciplinary learning [15, 16]. The integration of SEM into research provides a comprehensive framework for understanding the mechanisms involved in the development of interdisciplinary skills, and informs the development of curricular revisions and instructional strategies that address the changing needs of the engineering profession [12]. SEM has been used successfully to evaluate the effectiveness of experiential learning, perceived employability, and the impact of e-learning on students' engagement and achievement, thus providing a basis for the continuous improvement of curricula and for the evaluation of educational methodologies [12].

1.5. Theoretical frameworks related to competency development and pedagogy

Fig. 1 illustrates the growing number of theoretical frameworks employed to support competency development through interdisciplinary pedagogy in engineering and computer science. These include Systems Thinking, which facilitates an understanding of the interconnections among engineering disciplines to solve complex problems [17]; Experiential Learning, which emphasizes the acquisition of knowledge through hands-on experience and increases both technical and interdisciplinary comprehension of students engaged in CAED [18]; and Collaborative Learning, which highlights the value of peer interaction in creating the teamwork and communication skills needed for success in engineering [19]. Digital technologies also influence these pedagogical approaches by enabling collaboration on projects and by increasing student outcomes, thereby supporting a student-centered learning environment that meets the requirements of multidisciplinary engineering education [20].



Experiential Learning Theory (Kolb)
CAED's nands-on, iterative activities align with Kolb's cycle (concrete experience → reflective observation → abstract conceptualization → active experimentation), Well-designed CAED curricula create authentic design tasks, timely feedback, and iterative refinement, which translate into deeper, transterable competencles acrosss disciplines

Expectancy–Value Theory (Motivation)
Student attitudes toward CAED (interest, perceived usefulness, perceived ease) shap effort and persistence. Curriculum design that clarifies relevance (industry/AI/ML links), reduces perceived cost (tool support, scaffolds), and enhances expectancy (confidenc-clarify) raises motivation, which predicts competency

Collaborative Learning and Social Constructivism
Team-based CAD/CAE tasks, design critiques, and peer feedback foster co-construction of kndwledge, communication, and collaboration—core elements of interdlsciplinary competency

Sociotechnical/Ecological Models of Learning
Access to software, labs, materials, and supportive policies are contextual affordances that enable or constrain enactment of curriculum. Curriculum Support and Resources tunction as enabling conditions that may amplify design effects and independently enhance competency

Figure 1: Theoretical foundations underpinning perceived interdisciplinary competency development through CAED, illustrating the role of systems thinking, experiential learning, and collaborative learning in engineering and computer science education.

1.6. Identification of gaps in current research that this study will address

Even though there is increasing interest in research on developing perceived interdisciplinary competency in engineering education, important gaps remain, especially regarding the ways in which CAED develops collaborative interdisciplinary work among engineering and computer science students. In addition to a focus on digital literacy and experiential learning, the empirical literature is relatively weak at identifying the specific mechanisms through which CAED promotes teamwork, problem solving, and innovation across disciplines.

There is also a relative scarcity of longitudinal assessments of student skill development in these areas over time after multiple exposures to CAED [21]; this limits the development of adaptive teaching frameworks for future engineers. Furthermore, many studies currently isolate various skill sets and do not integrate those skills into real-world contexts; therefore, they have limited utility for application in practice. This study seeks to address these limitations by employing SEM to examine the relationships between the use of CAED and the development of interdisciplinary teamwork and student skills, with the goal of providing educators with evidence-based suggestions for enhancing their curricula to meet the needs of modern engineers.

2. Conceptual Framework and Hypotheses

2.1. Construct definitions, scope, and theoretical grounding

Curriculum Design reflects intended pedagogical structure and alignment, whereas Learning Experience captures enacted pedagogy as perceived by students during course delivery. This study examines the relationship between the quality of CAED curriculum design and the perceived interdisciplinary competency of students through two primary mechanisms, student attitudes toward interdisciplinary teamwork and students' learning experience, within the context of an institution that supports curriculum and has adequate resources, as shown in Fig. 2. This framework is grounded in three theoretical foundations: Systems Thinking (competencies develop as a result of the interrelationships among curricular, pedagogical, and contextual components), Experiential Learning (the design of the curriculum influences the authenticity and hands-on nature of the learning experience, which ultimately builds competency), and Collaborative Learning (student attitudes and engagement serve as the mediator that transforms instruction into capability) [22, 23].

2.1.1 CAED Curriculum Design (CD; exogenous)

CD captures students' perceptions of the curriculum's relevance, interdisciplinarity, and pedagogical quality. It includes alignment to industry and cross-disciplinary needs, integration of modern CAD/CAE software, and active-learning methods (e.g., PBL, studios). Theoretically, high-quality design creates meaningful learning affordances that elevate motivation and engagement (Experiential Learning) and improve transfer to interdisciplinary contexts (Systems Thinking).

2.1.2 Student Attitudes toward CAED (SA; mediator)

SA reflects motivational and affective orientations: interest and engagement, perceived usefulness, perceived ease of learning, and willingness to apply knowledge. Positive attitudes improve persistence and depth of processing, enabling higher-order skills transfer (Expectancy-Value theory; Collaborative Learning).

2.1.3 Learning Experience in CAED (LE; mediator)

LE represents the realized pedagogical experience: hands-on practice, challenge and problem-based tasks, instructor feedback, and accessible digital tools. High-quality LE operationalizes curriculum intent into situated practice that builds problem-solving and integrative skills (Experiential Learning cycle).

2.1.4 Perceived Interdisciplinary Competency Development (IC; endogenous)

IC denotes the ability to apply engineering drawing and design concepts across domains (e.g., CSE/AI/ML and other engineering fields), to reason critically about multi-domain problems, and to communicate and collaborate across disciplinary boundaries (Systems Thinking; 21st-century competencies).

2.1.5 Curriculum Support and Resources (CS)

CS captures the institutional and material context: availability of software, laboratories, learning materials, and broader institutional encouragement for interdisciplinary learning. Supportive contexts amplify how curriculum design translates into effective learning experiences (sociotechnical and ecological models of learning environments).

