

# Enhancing Faculty Pedagogical Competence through Collaborative HyFlex Training: A Quasi-Experimental Study

Yeqing Fan<sup>1,2</sup>, Norah Md Noor<sup>1</sup>

<sup>1</sup>School of Graduate Studies, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Johor, Malaysia, <sup>2</sup>Hangzhou Dianzi University Information Engineering College, 311305 Hangzhou, Zhejiang, China

Email: fanyeqing@graduate.utm.my, norah@utm.my

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## Abstract

As the HyFlex model continues to expand into teacher professional development worldwide, evaluating the effectiveness of Collaborative HyFlex Training (CHT) on faculty pedagogical competence has become practically significant. This study employed a quasi-experimental nonequivalent control group design with 60 university teachers (30 per group), collecting pre- and post-test data over a five-month period. Quantitative analyses were conducted using robust ANCOVA to assess intergroup differences, supplemented by the Mann-Whitney U test for non-parametric validation. The results showed that the experimental group significantly outperformed the control group in post-test pedagogical competence ( $\beta = 0.202$ ,  $p = .010$ ), with a moderate effect size ( $r = 0.333$ ). Sub-dimension analyses further revealed a differentiated pattern: the experimental group demonstrated substantial improvements in *reflective practice with iterative improvement* (gain = 0.90,  $p < .001$ ) and *technology integration* (gain = 0.90,  $p = .050$ ), while *instructional design* showed no significant group difference ( $p = .502$ ). The consistency between parametric and non-parametric results confirmed the robustness of the findings. These findings suggest that the CHT framework, operationalized through an “observation–reflection–practice” cycle, effectively enhances *teachers’ pedagogical competence* (TPC), particularly in higher-order reflective capacities and technology-enhanced teaching practices. This study provides preliminary empirical support for the cross-institutional collaborative HyFlex teacher training model and offers a replicable framework for digital transformation in higher education.

**Keywords:** Pedagogical Competence, Hyflex Training, Quasi-Experimental Design, Teacher Professional Development, Reflective Practice, Technology Integration

## Introduction

The demands placed on teachers’ competencies vary significantly across different instructional modes. Traditional face-to-face teaching emphasizes teacher-student interaction and instant feedback, requiring strong classroom organization skills and the ability to dynamically adjust learning progress (Hattie, 2009; Marzano & Marzano, 2003). In contrast, online teaching focuses on the application of technical tools and the digital design of course

content, necessitating proficient technical operation and online instructional design capabilities (Mishra & Koehler, 2006; Martin et al., 2019). Hybrid teaching, which integrates online and offline advantages, emphasizes flexibility and personalized learning, requiring teachers to synthesize multiple resources and design integrated learning activities (Eyal & Gil, 2022; Nørgård & Hilli, 2022; Suartama et al., 2019; Trede et al., 2019).

Building upon these evolving instructional models, the HyFlex (Hybrid Flexible) teaching approach was systematically conceptualized by Beatty (2019). Its core innovation lies in allowing students to independently choose their mode of participation (such as face-to-face, online synchronous, or asynchronous), which imposes higher demands on teachers' curriculum design, technology integration, and classroom management across multiple contexts (Raes, 2022; Wang, 2017; Wong et al., 2022). Recognizing these challenges, the professional development of HyFlex teaching competence has become a critical agenda in higher education institutions worldwide.

In response to this growing need, Chinese universities, led by Tsinghua University, have actively promoted cross-institutional collaborative HyFlex training programs in recent years. These initiatives aim to enhance participating teachers' digital teaching competencies through the sharing of high-quality instructors and curriculum resources across institutions (Wang & He, 2023; Li & Qiao, 2024). Despite the proliferation of such programs at both policy and practical levels, a significant research gap remains: systematic empirical evidence on whether HyFlex training effectively promotes teachers' pedagogical growth, and through what mechanisms, is notably absent. Most existing studies have focused on program descriptions or participant satisfaction surveys, with few employing rigorous quantitative designs to examine actual competence gains.

To address this gap, the present study employs a quasi-experimental design with a nonequivalent control group to systematically evaluate the effectiveness of a Collaborative HyFlex Training (CHT) program on university teachers' pedagogical competence. The novelty of this study lies in three aspects. First, it provides one of the first empirical investigations to adopt a quasi-experimental design with robust statistical controls (ANCOVA and non-parametric validation) to isolate the causal effects of HyFlex training, moving beyond descriptive or anecdotal evidence. Second, it unpacks pedagogical competence into sub-dimensions, including instructional design, technology integration, and reflective practice, allowing for a nuanced understanding of where training effects are most pronounced. Third, it operationalizes the CHT framework through an "observation – reflection – practice" cycle, offering a replicable cross-institutional professional development model that addresses the systemic isolation often faced by teachers in digital transformation contexts. Together, these contributions advance the field of social sciences by providing empirical rigor to the discourse on teacher professional development in higher education and offering actionable insights for policymakers and educators seeking scalable, evidence-based training solutions.

## Literature Review

### *The Emergence, Concept, and Characteristics of HyFlex Learning*

The construction of a learning society has stimulated the continuous demand for lifelong learning and flexible learning opportunities (Oliver, 2019; Pelletier et al., 2022, 2023). However, geographical distance, travel restrictions and work tasks often prevent individuals

from participating in traditional face-to-face teaching (Ghazi-Saidi et al., 2020; Wilson & Alexander, 2021). The progress of synchronous communication technology and intelligent learning space has spawned a technology enhanced hybrid learning environment that supports on-site and remote synchronous participation (Raes et al., 2020; Wong et al., 2022). Beatty (2019) systematically defined the HyFlex (Hybrid Flexible) learning mode. Two core standards that distinguish it from other mixed learning modes are: (1) providing at least two complete learning paths (usually offline classroom and online participation); (2) Support students' continuous and independent flexible choice between these paths without prior approval from teachers. Compared with traditional face-to-face learning, pure online learning and segmented blended learning, HyFlex integrates synchronous distance and on-site participation in the same teaching link, and is characterized by learners' independent choice and cross mode equivalence. Howell (2022) further pointed out that the real value of the HyFlex model lies not only in the multi-channel access at the technical level, but also in the reshaping of the power relationship between teaching and learning, and the return of learning autonomy from institutional arrangements to individual learners. Cumming et al.'s (2024b) scope review revealed that students' satisfaction and academic performance in HyFlex learning were generally positive, but teachers' workload and teaching design pressure increased significantly, suggesting that this model posed a systematic challenge to teachers' professional ability.

