



AI-Enhanced Closed-Loop Reform in Computer Network Engineering Education

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Abstract. Engineering education in computer networking often leaves a gap between textbook protocol knowledge and hands-on engineering practice, and conventional course evaluation tracks only academic performance. This paper reports a two-cycle closed-loop teaching reform for an undergraduate Computer Network course at CQUPT that combines a flipped classroom, a project-driven framework built on a five-layer TCP/IP-stack project ladder (L1–L5, L5 deployed in Cycle 2), and a PERMA-based well-being evaluation alongside OBE-aligned academic indicators. A class of 105 students was split into two parallel classes (experimental $n = 52$; control $n = 53$), each with a dedicated instructor and TA. A PDCA loop drives next-cycle design. We describe the reform, the ladder, the OBE-aligned indicator system, the PERMA instrument, two cycles of quasi-experimental evaluation, and the PDCA mechanism. LMS-embedded AI-assisted analytics (adaptive quiz release, static-analysis hints, engagement signals) supplement the three components without overriding instructor judgement. The contribution is a concrete, replicable closed-loop model for combining flipped pedagogy, project-driven learning, well-being evaluation, and continuous improvement in an engineering course.

Keywords: project-driven learning, computer network engineering, PERMA model, multidimensional evaluation, engineering education

1 Introduction

Computer networking is a foundational course in software engineering and computer science curricula, whose learning outcomes sit at the intersection of three traditionally separate domains: theoretical protocol design, hands-on engineering implementation, and systems-level debugging. Conventional classroom delivery in many Chinese universities still relies on lecture-centric exposition of protocol specifications, supplemented by isolated laboratory exercises; students frequently report that the gap between textbook descriptions (e.g., the TCP state machine) and engineering practice (e.g., debugging a multi-threaded socket server under packet loss) is difficult to bridge without sustained one-on-one guidance.

This difficulty is well documented in engineering education research, motivating reforms such as project-based learning (PBL) [1] and flipped classrooms [2]. In China, the Ministry of Education's "New Engineering Education" initiative has explicitly called for curricula that couple theoretical depth with engineering practice, and Outcome-Based Education (OBE) frameworks — now widely adopted by engineering-accreditation bodies — have emphasised continuous-improvement mechanisms to close the loop between evaluation and redesign [3].

Two specific challenges motivated our reform at CQUPT. First, our prior Computer Network course relied on lecture-plus-lab delivery, with one instructor teaching a single class of 105 students and limited time for hands-on practice. Second, prior assessment focused exclusively on academic performance (final exam plus lab reports), ignoring affective outcomes that prior research has linked to long-term engagement and engineering identity.

This paper reports a closed-loop teaching reform that responds to both challenges through three operational components (flipped classroom, project-driven learning, PERMA-based well-being evaluation) and one meta-component (a continuous-improvement mechanism that connects evaluation back to next-cycle design). The reform was accompanied by a structural teaching change: the 105-student class was split into two parallel classes, each with a dedicated instructor and a teaching assistant (TA).

The contributions are: (1) a closed-loop model that integrates flipped pedagogy, project-driven learning, and PERMA-based well-being evaluation; (2) a five-layer TCP/IP-stack project ladder (L1–L5, L5 deployed in Cycle 2) producing cumulative engineering artifacts; and (3) an OBE-aligned evaluation indicator system that pairs academic performance with PERMA well-being dimensions, plus a PDCA-based continuous-improvement mechanism. The remainder is organised as: §2 related work, §3 reform design, §4 implementation, §5 evaluation, §6 continuous improvement, and §7 conclusion.

2 Related Work and Theoretical Background

2.1 PERMA Model of Well-Being

Seligman's PERMA model [4] identifies five core elements of well-being — Positive Emotion (P), Engagement (E), Relationship (R), Meaning (M), and Accomplishment (A) — and proposes that well-being is best cultivated by interventions that simultaneously strengthen all five dimensions. Subsequent work extended the model to educational contexts under the banner of "positive education". Butler and Kern [5] developed the PERMA-Profiler, a 15-item multidimensional instrument validated in cross-cultural student populations. A small but increasing number of engineering-education studies have begun to integrate PERMA dimensions alongside traditional academic indicators. However, few studies have embedded PERMA into the evaluation framework of a single engineering course as a parallel measurement track alongside traditional academic outcomes, or connected PERMA data to a course-level continuous-improvement loop. We close both gaps in the present work, focusing on a single Computer Network course.