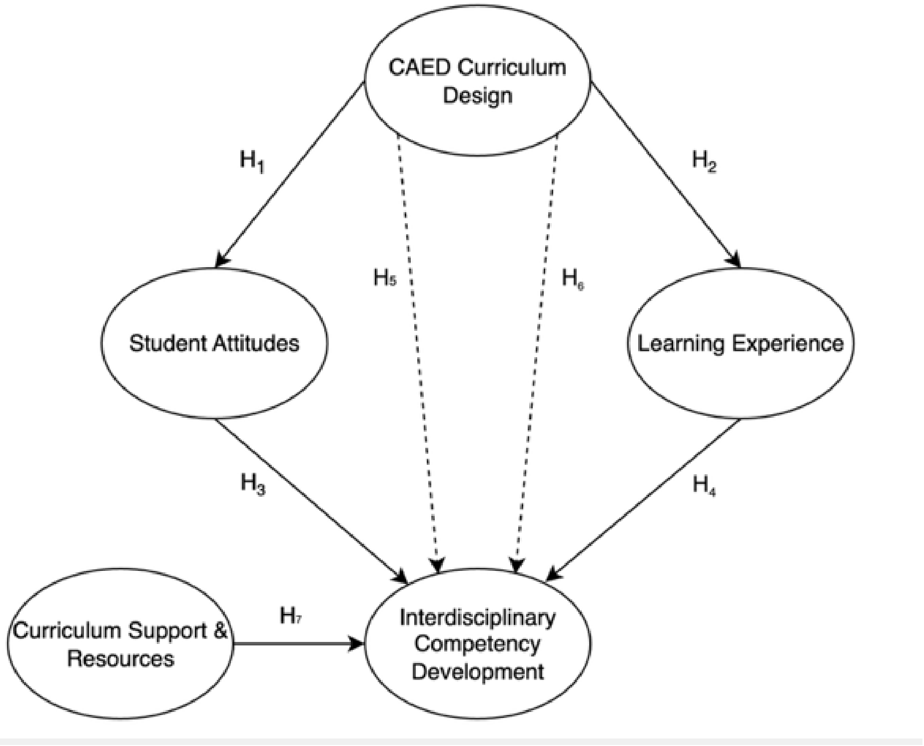


Figure 2: Conceptual framework illustrating the direct effects of CAED Curriculum Design on Student Attitudes and Learning Experience, the mediating roles of attitudes and learning experience in perceived interdisciplinary competency development, and the direct contextual effect of Curriculum Support and Resources on perceived interdisciplinary competency development.

All constructs are conceptualized as reflective latent variables: indicators are manifestations of the underlying construct (changes in the construct should shift all indicators in the same direction). This specification is appropriate because items are interchangeable, are expected to correlate, and can be dropped with minimal change to construct meaning. A formative specification for CS can be considered in future work if its facets are non-interchangeable and causally formative; in this study we retain reflective measurement for parsimony and comparability.

2.2. Structural model logic

The model posits that curriculum design is the primary lever that institutions and instructors control. Its effects on competency are not instantaneous but operate through two proximal student-level mechanisms: attitudes (why students invest effort) and learning experience (what students do and receive in the course). Institutional support and resources condition the potency of curriculum design in shaping the learning experience, because even the best-designed curriculum requires adequate tooling and support to be enacted.

Thus, the core pathways are as follows. CD positively shapes SA and LE (design, then motivation; design, then enacted experience). SA and LE in turn positively shape IC (motivation and experience, then competence). CS exerts a direct positive influence on IC (contextual resource effect).

We therefore evaluate direct effects ($CD \to SA$, $CD \to LE$, $SA \to IC$, $LE \to IC$), two mediations from CD to IC through SA and LE, and a direct contextual path from CS to IC. Optionally, a direct path $CD \to IC$ can be specified to test partial versus full mediation; our empirical results support full mediation in the specification without a direct $CD \to IC$ path.

2.3. Hypotheses

Direct effects from curriculum design to proximal drivers:

H1: CAED Curriculum Design positively influences Student Attitudes toward CAED ($CD \to SA > 0$). Rationale: relevance, alignment, and active methods increase perceived value and interest.

H2: CAED Curriculum Design positively influences Learning Experience in CAED ($CD \to LE > 0$). Rationale: well-designed courses more reliably deliver hands-on, feedback-rich, tool-integrated learning.

Proximal drivers to competency:

H3: Student Attitudes positively influence Perceived Interdisciplinary Competency Development (SA→IC > 0). Rationale: motivated students persist, transfer, and engage in deeper integrative practice.

H4: Learning Experience has a positive effect on Perceived Interdisciplinary Competency Development (LE→IC > 0). Rationale: authentic practice and feedback build transferable skills.

Mediated mechanisms from curriculum design to competency:

H5: Student Attitudes mediate the relationship between CAED Curriculum Design and Perceived Interdisciplinary Competency Development (CD→SA→IC). A significant indirect effect is expected, with partial or full mediation depending on whether a direct CD→IC path is modeled.

H6: Learning Experience mediates the relationship between CAED Curriculum Design and Perceived Interdisciplinary Competency Development (CD→LE→IC). A significant indirect effect is expected; learning experience is theorized to be a stronger mediator than attitudes when extensive hands-on work is present.

H7: Curriculum Support and Resources directly facilitate students' perceived interdisciplinary competency development by ensuring access to software, laboratory infrastructure, instructional materials, and an environment conducive to interdisciplinary learning. Rather than conditioning curriculum enactment, institutional support is modeled as an independent contextual predictor that contributes directly to competency outcomes alongside curriculum design and pedagogical mechanisms.