According to the comprehensive literature, HyFlex learning has three interrelated core features. First, it is highly flexible. Students can choose synchronous or asynchronous, online or offline participation according to their own preferences and situations, and can switch at any time (Pelletier et al., 2021; Ortega-Arranz et al., 2024). Second, the complex learning space, which integrates the physics classroom environment with rich digital tools and resources, depends on a sound technical infrastructure and teaching support system (Goodyear, 2020). Third, the in-depth sharing of educational resources enables the teaching resources of high-level universities to benefit a wider range of learning groups and promote educational equity (Wang & He, 2023; Li & Qiao, 2024). However, most of the existing studies focus on the learning experience and satisfaction at the student level (Raes et al., 2020; Ortega-Arranz et al., 2024), and the empirical study from the perspective of teachers is still insufficient, especially the systematic quantitative evaluation of the impact of HyFlex training on Teachers' ability development.

#### *Global Practices and Collaborative Training Cases of HyFlex Mode*

The synchronous HyFlex model has been accelerated in the field of global higher education. The University of Texas at San Antonio (UTSA) created the RowdyFlex special program to provide teachers with the training, technical resources and teaching support required for HyFlex teaching (Pelletier et al., 2021). James Madison University (JMU) carries out interdisciplinary innovation courses through X-Labs, adopts design thinking methodology, organizes students to solve real-world complex problems from governments, industries and non-profit organizations in the form of teams, and promotes interdisciplinary collaboration and industry university cooperation (Pelletier et al., 2023). Area-Moreira et al. (2023) implemented an alternative HyFlex mode in Spanish higher education (combining face-to-face teaching with asynchronous autonomous learning, and allowing students to independently choose project-based or topic based learning paths). The study found that students' satisfaction was high, and their academic performance was good no matter what

learning path they chose. However, the study also points out that the effective scaling of this model requires appropriate institutional support and that faculty possess adequate pedagogical and digital competencies.

In China, the “MOOC to the West” project (also known as the “Boosting MOOCs in Western China” Plan, Phase II) accurately meets the teaching and learning needs of colleges and universities in Western China by systematically promoting MOOC supply, teacher training, and teaching platform services (Wang & Guo, 2022). Since its launch in 2013, the project has provided 207,000 MOOCs and online course services to universities in the western regions, facilitated 9.36 million HyFlex teaching sessions between eastern and western institutions, benefited 590 million students in the west, and trained nearly two million western university teachers through MOOC-based professional development programs. This kind of classroom is characterized by distance, real-time and interaction, which realizes the coordinated development between eastern and western universities; At the same time, through the global integrated classroom and open class projects, students from different cultural backgrounds are connected to promote cross-cultural understanding and international academic exchanges (Wang & Guo, 2022).

The above cases show that HyFlex mode has a multi-level practical foundation from the technical platform to the organizational mechanism, providing a feasible path for its application in teacher training. The empirical study of Xiao et al. (2025) further confirmed that HyFlex training is feasible in improving teachers’ AI literacy, but the sustainability of the training effect depends on the systematic teaching design support and the continuous school-based follow-up mechanism, which provides an important empirical reference for understanding the effective implementation conditions of collaborative HyFlex training. Mulenga & Shilongo (2025) pointed out from the perspective of international comparison that the innovation and challenges of HyFlex and blended learning mode coexist in the post epidemic era, and the future development direction should focus on the systematic reconstruction of teacher training system, rather than just staying at the level of technical tools.

#### *HyFlex Training for Faculty Professional Development*

The complexity of HyFlex teaching environment puts forward new ability requirements for college teachers. At the technical level, teachers need to skillfully operate multiple sets of technical systems such as live broadcast equipment, asynchronous discussion platform and data analysis tools, and coordinate the technical stability and teaching fluency (Beatty, 2019; Miller & Baham, 2018). Elnara et al. (2026) pointed out that HyFlex teaching requires teachers to manage multimodal teaching at the same time, which faces great challenges in technology and teaching methods; Barr & Luo (2025) also confirmed that technology integration and giving consideration to remote and on-site students are the main difficulties faced by HyFlex teachers.

At the level of curriculum design, due to the differences in students’ participation methods and progress, teachers need to design flexible curriculum structure, taking into account the balance between synchronous and asynchronous, individual and collaborative activities (Huang et al., 2020; Raes et al., 2020). Blasiman et al. (2024) further pointed out that the participation of face-to-face students in HyFlex courses is usually higher than that of online or

asynchronous remote students, which puts forward higher requirements for teachers to design activities that can fairly mobilize all kinds of students' participation. Badiozaman and Sega (2025) interviewed seven university teachers in Malaysia and found that teachers who lack HyFlex teaching ability are difficult to maintain students' participation in multiple modes, resulting in unequal learning opportunities for online and offline students.

At the level of assessment management, students' learning behavior data are scattered on different platforms (such as offline check-in, online discussion, and homework submission), which requires teachers to have stronger data-driven learning monitoring and assessment ability in the HyFlex teaching environment (Beatty, 2019). Hapke (2026) pointed out that HyFlex curriculum research needs to integrate multi-source data such as learning management system activities and lecture video records, and use learning analysis methods to understand the relationship between students' behavior and academic performance, reflecting the requirements for teachers' data integration ability; Heil et al., (2026) discussed how the AI driven analysis tool supports personalized assessment and flexible teaching in the HyFlex environment through the data dashboard. The above research shows that in the HyFlex context of multi platform data coexistence, data-driven has become an important development direction of teachers' evaluation ability.