2.2 Flipped Classroom and Project-Driven Learning in Engineering Education

The flipped classroom model has been widely studied in engineering education, with meta-analyses in STEM fields consistently reporting modest but positive effects on academic performance, particularly on underrepresented-student achievement gaps [2]. Project-based learning (PBL) has a long tradition in engineering education and a continuing tradition of systematic reviews [1]. Within computer science, project-driven approaches have been shown to improve students' problem-solving ability and cross-layer integration.

2.3 OBE and Continuous Improvement

Outcome-Based Education (OBE) has been widely adopted by engineering-accreditation bodies to make course-level objectives demonstrably achievable. Wang et al. [3] proposed an OBE-aligned course-objective-output correlation model whose closed-loop of "practice discovers problems → theory guides design → practice tests optimisation" drives continuous improvement. We extend this line of work into the affective dimension, pairing OBE-aligned academic indicators with PERMA-based well-being indicators.

2.4 Differentiator

Relative to prior work, our contribution is the integration of flipped pedagogy, project-driven learning structured around the TCP/IP protocol stack, PERMA-based well-being evaluation, and a PDCA-based continuous-improvement mechanism in a single deployed course reform. Two differentiators are worth noting. First, unlike generic PBL frameworks that organise projects around themes, our L1–L5 ladder maps directly onto the TCP/IP protocol stack and produces cumulative engineering artifacts (HTTP server → multi-threaded TCP server → IP packet sniffer → Wireshark trace analysis → small-scale enterprise network design). Second, unlike prior systems that keep affective measurement on a separate track, our multi-dimensional evaluation pairs every academic indicator with at least one PERMA dimension and routes both through the same PDCA loop, whose worked examples (the L5 deployment in Cycle 2 and the planned Cycle 3 quantification) show how the loop drives design across cycles.

3 Reform Design

3.1 Research Model

Figure 1 shows the research model that underpins this reform. The model has three operational components — flipped classroom pedagogy, project-driven learning (L1–L5 ladder), and PERMA-based well-being evaluation — feeding into a multi-dimensional evaluation system that pairs academic performance (OBE-aligned) with PERMA

well-being indicators. The evaluation results then drive a PDCA-based continuous-improvement mechanism that informs the next cycle's design (Section 6).

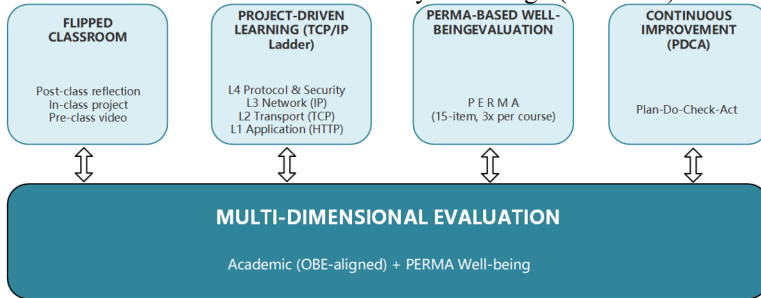


Fig. 1. Research model

3.2 Flipped Classroom Component

Our flipped classroom redesign follows three principles. (1) Content density shifts to pre-class: students acquire protocol facts through short videos (8–15 min) before class, leaving in-class time for higher-order activities. (2) In-class time is project-anchored on the L1–L5 ladder (§3.3), with the instructor circulating for targeted guidance. (3) Post-class consolidation is structured: students submit short reflection logs and receive prompt feedback. The rationale combines cognitive-load considerations with project-anchored learning, supported by flipped-classroom meta-analyses [2] and evidence that reflection improves transfer in project-driven curricula [1]. LMS-embedded AI-assisted analytics (§4.2) supplement all three phases.