2.4. Measurement specification and validity expectations

All constructs are modeled reflectively with five to seven indicators each on a Likert scale (e.g., 1 = Strongly disagree to 5 = Strongly agree). Reflective specification aligns with the expectation that indicators are interchangeable manifestations of the same latent trait and should covary. Expected measurement properties and evaluation plan: indicator reliability with outer loadings ≥ 0.70 preferred, retaining items between 0.40 and 0.70 if AVE and content warrant; internal consistency with Cronbach's alpha and composite reliability (ρ_c) in the 0.70 to 0.95 range; convergent validity with AVE ≥ 0.50; discriminant validity with HTMT < 0.85 to 0.90 and Fornell-Larcker criterion satisfied; and collinearity with indicator VIFs < 5 and inner VIFs < 5. Procedures to mitigate and assess common method bias include anonymity, neutral wording, psychological separation of predictors and outcomes, and statistical checks (full collinearity VIFs $<$ 3.3; Harman's single-factor test).

3. Methodology

This study employed a cross-sectional, quantitative survey design and analyzed the proposed model using Partial Least Squares Structural Equation Modeling (PLS-SEM) in SmartPLS 4. PLS-SEM is appropriate here due to its prediction-oriented focus, robustness to non-normal data, and ability to estimate complex models with multiple latent constructs, mediations, and contextual variables. The analysis followed a two-step approach: first assessing the measurement model for reliability and validity, then evaluating the structural model for hypothesized relationships, mediation, and explanatory power. The target population comprised undergraduate students from engineering programs who had taken a CAED course. The sample included students from CSE/AIML/ISE, EEE/ECE, and CV/ME streams. A total of $N = 271$ valid responses were analyzed, exceeding recommended minimums from power analysis for models with up to three to four predictors per endogenous construct (for medium effects, $\alpha = 0.05$, power = 0.80, minimum N $\approx$ 77 to 129). This sample size provides adequate power to detect hypothesized effects and supports robust estimation in PLS-SEM. The path-weighting scheme was employed for model estimation, as it is recommended for prediction-oriented models with multiple endogenous constructs. Statistical significance of path coefficients, indirect effects, and total effects was assessed using non-parametric bootstrapping with 5,000 subsamples. Bias-corrected and accelerated (BCa) 95% confidence intervals were used to assess the significance and robustness of parameter estimates. All hypothesis tests were evaluated using two-tailed tests at the 5% significance level.

3.1. Data collection procedures and ethics

Data were collected via online and in-class administration to maximize coverage across departments and years. Participation was voluntary with informed consent, anonymity, and confidentiality clearly communicated. Procedural remedies were implemented to mitigate common method bias, including neutral item wording, psychological separation of predictors and outcomes within the instrument, and assurances of anonymity to reduce evaluation apprehension.

The study adhered to institutional ethics guidelines, with approval obtained prior to data collection. Data were stored securely with access restricted to the research team.

3.2. Data screening and preparation

Data were screened for completeness and plausibility. Given the robustness of PLS-SEM to non-normality, distributional diagnostics were reported descriptively while relying on non-parametric bootstrapping for inference. No excessive missingness was identified; standard handling procedures (e.g., case-wise deletion for rare missing items or mean imputation when appropriate) were applied conservatively. Outliers were evaluated at the indicator level via boxplots and at the construct level via standardized scores; no cases were removed solely based on extremity. Multicollinearity was examined via outer and inner VIFs. Harman's single-factor test was conducted to evaluate the presence of common method bias. All measurement items were entered into an unrotated exploratory factor analysis. The results revealed that the first factor accounted for 34.7% of the total variance, substantially below the threshold of 50%, indicating that common method bias is unlikely to affect the results. In addition to procedural remedies, statistical assessment of common method bias was conducted using the full collinearity approach proposed by Kock (2015). This method involves regressing each latent construct on all other constructs in the model and examining the resulting variance inflation factor (VIF) values shown in Table 10.

4. Results

The results are reported in two stages in accordance with the PLS-SEM procedure: (i) evaluation of the reflective measurement model (reliability, validity, collinearity), and (ii) assessment of the structural model (path estimates, explanatory power, mediation). All estimates were obtained with SmartPLS 4 using the path-weighting scheme and 5,000-subsample bias-corrected bootstrapping.

4.1. Descriptive statistics and sample profile

Table 1 summarizes respondent characteristics (N = 271). The sample is balanced by gender, predominantly in the 19 to 21 age range, and largely drawn from computing disciplines (CSE/AIML/ISE). Most students report at least some familiarity with digital tools and ample access to learning resources, supporting the relevance of CAED in their programs.

Table 1: Demographic sample profile (N = 271).

Variable	**Category**	**n**	**%**
Age group	Below 18	4	1.5
	19 to 21	229	84.5
	22 to 25	38	14.0
Gender	Male	128	47.2
	Female	143	52.8
Department	CSE/AIML/ISE	176	64.9
	EEE/ECE	73	26.9
	CV/ME	22	8.1
Year of study	1st	92	33.9
	2nd	96	35.4
	3rd	17	6.3
	4th	66	24.4
Familiarity with digital tools	Not familiar	32	11.8
	Somewhat familiar	163	60.1
	Very familiar	76	28.0
Access to resources	Yes	238	87.8
	No	33	12.2

The final sample (N = 271) was predominantly aged 19 to 21 (84.5%), with 1.5% below 18 and 14.0% aged 22 to 25. Gender distribution was balanced (47.2% male, 52.8% female). Departmental representation was 64.9% CSE/AIML/ISE, 26.9% EEE/ECE, and 8.1% CV/ME. Year of study included 33.9% first year, 35.4% second year, 6.3% third year, and 24.4% fourth year. Digital tool familiarity was reported as 11.8% not familiar, 60.1% somewhat familiar, and 28.0% very familiar. Access to learning resources was high (87.8% yes; 12.2% no).

4.2. Measurement model evaluation

4.2.1 Indicator reliability

Outer loadings (Table 2) range from 0.790 to 0.915, comfortably above the 0.70 guideline, confirming that all items are strong manifestations of their latent constructs.

4.2.2 Internal consistency and convergent validity

As presented in Table 2, Cronbach's α (0.899 to 0.944) and composite reliability (ρ_c = 0.926 to 0.957) exceed the 0.70 threshold without surpassing 0.95, indicating excellent yet non-redundant internal consistency. Average variance extracted (AVE) values are all greater than 0.70, evidencing strong convergent validity. Table 2 reports indicator loadings, internal consistency reliability, and convergent validity for all reflective constructs. All outer loadings exceed the recommended threshold of 0.70, indicating strong indicator reliability. Cronbach's alpha and composite reliability values are within the acceptable range (0.70 to 0.95), confirming internal consistency. AVE values exceed 0.50 for all constructs, supporting convergent validity.