In addition to the requirements of skill dimension, HyFlex teaching also involves the challenges of teachers' digital ethics consciousness and data literacy at a deeper level. With the extensive collection and analysis of teaching data in a mixed environment, teachers need to have the ability to make ethical judgments such as data privacy protection, algorithm error identification and digital fairness maintenance (O'Brien, 2020), and can make smart data-driven decisions in a data-intensive teaching environment, which is beyond the scope of traditional teacher education courses (Van Audenhove et al., 2024). Howell et al. (2024) based on design research, extracted six core strategies of HyFlex teaching from the perspective of new media literacy, and emphasized that teachers should integrate traditional teaching methods with students' participatory cultural characteristics, rather than relying solely on technical tools to achieve multi-channel access. This direction is in line with the HyFlex "equivalence" principle proposed by Beatty (2019), which emphasizes that students should achieve equivalent learning outcomes regardless of which participation mode they choose, which depends on Teachers' active construction in teaching design.

Elnara et al. (2026) based on the hybrid method of TPACK framework, found that teachers experienced a progressive development stage from "technology adaptation" to "Teaching Reconstruction" and then to "identity change" in the process of becoming HyFlex teachers, suggesting that HyFlex training should respond differently to teachers' needs at different stages of development. Nagy & Dringó-Horváth (2024) conducted a survey of Hungarian university teachers and found that the core predictor of the willingness to integrate technology is not technical proficiency, but teachers' belief in teaching effectiveness and expectations of students' acceptance. This finding has important implications for the design of HyFlex training project: training should not only solve the problem of "will or not", but also respond to the psychological barriers of "will or not" and "fear or not".

*Theoretical Foundations of Collaborative HyFlex Training (CHT)*

Ramsden's (2003) *Learning to Teach in Higher Education Theory* and Bandura's (1977) *Social Learning Theory* provide dual theoretical support for this study. The former provides direction for research objectives, while the latter provides mechanism for research methods.

Ramsden (2003) changed his teaching view from "teaching" to "learning". First, the theory emphasizes that university teaching should be designed around students' learning rather than teachers' teaching. Teachers need to understand effective teaching principles from the perspective of students, and require teachers to experience real multimodal learning situations through "experiential learning", so as to understand students' emotional input and learning needs, and avoid training becoming a pure technical lecture (area Moreira et al., 2023). Second, the theory regards teaching as a closed-loop process of "design - implementation - evaluation" continuous improvement, suggesting that HyFlex research should be upgraded from a single course design training to a systematic teacher development mechanism (Cumming et al., 2024a). Ramsden regards teaching as a circular process of continuous improvement. The participating teachers return to their own classroom for teaching practice after observing the live broadcast classroom every week, and identify gaps and adjust strategies in reflection.

Bandura (1977) observed learning mechanism of social learning theory. Bandura pointed out that individuals can obtain new behavior patterns by observing the behavior of role models and their consequences. This process includes four sub processes: attention (focusing on the key behaviors of the demonstrator), retention (memorizing and coding the observed strategies), reproduction (copying and adjusting in their own practice) and motivation (generating learning intention after observing the positive effects of role models). The core training method of the intervention experiment of this study is to observe the HyFlex live classroom of famous university lecturers, and its theoretical basis comes from this. During the training, the participating teachers paid attention to the key teaching behaviors of "leading teachers" during observation, recorded and maintained them, and then tried to reproduce them in the synchronous course they were lecturing, and continued to adjust in reflection.

The integration logic of the two theories: Ramsden provided the direction of "what to see" for this study: the core of observation is not the technical operation, but the occurrence of students' effective learning; Bandura provided the mechanism of "how to learn from seeing" for this study: observing model behavior and internalizing it through practice. The two together support the research logic of Collaborative HyFlex Training (CHT) framework, which "takes observing HyFlex live classroom as the way and promoting students' effective learning as the goal", and become the theoretical basis for analyzing the effectiveness of CHT training.