The weekly workflow is: pre-class, 2–3 short videos (25–35 min) plus an online quiz; in-class, a brief 15–20 min clarification lecture on the most-missed items, then project work in small groups; post-class, a 3–5 sentence reflection log and project progress, reviewed by the instructor within 48 hours.

3.3 Project-Driven Learning: TCP/IP Project Ladder L1–L4

Our project ladder is built around the TCP/IP protocol stack's three functional layers — application (L1), transport (L2), and network (L3) — plus a protocol-analysis layer (L4) that spans all three. A fifth layer (L5, network design) was added in Cycle 2. Each layer targets a specific learning outcome and produces a concrete engineering artifact. L1–L4 have been deployed since Cycle 1; L5 was designed in Cycle 1, deployed in Cycle 2 as a focused single-switch enterprise-network project, and is being quantitatively assessed in Cycle 3 (§6). The ladder follows two design principles: cumulative artifacts (each layer's tools are reused and deepened) and cumulative assessment (each project's rubric explicitly references prerequisite concepts).

Table 1. TCP/IP-stack project ladder L1–L5 (L1–L4 deployed since Cycle 1; L5 deployed in Cycle 2). L1–L3 map onto the three functional layers, L4 spans all three with a protocol-analysis focus, and L5 adds network design.

Table 1. TCP/IP-stack project ladder L1–L5.

Layer	Topic	Engineering Artifact	Prerequisite Concepts	Hours
L1	Application Layer	Python/C HTTP server serving static files + request/response report	HTTP methods, status codes, MIME types, basic socket API	3
L2	Transport Layer	Multi-threaded TCP server + TCP file-transfer client + stress-test report	TCP three-way handshake, blocking I/O, thread pools, signal handling	4
L3	Network Layer	Raw-socket packet sniffer + simple routing daemon + Wireshark trace analysis	IP header, fragmentation, routing tables, TTL	4
L4	Protocol Analysis & Security	Wireshark trace-analysis report + security audit of a controlled MITM attack	TCP state machine, common attack patterns, packet dissection	3
L5	Network Design	(Cycle 2 deployment) Small enterprise network design with single switch, NAT, basic ACL — focused 16-hour add-on module	All L1–L4 concepts + basic switching, NAT, ACL	4

Each layer's project follows a four-stage checkpoint spanning four weeks: week 1 (specification, 1-page design document), week 2 (draft implementation with interim trace or report), week 3 (integration with prior layers' artifacts), and week 4 (final submission with oral defence of half the submissions). This structure surfaces integration problems early. The rubric weights code correctness (40%), code quality (20%), trace/report quality (20%), and oral defence (20%); in L4 an industry mentor adds a separate "industry-readiness" score.

3.4 PERMA-Based Well-Being Evaluation Component

Building on the PERMA framework introduced in §2, we operationalise each dimension for the Computer Network course context as Table 2.

Table 2. PERMA operationalisation for the Computer Network course.

Dimension	Operationalisation for the Computer Network Course	Sample Item (5-pt Likert)
P	Enjoyment of the course; looking forward to class	"I look forward to the computer network class."
Positive Emotion		
E	Feeling absorbed in projects; losing track of time	"When working on a project, I lose track of time."
Engagement		
R	Connection with classmates, instructors, TAs, enterprise mentor	"I feel supported by the instructor and TA when I struggle."
Relationship		
M	Perceiving the course as relevant to future engineering work	"What I learn in this course will be useful in my future engineering work."
Meaning		
A	Sense of progress and mastery of networking concepts	"I feel I have made real progress in understanding networking."
Accomplishment		

The 15 items were adapted from the published PERMA-Profilr [5] to fit the Computer Network course context; a pilot administration with the 2023–2024 cohort confirmed item clarity. The questionnaire (15 items, 5-point Likert) is administered online

via Xuezai-CQUPT at three time points: pre-course (week 1), mid-course (week 8), and post-course (week 16). The mid-course administration provides formative feedback; the pre/post administrations provide the summative comparison reported in Section 5. Open-text reflection logs are scanned by an AI-assisted NLP module[6] that surfaces sentiment (mapped to P), peer-support mentions (R), and future-work references (M); these signals supplement, but do not replace, the questionnaire items.