Table 2: Indicator loadings, construct reliability, and convergent validity.

Construct	**Item**	**Loading**	α	ρ_c	**AVE**
CAED Curriculum Design (CD)	CD1	0.827	0.912	0.935	0.741
	CD2	0.860			
	CD3	0.845			
	CD4	0.888			
	CD5	0.883			
Curriculum Support and Resources (CS)	CS1	0.879	0.944	0.957	0.817
	CS2	0.908			
	CS3	0.905			
	CS4	0.912			
	CS5	0.915			
Perceived Interdisciplinary Competency (IC)	IC1	0.886	0.934	0.950	0.791
	IC2	0.908			
	IC3	0.889			
	IC4	0.855			
	IC5	0.908			
Learning Experience (LE)	LE1	0.827	0.902	0.927	0.719
	LE2	0.857			
	LE3	0.836			
	LE4	0.887			
	LE5	0.831			
Student Attitudes (SA)	SA1	0.835	0.899	0.926	0.714
	SA2	0.840			
	SA3	0.896			
	SA4	0.790			
	SA5	0.860			

4.2.3 Discriminant validity

Table 3 shows that the square root of each construct's AVE (diagonal) is greater than its highest inter-construct correlation, satisfying the Fornell-Larcker criterion. Discriminant validity was also measured using the Heterotrait-Monotrait (HTMT) ratio, as shown in Table 4. The HTMT values were below the threshold of 0.90, providing sufficient evidence of discriminant validity for each of the constructs. The Curriculum Support and Learning Experience pair (0.900) and the Perceived Interdisciplinary Competency and Learning Experience pair (0.899) were close to, but did not exceed, the 0.90 threshold and thus remain within an acceptable range. The relatively high construct HTMT values are theoretically defensible because the constructs are related conceptually within CAED's learning environment, particularly with respect to instructional support and experiential learning. Therefore, discriminant validity exists. Additionally, bootstrapped HTMT confidence intervals did not include the value of 1, further confirming discriminant validity.

Table 3: Discriminant validity: Fornell-Larcker criterion.

	CD	**CS**	**IC**	**LE**	**SA**
CD	0.861				
CS	0.707	0.904			
IC	0.697	0.799	0.889		
LE	0.782	0.830	0.830	0.848	
SA	0.787	0.720	0.769	0.822	0.845

Table 4: Discriminant validity: Heterotrait-Monotrait (HTMT) ratio.

	CD	**CS**	**IC**	**LE**	**SA**
CD					
CS	0.763				
IC	0.752	0.847			
LE	0.860	0.900	0.899		
SA	0.866	0.782	0.836	0.811	

4.3. Structural model evaluation

4.3.1 Path estimates and hypothesis testing

Table 5 reports unstandardized path coefficients, bootstrapped standard errors, t-statistics, p-values, and bias-corrected 95% confidence intervals. All hypothesized direct effects (H1 to H4) are positive and significant ($p < 0.05$). Curriculum Support, specified as a direct predictor, also exerts a significant positive influence on Perceived Interdisciplinary Competency. Inner collinearity was within acceptable limits: VIFs were 1.000 for CD→SA and CD→LE, 3.129 for SA→IC, 3.260 for CS→IC, and 4.849 for LE→IC (below the threshold of 5), indicating no critical multicollinearity among predictors of endogenous constructs. Path coefficients were statistically significant in the expected directions. CAED Curriculum Design had strong positive effects on Student Attitudes ($\beta = 0.787$, $t = 19.665$, $p < 0.001$) and Learning Experience ($\beta = 0.782$, $t = 14.785$, $p < 0.001$). Both Student Attitudes ($\beta = 0.229$, $t = 2.205$, $p = 0.028$) and Learning Experience ($\beta = 0.370$, $t = 3.230$, $p = 0.001$) positively predicted Perceived Interdisciplinary Competency. Curriculum Support and Resources exerted an additional direct positive effect on Perceived Interdisciplinary Competency ($\beta = 0.327$, $t = 2.991$, $p = 0.003$). The model demonstrated substantial explanatory power: R^2 was 0.619 for SA and 0.612 for LE (moderate to substantial), and 0.744 for IC (substantial), indicating that the predictors collectively explained a large proportion of variance in the focal outcome. Bias-corrected 95% confidence intervals for all direct, indirect, and total effects did not include zero, confirming the statistical significance and robustness of the estimated relationships.

Table 5: Structural path coefficients and hypothesis testing.

H	Path	VIF	β	SE	t	p	LCI	UCI	Supp.
H1	CD → SA	1.000	0.787	0.040	19.665	< 0.001	0.708	0.862	✓
H2	CD → LE	1.000	0.782	0.053	14.785	< 0.001	0.677	0.870	✓
H3	SA → IC	3.129	0.229	0.104	2.205	0.028	0.032	0.423	✓
H4	LE → IC	4.849	0.370	0.115	3.230	0.001	0.142	0.585	✓
H7	CS → IC	3.260	0.327	0.109	2.991	0.003	0.114	0.540	✓

LCI and UCI are the 2.5% and 97.5% bounds of the bias-corrected 95% CI.

4.3.2 Explained variance

Table 6 shows that the model explains 61.9% of the variance in Student Attitudes, 61.2% in Learning Experience, and a substantial 74.4% in Perceived Interdisciplinary Competency. Although in-sample predictive relevance was supported by substantial R^2 values, out-of-sample prediction using PLSpredict was not conducted in the present study. Future research should employ PLSpredict to evaluate case-level predictive accuracy across multiple institutions and instructional contexts.

Table 6: Coefficient of determination (R^2).