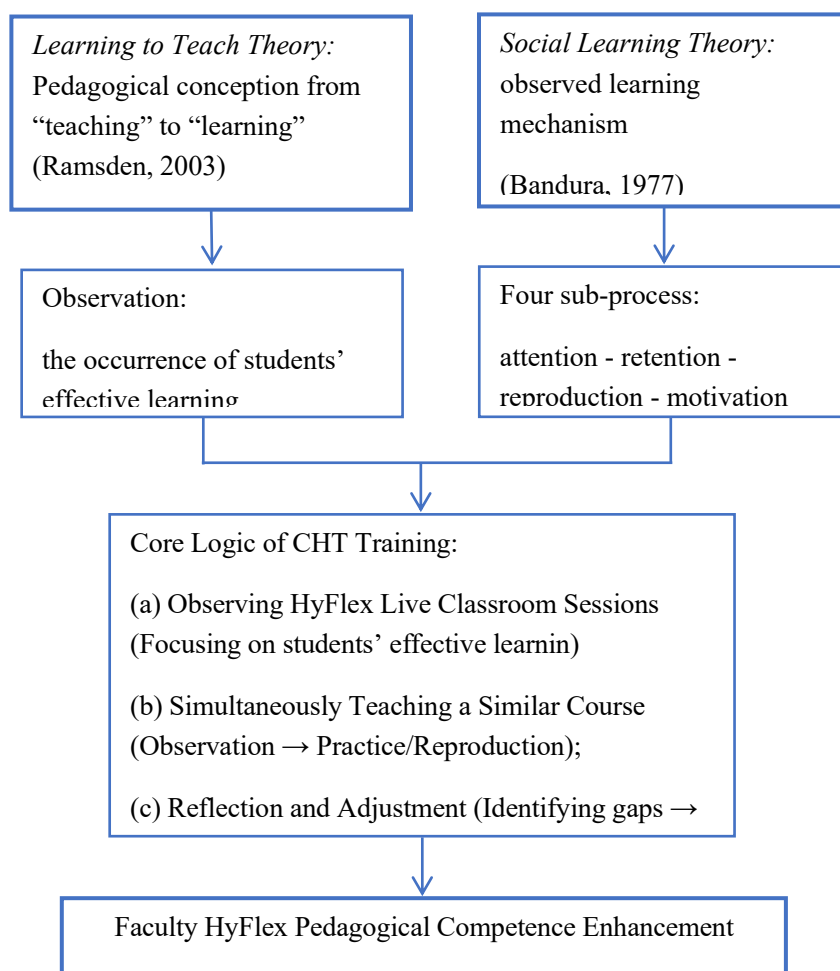


Figure 1 Theoretical Logic of Faculty Training Under the CHT Intervention

As shown in Figure 1, The faculty training under the CHT intervention follows a cyclical logic: participants observe HyFlex live classroom sessions (focusing on students' effective learning), simultaneously teach a comparable course of their own (translating observation into practice), and engage in reflection and adjustment (identifying performance gaps and retaining effective strategies) to inform the next cycle.

#### *Research Gaps and the Positioning of This Study*

To sum up, the HyFlex teaching environment puts forward higher requirements for University Teachers' technology integration, flexible curriculum design and data-driven learning evaluation ability. Although the above capability requirements have been identified from the theoretical level, most of the existing studies are theoretical inference, small-scale qualitative description or cross-sectional survey (Adi Badiozaman & Segar, 2025; Beatty, 2019; Howell et al., 2024; Elnara et al., 2026), and there is still a lack of systematic quantitative evidence based on quasi-experimental design to test the actual promotion effect of collaborative HyFlex training on Teachers' digital pedagogical competence. Previous studies have identified multiple factors influencing HyFlex teaching implementation, including technical support and instructional design guidance (Bower et al., 2014, 2015), faculty training, and institutional resource investment (Romero-Hall & Ripine, 2021). However, these studies have largely focused on macro-level institutional conditions, with limited attention to how training interventions systematically address the differentiated competency demands that HyFlex

teaching places on faculty from a professional development perspective. Whether and to what extent collaborative HyFlex training can improve teachers' teaching professional ability and how its mechanism of action are still lack of empirical response. To this end, this study systematically investigated the intervention effect of collaborative HyFlex training on College Teachers' teaching ability through a quasi-experimental design and a quantitative analysis method of pre-test and post test comparison, in order to provide an empirical basis for the application of HyFlex mode in Teachers' professional development.

## Methodology

### *Research Questions*

Based on the theoretical logic and the research gaps identified above, this section presented the approach adopted to evaluate the Collaborative HyFlex Training (CHT) intervention. The study addressed the following three research questions:

- (1) Does the CHT intervention significantly improve teachers' overall pedagogical competence in HyFlex teaching compared to the control group?
- (2) Which of the three dimensions of pedagogical competence (such as instructional design, technology integration, and reflective practice with iterative improvement) are most significantly enhanced by the CHT intervention?
- (3) What is the differential effect of the CHT intervention across these three dimensions of pedagogical competence?

### *Experimental Design and Procedures*

This study employed a quasi-experimental design with a Collaborative HyFlex Training (CHT) experimental group and a non-equivalent control group to assess the intervention effectiveness of the CHT experiment on participating teachers' pedagogical competence (Kenny, 1975).

The CHT training comprised three iterative components aligned with its core logic: (a) cloud-based classroom observation: participants observed HyFlex live sessions delivered by renowned university lecturers via digital twin technology, focusing on how effective student learning was facilitated; (b) simultaneous teaching practice: participants taught their own comparable courses while applying observed strategies, translating observation into classroom reproduction; and (c) reflection and adjustment: participants systematically compared their own instruction with the model teaching, identified performance gaps, retained effective approaches, and refined their practices iteratively.

The training was implemented as a 12-week intervention in two phases. During the first eight weeks, participants engaged in a weekly cycle of observation, practice, and reflection as described above. In each cycle, participants observed a HyFlex live session, concurrently taught their own comparable courses, and engaged in post-class reflection, using insights gained to adjust their teaching strategies for the following week. In Weeks 9-12, participants continued their professional learning through online review of previously recorded sessions, followed by re-practice and re-reflection, allowing them to consolidate their learning from the initial cycle. Throughout this process, each week's reflection informed the next week's observation, creating an iterative learning loop for continuous pedagogical improvement.