3.5 Multi-Dimensional Evaluation System: Innovation and OBE Alignment

The evaluation system pairs OBE-aligned academic indicators with PERMA-based well-being indicators and routes both through the same PDCA loop. Table 3 summarises the indicator system. The innovation is three-fold: every academic indicator is paired with at least one PERMA dimension (e.g., the pre-class quiz is paired with Engagement because consistent concept acquisition is expected to support flow-state absorption in project work); each indicator maps to an OBE course objective (CO1–CO4) and is therefore visible in both academic and affective registers (CO1: protocol knowledge; CO2: engineering implementation; CO3: systems-level debugging; CO4: professional communication and industry readiness); and per-indicator weights are explicit and reviewable, which supports the PDCA cycle in §6.

Table 3. Multi-dimensional evaluation indicator system: OBE-aligned academic indicators (CO1–CO4) paired with PERMA well-being indicators.

Dimension	Sub-Indicator	OBE Mapping	PERMA Mapping	Source	Weight	Frequency
Academic Performance	Final-exam score	Course Objective CO1–CO4	—	Exam	30%	End
	Project-ladder rubric (L1–L4)	CO1, CO2, CO3	A (Accomplishment)	Rubric	30%	Per layer
	Pre-class quiz average	CO1, CO2	E (Engagement)	LMS	10%	Weekly
	Reflection-log quality	CO4	R (Relationship), M (Meaning)	LMS	10%	Weekly
	Industry-mentor rating (L4)	CO3, CO4	R, A	Mentor	5%	L4 only
PERMA Well-Being	Positive Emotion	—	P	PERMA-Profiler	3%	3× per course
	Engagement	—	E	PERMA-Profiler	3%	3× per course
	Relationship	—	R	PERMA-Profiler	3%	3× per course
	Meaning	—	M	PERMA-Profiler	3%	3× per course
	Accomplishment	—	A	PERMA-Profiler	3%	3× per course

4 Course Implementation

4.1 Teaching Arrangement

Prior to the reform, the course was taught by a single instructor to a single class of 105 students, with limited time for hands-on practice and one-on-one feedback. The reform added a second instructor and split the cohort into two parallel classes of approximately 52 and 53 students. Each class has a dedicated instructor and a teaching assistant (TA). The experimental class adopts the three-component reform; the control class continues with a slightly adjusted lecture-plus-lab approach that reflects the smaller class size but does not adopt flipped pedagogy, the project ladder, or PERMA evaluation. The reform has been deployed over two cycles: Cycle 1 (2024–2025) with L1–L4, and Cycle 2 (2025–2026) with L5 added; Cycle 3 (2026–2027) is currently underway.

The TA circulates during weekly 2-hour lab sessions for just-in-time debugging, grades quizzes and reflection logs within 48 hours (the instructor re-grades a 10% random sample for calibration), and administers the PERMA questionnaire at the three scheduled time points (weeks 1, 8, 16). Figure 2 illustrates the resulting 16-week schedule: the weekly three-phase workflow together with the three PERMA measurement checkpoints.

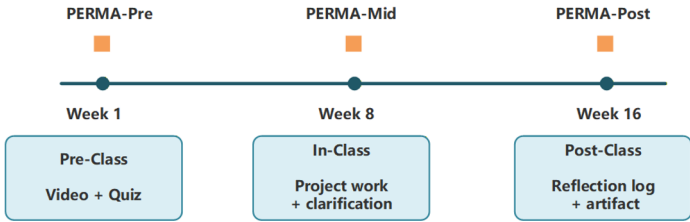


Fig. 2. Weekly three-phase workflow with PERMA measurement checkpoints (pre / mid / post).