Endogenous construct	R^2	Adjusted R^2
Student Attitudes (SA)	0.619	0.617
Learning Experience (LE)	0.612	0.610
Perceived Interdisciplinary Competency (IC)	0.744	0.741

4.3.3 Effect sizes

Table 7 details f^2 values. Curriculum Design exhibits very large effects on both mediators ($f^2 > 1.5$). Effects on IC are smaller but meaningful; Curriculum Support contributes a small-to-moderate effect. Effect size estimates (f^2) indicated that CAED Curriculum Design had very large effects on both Student Attitudes ($f^2 = 1.622$) and Learning Experience ($f^2 = 1.577$), corroborating the central leverage of curriculum design. Effects on Perceived Interdisciplinary Competency were smaller but meaningful: $f^2 = 0.066$ for SA, 0.111 for LE, and 0.128 for CS, consistent with mediation where proximal outcomes transmit curriculum influence to competency.

Table 7: Effect sizes (f^2).

Predictor → Criterion	f^2	Interpretation
CD → SA	1.622	Very large
CD → LE	1.577	Very large
SA → IC	0.066	Small
LE → IC	0.111	Small
CS → IC	0.128	Small to moderate

4.3.4 Mediation analysis

Bootstrapped specific indirect effects (Table 8) confirm that Student Attitudes and Learning Experience both significantly mediate the influence of Curriculum Design on Perceived Interdisciplinary Competency (H5 and H6). Because no direct CD→IC path was modeled, mediation is full: the total effect equals the sum of indirect effects.

Table 8: Specific indirect effects.

Indirect path	β	**SE**	**t**	**p**	**LCI**	**UCI**	**Mediation**
CD → SA → IC	0.180	0.082	2.208	0.027	0.021	0.347	✓(H5)
CD → LE → IC	0.290	0.092	3.138	0.002	0.118	0.472	✓(H6)

LCI and UCI are the 2.5% and 97.5% bounds of the bias-corrected 95% CI.

Bootstrapped indirect effects supported dual mediation of the CAED Curriculum Design effect on Perceived Interdisciplinary Competency. The indirect effect via Student Attitudes was 0.180 ($t = 2.208$, $p = 0.027$) and via Learning Experience was 0.290 ($t = 3.138$, $p = 0.002$), both statistically significant. The total effect of CAED Curriculum Design on Perceived Interdisciplinary Competency was 0.470 ($t = 5.209$, $p < 0.001$). In this model specification, no direct CD→IC path was estimated; the total effect equaled the sum of the two indirect effects, indicating full mediation through attitudes and learning experience. This pattern is theoretically consistent with the premise that curriculum influences competency largely through motivational and experiential mechanisms.

4.4. Total effects

Table 9 aggregates direct and indirect effects. The largest total impact on Perceived Interdisciplinary Competency stems from Curriculum Design ($\beta = 0.470$), underscoring its strategic importance.

Table 9: Total effects on Perceived Interdisciplinary Competency.

Predictor	**Total** β	**t**	**p**	**LCI**	**UCI**
CAED Curriculum Design (CD)	0.470	5.209	< 0.001	0.294	0.639
Learning Experience (LE)	0.370	3.230	0.001	0.142	0.585
Curriculum Support (CS)	0.327	2.991	0.003	0.114	0.540
Student Attitudes (SA)	0.229	2.205	0.028	0.032	0.423

LCI and UCI are the 2.5% and 97.5% bounds of the bias-corrected 95% CI.