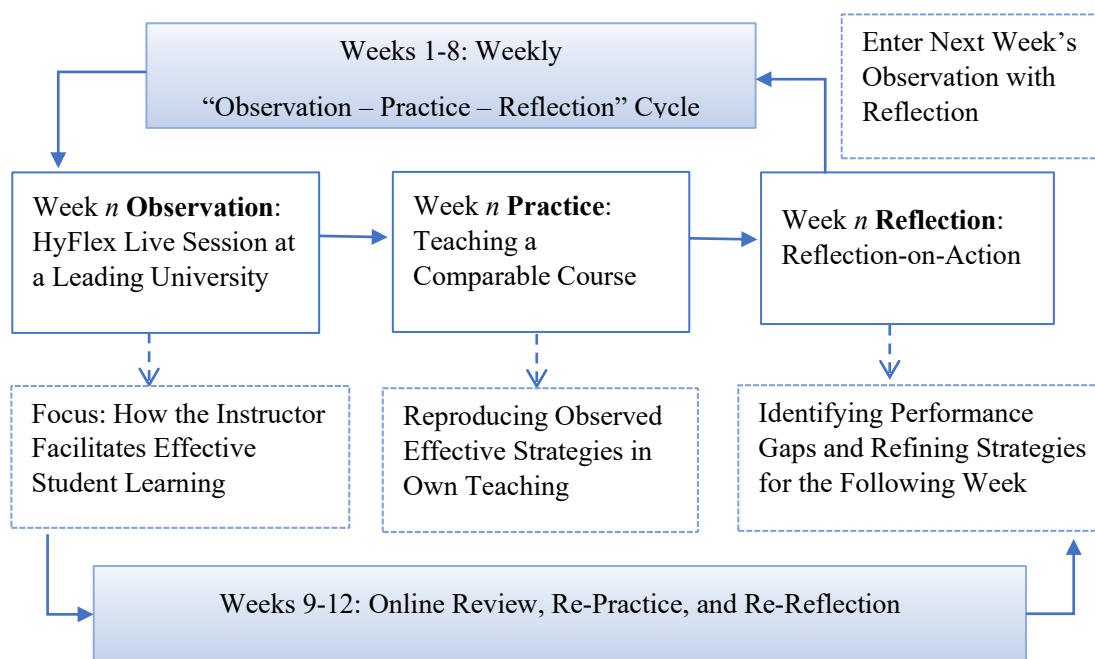


Figure 2 CHT Implementation Process: A 12-Week Intervention

In contrast, the control group received routine face-to-face professional development training offered by their respective institutions, which focused on general teaching strategies without specific emphasis on HyFlex pedagogy. To address ethical considerations, the CHT training video resources were made accessible to the control group within one month after the experimental period.

### Participants

A total of 67 university faculty members from higher education institutions in eastern China were initially recruited for this study. Seven participants withdrew during the intervention, yielding a final sample of 60 participants (30 in the experimental group and 30 in the control group) who completed both the pre-test and post-test questionnaires.

As shown in Table 1, the experimental and control groups were well balanced with respect to key demographic variables, including teaching discipline, age, years of teaching experience, and professional title. The experimental group comprised 30 teachers (15 female, 15 male), with a mean age of 37.5 years ( $SD = 7.3$ ) and an average of 9.7 years of teaching experience. The control group comprised 30 teachers (17 female, 13 male), with a mean age of 38.9 years ( $SD = 7.6$ ) and an average of 10.3 years of teaching experience. No significant differences were found between the two groups on any demographic variable at baseline.

All participants provided informed consent prior to the intervention. Ethical considerations regarding the control group's access to the CHT training materials are addressed in the experimental design section.

Table 1

*Demographic Information of Teacher Groups (n=60)*

| Variable            | Item                   | Number (n) | Percent (%) |
|---------------------|------------------------|------------|-------------|
| Group               | HyFlex (Experimental)  | 30         | 50.0        |
|                     | Offline (Control)      | 30         | 50.0        |
| Gender              | Male                   | 28         | 46.7        |
|                     | Female                 | 32         | 53.3        |
| Teaching Discipline | Science & Engineering  | 31         | 51.7        |
|                     | Social Sciences & Arts | 29         | 48.3        |
|                     | ≤30                    | 9          | 15.0        |
| Age                 | 31-40                  | 28         | 46.7        |
|                     | ≥41                    | 23         | 38.3        |
|                     | Senior                 | 15         | 25.0        |
| Professional Title  | Intermediate           | 20         | 33.3        |
|                     | Junior                 | 25         | 41.7        |

*Research Instruments and Data Collection*

The primary instrument for this study was the Teachers' Pedagogical Competence Self-Evaluation Questionnaire (TPC-SQ), a self-developed five-point Likert scale (1 = strongly disagree, 5 = strongly agree) designed to measure faculty pedagogical competence in HyFlex teaching contexts. The scale was developed based on a comprehensive literature review of pedagogical competence frameworks (e.g., Ramsden, 2003; Mishra & Koehler, 2006) and adapted from existing instruments (e.g., Martin et al., 2019; Suartama et al., 2019). The initial item pool was reviewed by three experts in educational technology and teacher education to establish content validity.

The scale comprises seven items across three theoretically grounded sub-dimensions: Instructional Design (ID), Technology Integration (TI), Reflective practice with Iterative improvement (RI) (see Table 2 for details). A total score was computed as the mean of all seven items, with higher scores indicating greater self-perceived pedagogical competence. Sub-dimension scores were calculated as the mean of the respective items.

Table 2

*Items of Teachers' Pedagogical Competence Self-evaluation Questionnaire (TPC-SQ)*

| Dimension                                           | Item                                                                                               |
|-----------------------------------------------------|----------------------------------------------------------------------------------------------------|
| Instructional Design (ID)                           | 1. I can organize appropriate teaching content based on teaching objectives                        |
|                                                     | 2. I can analyze students' learning situations, design and implement teaching activities           |
|                                                     | 3. I can collaborate with others using digital technology to enhance students' learning experience |
| Technology Integration (TI)                         | 4. I can provide differentiated teaching guidance based on students' characteristics               |
|                                                     | 5. I can utilize digital technology to assess students' learning progress                          |
| Reflective practice with iterative improvement (RI) | 6. I can regularly evaluate teaching effectiveness, and provide reports and feedback               |
|                                                     | 7. I can reflect on and improving teaching and practical activities                                |

The reliability and validity of the scale were examined through a pilot test with 20 university teachers who did not participate in the main experiment. The results indicated satisfactory internal consistency (Cronbach's  $\alpha = .91$  for the full scale). The adequacy of the data for exploratory factor analysis was confirmed by a KMO value of .70 and a significant Bartlett's test of sphericity ( $\chi^2(21) = 100.48, p < .001$ ). A three-factor solution was extracted, accounting for 84% of the total variance, thus supporting the construct validity of the scale.

Data were collected at two time points: pre-test (T1) was administered one week prior to the start of the CHT intervention, and post-test (T2) was administered two weeks before the conclusion of the experiment (late December 2025), ensuring a minimum interval of three months between the two measurements. The questionnaire was distributed via an online survey platform to both the experimental and control groups. A total of 60 valid questionnaires were returned, with 30 respondents in each group. The same measurement instrument was used at both time points to ensure comparability of the data.

*Data Analysis*

Quantitative analyses were conducted using R software (version 4.5.2) in four steps.

Step 1: Data pre-processing. Data were screened for completeness, missing values, duplicate entries, and outliers ( $Z > \pm 3.29$ ) to determine whether they are included in the valid samples. No outliers were identified based on the predetermined threshold.