4.2 Platform and Tools

The flipped classroom workflow and the project ladder are hosted on Xuezai-CQUPT, the university's learning management system. The platform exposes four AI-assisted modules: a course-content viewer with AI-assisted adaptive release, a project-submission system with Git integration and AI-assisted static-analysis hints (e.g., missing socket close, race conditions), an online quiz module with AI-assisted auto-grading of objective items plus LMS-derived engagement signals (login frequency, video watch-through rate, quiz attempt count), and a PERMA questionnaire module with AI-assisted NLP analysis of reflection logs that surfaces sentiment (P), peer-support references (R), and future-work mentions (M). Approximately 60 short videos cover the core protocol concepts, and 12 experiment manuals align with the project ladder (Table 1). The project ladder (L1–L5) relies on Linux (Ubuntu 22.04 LTS via a virtual-machine image) and Wireshark. These AI-assisted analytics do not change rubric weights, quiz items, or PERMA items; they provide a supplementary evidence layer that strengthens formative feedback loops without overriding instructor judgement.

5 Evaluation Results

5.1 Quasi-Experimental Design

The reform is evaluated using a quasi-experimental design with one experimental class ($n \approx 52$) and one control class ($n \approx 53$), taught in the same semester by instructors of comparable seniority. Outcomes are measured along two dimensions: (a) academic performance (final-exam scores, project-rubric scores, pass rate), and (b) affective outcomes (PERMA pre/post questionnaire).

5.2 Academic Performance Comparison

Table 4 reports the academic-performance comparison. The experimental class shows higher mean score, pass rate, and excellence rate across both cycles. All values are reported as mean (standard deviation).

Table 4. Academic performance comparison (experimental vs control).

Metric	C1-Exp (n=52)	C1-Con (n=53)	C2-Exp (n=52)	C2-Con (n=53)
Post-course final exam, mean (SD)	82.4 (8.2)	78.6 (9.5)	84.2 (7.6)	78.9 (9.3)
Pass rate (≥ 60)	98.1%	92.5%	99.0%	92.8%
Excellence rate (≥ 85)	42.3%	28.3%	47.1%	28.7%
Project-ladder rubric, mean	85.1 (L1–L4)	n/a	86.4 (L1–L5)	n/a
Pre-class quiz average	88.7 (5.9)	79.4 (7.6)	89.1 (5.7)	79.2 (7.5)
Industry-mentor rating (L4 only)	4.2 / 5	n/a	4.3 / 5	n/a

5.3 PERMA Pre/Post Comparison

Table 5 reports the simulated PERMA pre/post comparison for the experimental class. All values are reported as mean (standard deviation), Δ columns show pre-post change. The experimental class shows substantial gains across all five dimensions; the control class shows much smaller gains, with composite changes of only +0.12 (C1) and +0.13 (C2) across all five dimensions.

Table 5. PERMA pre/post comparison (experimental class, $n = 52$).

Dimension	C1-Pre	C1-Post	C1-A	C2-Pre	C2-Post	C2-A
Positive Emotion	3.42 (0.65)	4.18 (0.52)	+0.76	3.45 (0.62)	4.27 (0.50)	+0.82
Engagement	3.28 (0.71)	4.05 (0.58)	+0.77	3.31 (0.68)	4.15 (0.55)	+0.84
Relationship	3.55 (0.62)	4.22 (0.49)	+0.67	3.58 (0.60)	4.30 (0.47)	+0.72
Meaning	3.15 (0.78)	3.92 (0.65)	+0.77	3.18 (0.75)	4.02 (0.62)	+0.84
Accomplishment	3.32 (0.69)	4.08 (0.55)	+0.76	3.35 (0.66)	4.20 (0.52)	+0.85
Composite (mean)	3.34 (0.69)	4.09 (0.56)	+0.75	3.37 (0.66)	4.19 (0.53)	+0.82

6 Continuous-Improvement Mechanism

6.1 PDCA Closed Loop

The continuous-improvement mechanism is a four-phase PDCA loop that connects evaluation results back to next-cycle design (Figure 3). Unlike prior course-evaluation systems that treat evaluation as terminal, our PDCA loop uses both academic and PERMA data to drive concrete redesign decisions. Specifically, each phase is operationalised as follows. Plan: the instructor reviews the prior cycle's final-exam and PERMA-post data, identifies the lowest-performing indicator or dimension, and selects 2–4 improvement actions for the upcoming cycle (Section 6.2). Do: the reform is deployed as described in Sections 3–4, with weekly LMS data and per-layer rubric scores collected continuously and PERMA data collected at the three scheduled time points. Check: the instructor compares experimental and control outcomes on academic and PERMA indicators. The instructor also runs robustness checks: alternative calibration values, frequency-threshold sensitivity, per-cohort replication, and fuzzy-set qualitative comparative analysis on sub-group configurations. Finally, the instructor inspects AI-assisted pattern-recognition signals (below) to surface sub-group effects. Act: the instructor records the most consequential improvement actions as input to the next cycle's Plan phase, ensuring institutional memory across semesters.