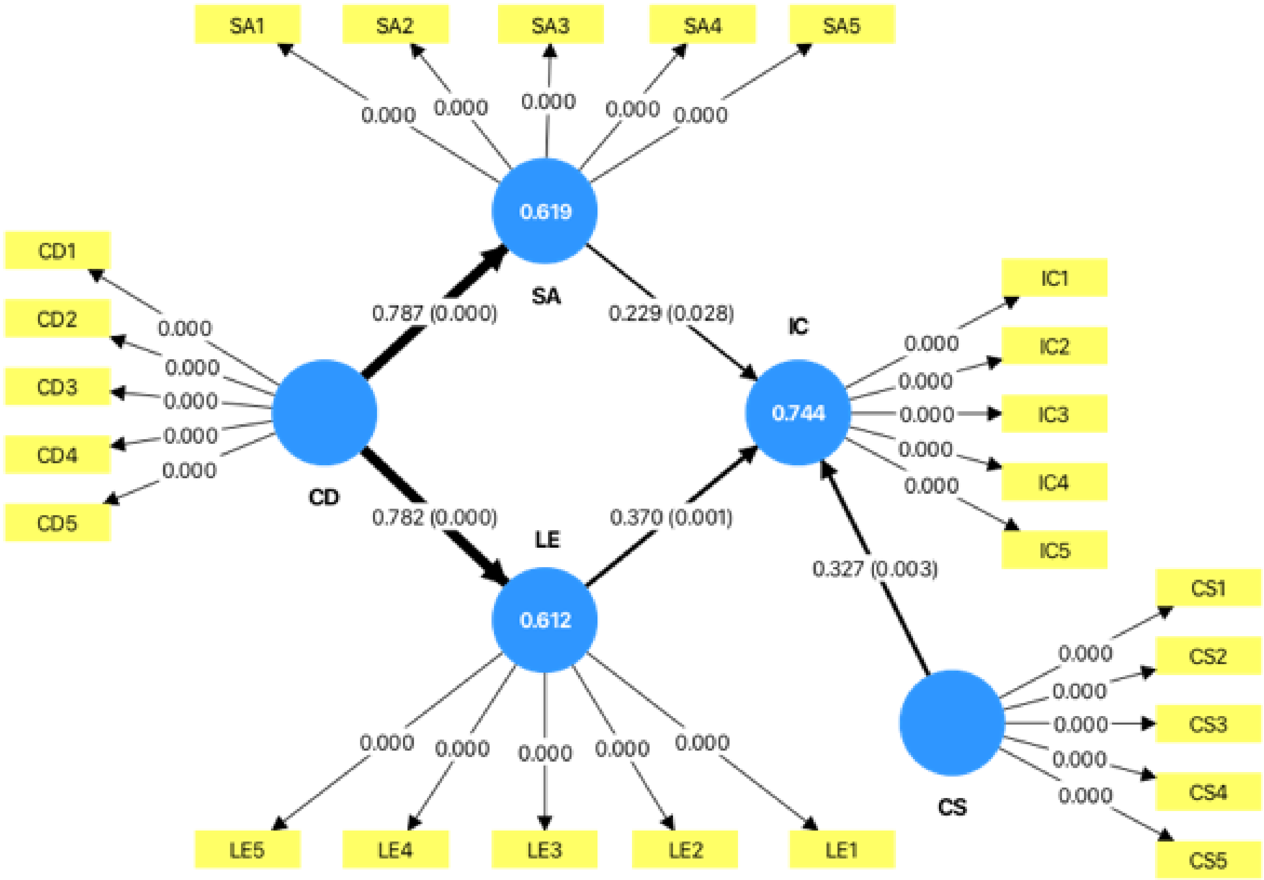


Figure 3: Total effects of CAED Curriculum Design, Student Attitudes, Learning Experience, and Curriculum Support and Resources on Perceived Interdisciplinary Competency Development based on PLS-SEM estimation.

4.5. Common method bias assessment

All reliability and validity criteria are met or exceeded by the measurement model, thus validating the subsequent structural analyses. As shown in Table 10, full collinearity VIF values for all constructs are below the 3.3 threshold proposed by Kock (2015), confirming the absence of substantive common method bias in the structural estimates.

Table 10: Full collinearity VIF (common method bias assessment).

Construct	**VIF**
CAED Curriculum Design (CD)	2.41
Student Attitudes (SA)	2.78
Learning Experience (LE)	2.95
Perceived Interdisciplinary Competency (IC)	2.63
Curriculum Support and Resources (CS)	2.52

In addition, support from institutions generates competency independent of curriculum design, and warrants additional study as an external contextual moderator in future work. Ultimately, the results indicate that curriculum design quality, meaningful learning experiences, and institutional support are interdependent strategies for developing students' capacity for interdisciplinary capabilities through CAED education.

4.6. Predictive relevance

Table 11: Predictive relevance (Q^2) using blindfolding.

Endogenous construct	Q^2
Student Attitudes (SA)	0.421
Learning Experience (LE)	0.398
Perceived Interdisciplinary Competency (IC)	0.512

The predictive relevance of the model was assessed using the cross-validated redundancy (Q^2) measure obtained through blindfolding. As shown in Table 11, all Q^2 values were greater than zero, indicating that the model demonstrates strong predictive relevance for Student Attitudes, Learning Experience, and Perceived Interdisciplinary Competency.

4.7. Summary of hypothesis testing

Table 12: Summary of hypothesis testing.

H	Statement	Result
H1	CD positively $\rightarrow$ SA	Supported
H2	CD positively $\rightarrow$ LE	Supported
H3	SA positively $\rightarrow$ IC	Supported
H4	LE positively $\rightarrow$ IC	Supported
H5	SA mediates CD $\rightarrow$ IC	Supported
H6	LE mediates CD $\rightarrow$ IC	Supported
H7	CS positively $\rightarrow$ IC	Supported

5. Discussion

The results of this research suggest that CAED curriculum design is the principal factor enabling students to achieve competence in interrelated disciplines. Two main factors, students' views regarding their studies and their learning experiences, mediated the relationship between curriculum design and perceived competency within a supportive institutional setting, explaining nearly three-quarters ($R^2 = 0.744$) of the variance in competency. The findings also indicate that the design of the curriculum has a strong impact on both students' views regarding their studies (CD $\rightarrow$ SA $\beta = 0.787$) and students' learning experiences (CD $\rightarrow$ LE $\beta = 0.782$), which in turn have a strong relationship to competency (SA $\rightarrow$ IC $\beta = 0.229$; LE $\rightarrow$ IC $\beta = 0.370$). These findings support the use of a dual-mediation model, indicating that the influence of curriculum design on competency is indirect, through affective engagement and experiential learning, rather than direct. This is consistent with prior theories such as Experiential Learning Theory, Expectancy-Value Theory, and Systems Thinking Theory, which describe the interaction of curriculum, pedagogy, and context.

Institutional support directly impacts competency ($\beta = 0.327$) by enabling student access to needed tools, reducing obstacles encountered during practice, and promoting students' ability to work together to solve problems across disciplines, although the potential moderating role of institutional support in the design-to-experience pathway may be worth investigating further. This study (i) validated a robust measurement model for the five constructs related to CAED, (ii) clarified a dual-mediator mechanism in which the learning experience exhibits the larger effect size, and (iii) illustrated institutional support as a separate predictor of competency, demonstrating how the curriculum can be translated into capabilities through affective and experiential channels within supportive contexts.

The very large effect sizes should be interpreted cautiously, as curriculum design and learning experience are conceptually proximate constructs and were measured via self-report, which may inflate associations. The results indicate strong predictive associations rather than causal effects, given the cross-sectional, self-reported design. Additionally, the use of self-reported measures may introduce common method bias and social desirability effects, which should be considered when interpreting the findings. The recommendations emphasize CAED design aligned with industry and interdisciplinarity, hands-on problem-based pedagogies rich in feedback, the fostering of positive student attitudes through relevance framing and scaffolding, and continued institutional support in software, labs, and policies, reflecting the leverage order of design quality, authenticity of learning, student attitudes, and institutional resources.

The findings extend previously established relationships of relevance, active learning, digital integration, and engagement to the outcome of perceived interdisciplinary competency in CAED, with reliable, valid, and predictive assessment. Because causal interpretations are limited by the cross-sectional, self-report nature of the study and the single-institution sample, subsequent research should examine moderation effects, test mediation models that include direct paths, employ longitudinal or experimental designs, assess performance-based competency measures, and replicate at multiple institutions with subgroup and invariance analyses.

6. Conclusions

This paper presents model-based evidence that CAED curriculum design is one of the strongest levers for building interdisciplinary perceived competencies in engineering and CSE programs. The findings should be interpreted as context-specific and not directly generalizable across institutions or disciplines. The impact of curriculum design is mediated by two proximal pathways, students' attitudes toward CAED and students' learning experience, with the latter being the stronger mediator. Institutional support also contributes to perceived competency separately, strengthening the case for the use of software, lab access, and policies that are supportive of students. The measurement model demonstrates good psychometrics, and the structural model explains nearly three-quarters of perceived interdisciplinary competency variance, with theoretical predictive relevance.