Step 2: Reliability and validity. Internal consistency was assessed using Cronbach's alpha. Construct validity was examined through exploratory factor analysis (EFA) on pre-test data and confirmatory factor analysis (CFA) on post-test data, with model fit evaluated using  $CFI \geq .90$ ,  $TLI \geq .90$ ,  $RMSEA \leq .08$ , and  $SRMR \leq .08$  (Hu & Bentler, 1999).

Step 3: Baseline comparability. Normality was checked using the Shapiro-Wilk test. Independent samples t-tests (or Mann-Whitney U tests) were performed on overall and dimensional pre-test scores to confirm baseline equivalence between groups.

Step 4: Intervention effects. A one-way ANCOVA was conducted on overall post-test scores with group as the independent variable and overall pre-test scores as the covariate to evaluate the overall intervention effect (RQ1). To examine dimensional effects (RQ2 and RQ3), three separate ANCOVAs were performed, one for each dimension, with the corresponding

dimensional post-test score as the dependent variable, group as the independent variable, and the dimensional pre-test score as the covariate. Bonferroni correction was applied for multiple comparisons ( $\alpha = .017$ ). Effect sizes were reported as partial eta-squared ( $\eta^2$ ).

## Results

To address the three research questions, the quality of the data and baseline comparability were first examined, followed by the main analyses of the overall and dimensional intervention effects.

### *Preliminary Analyses*

Preliminary analyses were conducted to examine the psychometric properties of the TPC-SQ and to confirm baseline comparability between groups. Reliability analysis indicated excellent internal consistency for both pre-test (Cronbach's  $\alpha = .92$ ) and post-test ( $\alpha = .92$ ). Construct validity was supported by EFA, with KMO = .86 and significant Bartlett's test ( $p < .001$ ) for both time points. Parallel analysis suggested a single-factor structure, which accounted for 64% of the total variance, with factor loadings ranging from .54 to .90 (all exceeding the .40 threshold). These results support the use of the TPC-SQ as a reliable and valid measure for subsequent intervention effect analyses.

Baseline comparisons revealed no significant differences between the two groups on any item or the TPC total score, as confirmed by both independent samples *t*-tests and Mann-Whitney *U* tests (all  $p > .05$ ), confirming initial equivalence. As shown in Table 3, item means ranged from 3.9 to 4.3, with an overall mean of 4.2 (SD = 0.52), indicating a relatively high baseline level of self-perceived pedagogical competence among participants. The established baseline equivalence provides a solid foundation for subsequent analyses of intervention effects (e. g., ANCOVA), ensuring that any observed post-test differences can be more confidently attributed to the experimental manipulation rather than pre-existing group disparities.

Table 3

*Comparison of Baseline Scores Between Groups for TPC*

| Subscale                    | Variable | Group        | n  | Mean | SD   | <i>t</i> -test <i>p</i> -value | Wilcoxon <i>p</i> -value |
|-----------------------------|----------|--------------|----|------|------|--------------------------------|--------------------------|
| Instructional Design (ID)   | P1       | Control      | 30 | 4.3  | 0.7  | 0.67                           | 0.43                     |
|                             |          | Experimental | 30 | 4.2  | 0.5  |                                |                          |
|                             | P2       | Control      | 30 | 4.2  | 0.73 | 0.70                           | 0.52                     |
|                             |          | Experimental | 30 | 4.2  | 0.59 |                                |                          |
| Technology Integration (TI) | P3       | Control      | 30 | 4.2  | 0.73 | 1.00                           | 0.79                     |
|                             |          | Experimental | 30 | 4.2  | 0.57 |                                |                          |
|                             | P4       | Control      | 30 | 4.2  | 0.75 | 0.84                           | 0.89                     |
|                             |          | Experimental | 30 | 4.2  | 0.48 |                                |                          |
|                             | P5       | Control      | 30 | 4.1  | 0.64 | 0.82                           | 0.87                     |
|                             |          | Experimental | 30 | 4.1  | 0.48 |                                |                          |
|                             | P6       | Control      | 30 | 4.2  | 0.71 | 0.07                           | 0.05                     |

|                                                        |              |    |     |      |      |      |
|--------------------------------------------------------|--------------|----|-----|------|------|------|
| Reflective practice with iterative improvement P7 (RI) | Experimental | 30 | 3.9 | 0.68 | 0.22 | 0.13 |
|                                                        | Control      | 30 | 4.3 | 0.66 |      |      |
|                                                        | Experimental | 30 | 4.1 | 0.57 |      |      |

**Note.** Details for Items P1-P7 are provided in Teachers' Pedagogical Competence Self-evaluation Questionnaire (TPC-SQ).

### **Overall Intervention Effect on Pedagogical Competence**

#### **a. Assumption Testing for Parametric Group Comparisons**

Analysis of covariance (ANCOVA) is a commonly used analytical method for assessing the effects of interventions on outcome variables by controlling for pretest conditions (Jamieson, 2004; Philippas, 2024). Before evaluating the intervention effect, ANCOVA assumptions were tested. The homogeneity of regression slopes assumption was satisfied (Group  $\times$  TPC1 interaction:  $F(1,56) = 1.75$ ,  $p = .191$ ). However, residuals were non-normal (Shapiro–Wilk  $W = 0.96$ ,  $p = .046$ ) and heteroscedastic (Levene's  $F(1,58) = 12.11$ ,  $p = .001$ ). Accordingly, robust standard errors (Huber-White) were employed for ANCOVA, and the Mann-Whitney U test was used for non-parametric validation of gain scores.

#### **b. Group Differences Based on Robust ANCOVA**

As the robust ANCOVA results presented in Table 4, after controlling for pre-test scores (TPC1), the experimental group demonstrated significantly higher post-test scores compared to the control group ( $\beta = 0.202$ , robust  $SE = 0.076$ ,  $p = .010$ ). The effect size  $r = 0.333$  represented a moderate effect. The model exhibited strong explanatory power, with adjusted  $R^2 = 0.751$ , indicating that TPC1 and group together explained 75.1% of the variance in TPC2. As expected, pre-test scores strongly predicted post-test scores ( $\beta = 0.856$ ,  $p < .001$ ).