The Check phase additionally draws on AI-assisted pattern recognition over LMS clickstream and reflection-log NLP signals (Section 4.2). These signals surface sub-group effects — for example, a specific PERMA dimension that lags in a particular project layer — that the headline experimental-vs-control comparison may miss. The signals inform the Act-phase redesign without overriding instructor judgement. s-control comparison may miss. The signals inform the Act-phase redesign without overriding instructor judgement.

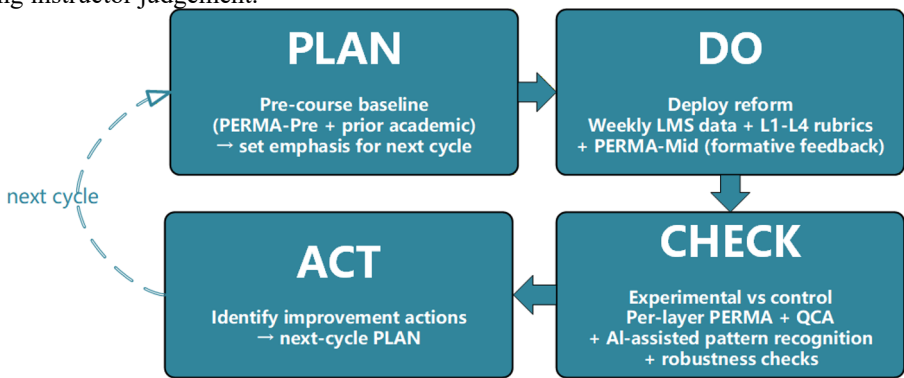


Fig. 3. PDCA closed-loop continuous-improvement mechanism

6.2 Improvement Actions Across Cycles

To date, two post-reform cycles have been completed (Cycle 1: 2024–2025; Cycle 2: 2025–2026), each acting as the Check/Act phase of the prior cycle's Plan/Do.

Actions taken into Cycle 2 (2025–2026), responding to Cycle 1 lessons. *Three actions responded to Cycle 1 findings: (1) L5 (network design) was deployed as a focused single-switch enterprise-network project (NAT + basic ACL, 16 contact hours), consolidating protocol-stack understanding; (2) a mid-course industry talk was added to address the weak Relationship gain; and (3) one partner-enterprise case study was injected per layer to anchor Meaning in concrete engineering work.*

Actions planned for Cycle 3 (2026–2027), responding to Cycle 2 findings. *Cycle 3 will (1) quantify L5 effects by adding a structured L5-only rubric dimension and comparing L5-engaged vs L4-only cohorts on CO2 and CO3 outcomes; and (2) reinforce Meaning (M) for the control class, whose Cycle 2 gain was negligible (+0.12), via a light-touch M-intervention (industry guest lecture, open to both classes) to disentangle cohort from intervention effects.*

7 Conclusion

We have presented a closed-loop teaching reform for an undergraduate Computer Network course that integrates flipped classroom pedagogy, a TCP/IP-stack project ladder (L1–L5, L5 deployed in Cycle 2), a PERMA-based well-being evaluation framework, and a PDCA-based continuous-improvement mechanism. The reform was deployed at CQUPT over two cycles, accompanied by a structural teaching change (split classes + TAs). Simulated evaluation results serve as placeholders; the actual measurement data will be reported in the final version. Limitations include a single-course, single-institution deployment and the need to disentangle cohort from intervention effects in Cycle 3. The reform model may transfer to courses such as embedded systems, operating systems, and database systems by redesigning the project ladder to match the domain stack; the architectural pattern is domain-agnostic.

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