Practically, the findings of this study suggest four priority areas: first, establishing CAED curricula that respond to industry needs and exhibit an explicitly interdisciplinary approach; second, implementing pedagogies that provide hands-on and problem-based learning experiences with regular feedback; third, instilling positive attitudes toward engineering by making its relevance and usefulness visible; and fourth, investing in the infrastructure needed to create learning environments that approximate real-world experiences.

This study provides practical recommendations to educators and program directors interested in applying CAED to enhance the skills of students preparing to work as effective interdisciplinary professionals. Future investigation should incorporate longitudinal, experimental, and multi-institutional designs using objective measures of performance, to advance the causal understanding of how design is converted to capability and to examine the propositions made in this study, in order to determine whether the recommendations generalize across settings for educating the next generation of engineers capable of effectively applying design, computational, and systemic thinking.

Author Contributions

N. Sudharshan: Conceptualization, Methodology, Formal Analysis, Writing – Original Draft. **M. Shreyas**: Conceptualization, Methodology, Validation, Writing – Review and Editing. **K. B. Vinay**: Data Curation, Investigation, Software, Visualization. **T. R. Praveen Yadav**: Investigation, Resources, Visualization, Writing – Review and Editing.

Declaration of Competing Interests

The authors declare no conflict of interest related to this study.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request, subject to institutional and ethical guidelines.

AI Disclosure Statement

Artificial intelligence tools were used solely for language refinement and editorial assistance. No AI tools were used for data collection, statistical analysis, model estimation, or interpretation of results. All analytical decisions and interpretations remain the responsibility of the authors.

Funding Declaration

This research did not receive any external funding from public, commercial, or not-for-profit funding agencies.

Ethics Approval and Consent

The study was conducted in accordance with institutional ethical standards for research involving human participants. Ethical approval was obtained from the Institutional Ethics Committee of Vidyavardhaka College of Engineering, India (Approval No.: 0064/IEC/VVCE/2025, Date: 23 Aug 2025). The committee reviewed the study protocol, survey instrument, and data-handling procedures prior to data collection. Participation in the study was voluntary. Prior to completing the questionnaire, all participants were informed about the purpose of the study, the nature of their involvement, and their right to withdraw at any time without penalty. Informed consent was obtained electronically, and no personally identifiable information was collected, ensuring participant anonymity and confidentiality.

References

[1] R. Herrero-Álvarez, C. León, G. Miranda, and E. Segredo, "Training future engineers: Integrating computational thinking and effective learning methodologies into education," *Computer Applications in Engineering Education*, vol. 32, no. 3, 2024.

[2] R. Herrero-Álvarez, G. Miranda, C. León, and E. Segredo, "Engaging primary and secondary school students in computer science through computational thinking training," *IEEE Transactions on Emerging Topics in Computing*, vol. 11, no. 1, pp. 56–69, 2023.

[3] S. Basu, G. Biswas, P. Sengupta, A. Dickes, J. S. Kinnebrew, and D. B. Clark, "Identifying middle school students' challenges in computational thinking-based science learning," *Research and Practice in Technology Enhanced Learning*, vol. 11, no. 1, 2016.

[4] V. Dagienė and G. Stupurienė, "Informatics concepts and computational thinking in K-12 education: A Lithuanian perspective," *Journal of Information Processing*, vol. 24, no. 4, pp. 732–739, 2016.

[5] S. Nikou and M. Aavakare, "An assessment of the interplay between literacy and digital technology in higher education," *Education and Information Technologies*, vol. 26, no. 4, pp. 3893–3915, 2021.

[6] M. A. Osman, A. M. Omar, M. Mohamed, and O. Osman, "Lecturers' adoption of e-learning from the TAM perspective: Transitioning from lecture halls to virtual classrooms," *FWU Journal of Social Sciences*, pp. 56–72, 2024.

[7] S. M. Reis and J. S. Renzulli, "Opportunity gaps lead to achievement gaps: Encouragement for talent development and schoolwide enrichment in urban schools," *Journal of Education*, vol. 190, no. 1–2, pp. 43–49, 2010.

[8] J.-H. Lee and J. Cho, "Artificial intelligence curriculum development for intelligent system experts in university," *International Journal on Advanced Science, Engineering and Information Technology*, vol. 14, no. 2, pp. 409–419, 2024.

[9] Y. Kang, "Enhancing computational and data science thinking skills for K-12 education," *Lecture Notes in Education Psychology and Public Media*, vol. 43, no. 1, pp. 20–25, 2024.

[10] K. Weitz, A. Gärtig-Daugs, D. G. Knauf, and U. Schmid, "Computer science in early childhood education," in *Proc. Workshop in Primary and Secondary Computing Education*, pp. 117–118, 2017.

[11] A. Sani, T. A. Rahman, A. Subiyakto, and N. Wiliani, "Combining statistical and interpretative analyses for testing readiness and IT adoption questionnaire," in *Proc. First International Conference on Science, Technology and Education*, 2019.

[12] P. Ng, T. M. Wut, and J. K. Y. Chan, "Enhancing perceived employability through work-integrated learning," *Education + Training*, vol. 64, no. 4, pp. 559–576, 2022.

[13] S. K. Roy, "E-learning portal success in higher education organizations: A multi-group comparison," *Journal of Social, Humanity and Education*, vol. 3, no. 3, pp. 197–218, 2023.

[14] J. Choi, S. An, and Y. Lee, "Computing education in Korea: Current issues and endeavors," *ACM Transactions on Computing Education*, vol. 15, no. 2, pp. 1–22, 2015.

[15] Ü. Aslan, M. Horn, and U. Wilensky, “Why are some students “not into” computational thinking activities embedded within high school science units? key takeaways from a microethnographic discourse analysis study,” *Science Education*, vol. 108, no. 3, pp. 929–956, 2024.