Table 4

#### **Robust ANCOVA Results for TPC2 (Controlling for TPC1)**

| Predictor            | Estimate | Robust SE | p-value | partial $\eta^2$ | Effect Size $r$ | Magnitude |
|----------------------|----------|-----------|---------|------------------|-----------------|-----------|
| Intercept            | 0.360    | 0.335     | .287    | —                | —               | —         |
| Group (Experimental) | 0.202    | 0.076     | .010    | 0.111            | 0.333           | Medium    |
| TPC1                 | 0.940    | 0.075     | < .001  | 0.732            | 0.856           | Large     |

Note: Robust standard errors (Huber-White) were used to correct for heteroscedasticity; Partial  $\eta^2$  interpretation: 0.01 = small, 0.06 = medium, 0.14 = large; Effect size  $r$ : with magnitude interpreted as small ( $\geq 0.10$ ), medium ( $\geq 0.30$ ), large ( $\geq 0.50$ ) (Cohen, 1988).

#### **c. Group Differences Based on Mann-Whitney U Test**

Table 5 presented the TPC post-test descriptive statistics. Following the intervention, the experimental group showed slightly higher post-test TPC4 scores (Mean = 4.45, SD = 0.57) compared to the control group (Mean = 4.32, SD = 0.57). The experimental group's post-test mean rank was 32.4, compared to 28.6 for the control group, a difference of 3.8, indicating a slight overall advantage for the experimental group.

For the gain score descriptive statistics, the experimental group showed a mean gain of 0.31 points (Median = 0.36), substantially higher than the control group's mean gain of 0.11 points (Median = 0.13), yielding a mean difference of 0.20 points. The experimental group exhibited greater variability in gain scores (SD = 0.37) compared to the control group (SD = 0.16), indicating individual differences in intervention response. Distribution analysis revealed positive skewness in the control group (Skewness = 0.94), indicating most participants showed small gains, while the experimental group exhibited negative skewness (Skewness = -0.44), indicating most participants achieved substantial gains.

Table 5

*Descriptive Statistics for TPC2 by Group*

| Group        | n  | TPC2        | Gain Score (TPC2 - TPC1) |             |        |           |          |
|--------------|----|-------------|--------------------------|-------------|--------|-----------|----------|
|              |    | Mean(SD)    | Mean Rank                | Mean (SD)   | Median | Skew-ness | Kurtosis |
| Control      | 30 | 4.32 (0.57) | 28.6                     | 0.11 (0.16) | 0.13   | 0.94      | 0.86     |
| Experimental | 30 | 4.45 (0.57) | 32.4                     | 0.31 (0.37) | 0.36   | -0.44     | -0.23    |

Note: TPC1:Pre-test, TPC2: Post-test.

The Mann-Whitney  $U$  test revealed significantly higher gain scores in the experimental group compared to the control group ( $W = 239.5$ ,  $p = .002$ ). The rank-biserial correlation was -0.47 (95% CI [-0.67, -0.21]), representing a moderate-to-large effect. The negative value indicates higher gain scores in the experimental group. The experimental group's mean rank (37.5) substantially exceeded that of the control group (23.5), a difference of 14, further confirming greater improvement in TPC2.

Table 6

*Mann-Whitney  $U$  Test Results for TPC Gain Scores*

| Group        | n  | Mean Rank | Mann-Whitney $U$ ( $p$ ) | Effect Size $r$ | Rank-Biserial Correlation [95% CI] | Magnitude         |
|--------------|----|-----------|--------------------------|-----------------|------------------------------------|-------------------|
| Control      | 30 | 23.5      | 239.5 (.002)             | 0.407           | -0.47 [-0.67, -0.21]               | Moderate-to-large |
| Experimental | 30 | 37.5      |                          |                 |                                    |                   |

Note: Gain scores calculated as TPC2 - TPC1; Magnitude interpreted as small ( $\geq 0.10$ ), moderate ( $\geq 0.30$ ), large ( $\geq 0.50$ ).

The post-test mean rank difference was only 3.8, while the gain score mean rank difference reached 14.0. This contrast clearly illuminates the true intervention effect, while the control group maintained some advantage in post-test due to slightly higher pre-test scores, the experimental group's magnitude of improvement substantially surpassed that of the control group. Gain score analysis, by removing baseline differences, provides a purer estimate of the intervention's causal effect.

The intervention effect estimated by robust ANCOVA (0.202 points) closely matched the mean gain difference (0.206 points). The rank-biserial correlation (-0.47) aligned perfectly with the Mann-Whitney  $U$  test results ( $p = .002$ , effect size  $r = 0.407$ ). Both analytical approaches yielded consistent conclusions of significant intervention effects, with effect sizes reaching moderate-to-large levels (ANCOVA partial  $\eta^2 = 0.111$ , rank-biserial  $r = 0.47$ , Mann-Whitney  $r = 0.407$ ), demonstrating exceptional robustness of the findings.

For conclusion, the intervention produced statistically significant and practically meaningful improvements in TPC. The persistence of significance even with the most conservative non-parametric validation further confirms the reliability of this conclusion. The contrast between post-test and gain score analyses further reveals the true magnitude of the intervention effect.

#### *Sub-Dimensional Intervention Effects*

To further examine the differential patterns of intervention effects, sub-dimension gain scores were computed by subtracting pre-test dimension totals from post-test dimension totals, and group differences were assessed using Mann-Whitney  $U$  tests.

Table 7

*Sub-Dimension Gain Scores and Group Comparisons*

| Sub-dimension                                       | Items      | Group        | Gain | Group Difference | Mann-Whitney $U$ ( $p$ ) |
|-----------------------------------------------------|------------|--------------|------|------------------|--------------------------|
| Instructional Design (ID)                           | P1, P2     | Control      | 0.3  | 0.1              | 408.5 (.502)             |
|                                                     |            | Experimental | 0.4  |                  |                          |
| Technology Integration (TI)                         | P3, P4, P5 | Control      | 0.4  | 0.5              | 326 (.05)                |
|                                                     |            | Experimental | 0.9  |                  |                          |
| Reflective practice with iterative improvement (RI) | P6, P7     | Control      | 0    | 0.9              | 227.5 (< .001)           |
|                                                     |            | Experimental | 0.9  |                  |                          |

As presented in Table 7, the experimental group showed the largest gains in reflective practice with iterative improvement (gain = 0.90) and technology integration (gain = 0.90), while the instructional design dimension exhibited a comparatively smaller gain (0.40). The group difference was highly significant for reflective practice ( $W = 227.5$ ,  $p < .001$ ), approached significance for technology integration ( $W = 326.0$ ,  $p = .050$ ), and was non-significant for instructional design ( $W = 408.5$ ,  $p = .502$ ). This pattern suggests that the CHT intervention was most effective in enhancing teachers' capacity for systematic reflection and iterative improvement, with a moderate effect on technology integration, while its impact on foundational instructional design competencies was limited. These findings align with the intervention's design emphasis on observational learning and reflective practice, which may have more directly targeted higher-order teaching competencies rather than basic design skills.

## **Discussion, Implications and Conclusion**

### *Key Findings*

This study provides robust empirical evidence that the Collaborative HyFlex Training (CHT) program effectively enhances university teachers' pedagogical competence. Through a quasi-

experimental design combining robust ANCOVA with non-parametric validation, the CHT program demonstrated a significant positive effect on participants' overall teaching competence ( $\beta = 0.202$ ,  $p = .010$ ,  $r = 0.333$ ). At the sub-dimension level, a differentiated pattern emerged: the strongest effect was observed in reflective practice with iterative improvement ( $W = 227.5$ ,  $p < .001$ ), followed by a moderate effect on technology integration ( $W = 326.0$ ,  $p = .050$ ), while instructional design showed no significant group difference ( $W = 408.5$ ,  $p = .502$ ). These findings suggest that the CHT program is particularly effective in cultivating higher-order reflective capacities, while foundational design skills may require longer-term intervention. The study contributes a validated, replicable framework for cross-institutional teacher professional development and offers methodological insights for future research in the digital transformation of higher education.

## Discussion

### *Overall Intervention Effects and Methodological Contributions*

After controlling for pre-test scores, the experimental group maintained a significant advantage over the control group, with a medium effect size. This finding aligns with prior HyFlex training research (Xiao et al., 2025), which demonstrated that HyFlex-based professional development can effectively enhance teachers' competence across multiple domains. The dual-validation strategy combining robust ANCOVA with non-parametric testing represents a methodological contribution, as educational data often violate parametric assumptions (Jamieson, 2004), and the high consistency between the two analytical approaches strengthens the reliability of our conclusions.

### *Differential Patterns Across Sub-Dimensions*

The most pronounced improvement in reflective practice aligns with the CHT program's core design, the "observation–practice–reflection" cycle, which actively cultivated teachers' capacity for systematic self-evaluation and pedagogical adjustment. The moderate yet marginally significant improvement in technology integration suggests that observational learning can enhance teachers' awareness and confidence in using digital tools, but sustained improvement may require more hands-on technical practice beyond the current 8-week observation-based format. The non-significant result for instructional design may be attributed to two factors: the dimension comprised only two items, potentially limiting its sensitivity to detect change, and participants already reported relatively high baseline scores in this dimension ( $M > 4.1$ ), suggesting a possible ceiling effect. It is also plausible that instructional design competency, as a foundational skill, requires longer-term professional development to yield measurable improvement.

### *Cross-Institutional Collaborative Mechanisms and Systemic Implications*

The cross-institutional collaborative mechanism proved effective in addressing the "systemic isolation" challenge documented in prior literature (Naeem & Raad, 2025). Through cloud-based observation of HyFlex demonstration lessons delivered by instructors from renowned universities, teachers from ordinary institutions achieved a competency transformation progressing from awareness to strategy transfer and ultimately to school-based innovation. The CHT framework provides an actionable pathway for cross-institutional sharing of high-quality resources and the promotion of educational equity, characterized by anchor institutions providing leadership, the HyFlex mode serving as the foundation, and institutional support forming the operational skeleton.

Furthermore, the effectiveness of HyFlex training is shaped not only by content design but also by teachers' professional learning communities and institutional support culture. Prior studies have similarly emphasized that sustainable teacher development must address technical skills, psychological readiness, peer collaboration, and institutional culture collectively (Faisal et al., 2026; Salhab, 2024; Ozan & Özarslan, 2025). These findings suggest that effective HyFlex teacher training should move beyond skill transfer toward a systematic framework integrating cultural cultivation, community building, and institutional support.

### **Limitations and Future Research**

Several limitations should be acknowledged. First, the sample size is relatively modest (60 teachers), which may affect the stability of statistical power and effect size estimation. Future research should expand the sample or conduct cross-validation across different training programs. Second, this study only examined immediate effects without tracking long-term retention and transfer of pedagogical competence; longitudinal designs are needed to assess sustained impact. Third, the research context is limited to specific disciplinary areas within Chinese higher education; the generalizability of the CHT framework to K-12 education, vocational training, or different cultural settings requires further testing. Future studies may also employ mixed-methods approaches to investigate the mechanisms underlying the observed sub-dimension differences and the role of institutional culture in moderating training effectiveness.

### **Conclusion**

This study provides empirical evidence that the CHT program effectively enhances university teachers' pedagogical competence, particularly in reflective practice and technology integration. The CHT framework addresses the "systemic isolation" challenge in cross-institutional teacher development by operationalizing an "observation–reflection–practice" cycle, providing an actionable pathway for the sharing of high-quality resources and the promotion of educational equity. The dual-validation analytical strategy employed in this study also offers a methodological reference for future research in contexts where educational data violate parametric assumptions. While the sample size and contextual scope limit generalizability, the findings support the broader application of HyFlex models in the digital transformation of higher education and provide a methodological reference for future research in this area.

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## Declarations

**Conflict of interest** The authors declare there is no conflict of interest.

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