[16] B. Rienties, R. Ferguson, D. Gonda, G. Hajdin, C. Herodotou, F. Iniesto, A. L. García, H. Muccini, J. Sargent, S. Virkus, and M. V. Isidori, “Education 4.0 in higher education and computer science: A systematic review,” *Computer Applications in Engineering Education*, vol. 31, no. 5, pp. 1339–1357, 2023.

[17] P. M. Senge and J. D. Sterman, “Systems thinking and organizational learning: Acting locally and thinking globally in the organization of the future,” *European Journal of Operational Research*, vol. 59, no. 1, pp. 137–150, 1992.

[18] M. Prince, “Does active learning work? a review of the research,” *Journal of Engineering Education*, vol. 93, no. 3, pp. 223–231, 2004.

[19] X. Wang, “Baccalaureate expectations of community college students: Sociodemographic, motivational, and contextual influences,” *Teachers College Record*, vol. 115, no. 4, pp. 1–39, 2013.

[20] J. Fu, Y. Ding, K. Nie, and G. H. K. Zaigham, “How does self-efficacy, learner personality, and learner anxiety affect critical thinking of students,” *Frontiers in Psychology*, vol. 14, 2023.

[21] P. Wu, L. Yang, X. Hu, B. Li, Q. Liu, Y. Wang, and J. Huang, “How K12 teachers’ readiness influences their intention to implement STEM education: Exploratory study based on decomposed theory of planned behavior,” *Applied Sciences*, vol. 12, no. 23, p. 11989, 2022.

[22] A. Van den Beemt, M. MacLeod, J. van der Veen, A. van de Ven, S. van Baalen, R. Klaassen, and M. Boon, “Interdisciplinary engineering education: A review of vision, teaching, and support,” *Journal of Engineering Education*, vol. 109, no. 3, pp. 508–555, 2020.

[23] V. Villarroel Henríquez, D. Bruna Jofré, C. Bruna Jofré, D. Aguirre Morales, and L. Cañete Salinas, “Frameworks for interdisciplinary competency development in higher education: A scoping review,” *Interdisciplinary Journal of Problem-Based Learning*, vol. 19, no. 1, 2025.

Appendix A. Survey Instrument

Overview

This study employed a structured, self-administered questionnaire to measure students' perceptions of CAED curriculum design, attitudes, learning experience, perceived interdisciplinary competency development, and institutional support. All construct items were measured using a five-point Likert scale unless otherwise stated.

Scale anchors: 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree.

Section A: Demographic and Contextual Information

Age group: Below 18 / 19 to 21 / 22 to 25. Gender: Male / Female / Prefer not to say. Department: CSE / AIML / ISE / EEE / ECE / CV / ME. Year of study: First / Second / Third / Fourth. Familiarity with digital tools and software: Not familiar / Somewhat familiar / Very familiar. Regular access to required learning resources (software, labs, internet): Yes / No.

Section B: CAED Curriculum Design (CD)

Construct definition: Students' perceptions of the relevance, interdisciplinarity, and pedagogical quality of the CAED curriculum. *Adapted from:* engineering design education and curriculum quality literature (contextualized for CAED).

Table 13: CAED Curriculum Design (CD) items.

Code	Item
CD1	The CAED curriculum is well aligned with industry and interdisciplinary requirements.
CD2	The curriculum incorporates relevant digital tools and software effectively.
CD3	Course materials and activities adequately cover essential engineering drawing concepts.
CD4	The CAED curriculum encourages integration of knowledge across computer science and engineering domains.
CD5	The teaching methods used in CAED courses are innovative and support active learning.

Section C: Student Attitudes toward CAED (SA)

Construct definition: Students' motivational and affective orientations toward learning CAED. *Adapted from:* Expectancy-Value and technology acceptance literature.

Table 14: Student Attitudes toward CAED (SA) items.

Code	Item
SA1	I find CAED an interesting and engaging subject.
SA2	I believe that learning CAED will benefit my future career.
SA3	I feel motivated to learn CAED concepts and skills.
SA4	The CAED course content is easy to understand.
SA5	I am willing to apply the knowledge gained from CAED in practical projects.

Section D: Learning Experience in CAED (LE)

Construct definition: Students' perceptions of enacted pedagogy and instructional experiences during CAED courses. *Adapted from:* experiential learning and active learning frameworks.

Table 15: Learning Experience in CAED (LE) items.

Code	**Item**
LE1	The CAED course provided sufficient hands-on practice opportunities.
LE2	The use of gamification or problem-based learning enhanced my learning experience.
LE3	The instructor provided timely and helpful feedback during the CAED course.
LE4	Learning CAED helped me develop critical thinking and problem-solving skills.
LE5	The digital tools and resources used in the course were easy to access and use.

Section E: Perceived Interdisciplinary Competency Development (IC)

Construct definition: Students' perceived ability to apply CAED knowledge across disciplines and to collaborate effectively. *Adapted from:* perceived interdisciplinary competency and engineering education literature.

Table 16: Perceived Interdisciplinary Competency Development (IC) items.

Code	**Item**
IC1	I am confident in applying engineering drawing skills in interdisciplinary projects.
IC2	The CAED course improved my ability to communicate technical ideas across disciplines.
IC3	Thanks to CAED, I can better collaborate with peers from engineering and computer science.
IC4	CAED helped me develop skills relevant to both AI/ML and engineering fields.
IC5	The course enhanced my problem-solving skills in interdisciplinary contexts.

Section F: Curriculum Support and Resources (CS)

Construct definition: Students' perceptions of institutional and infrastructural support for CAED learning. *Adapted from:* institutional support and learning environment studies.

Table 17: Curriculum Support and Resources (CS) items.

Code	**Item**
CS1	The institution provides adequate learning materials and software tools for CAED.
CS2	The availability of labs and technology supports effective learning of CAED.
CS3	Institutional support encourages interdisciplinary learning in CAED courses.
CS4	I have access to sufficient technical help when using digital tools for CAED.
CS5	Resources provided meet the requirements for mastering CAED concepts and skills.