2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #50783

Peer Teaching in Engineering: An In-Depth Study

Dr. Wenbing Zhao, Cleveland State University

Dr. Zhao is a Full Professor at the Department of Electrical and Computer Engineering, Cleveland State University. He earned his Ph.D. at University of California, Santa Barbara in 2002.

Dr. Xiongyi Liu, Cleveland State University

Xiongyi Liu is an Associate Professor in the School of Education and Counseling at Cleveland State University (CSU), USA. Dr. Liu obtained her Ph.D. in Educational Psychology from University of Nebraska-Lincoln, USA. Prior to joining CSU, she has worked as research faculty at the Center for Research and Evaluation, University of Maine-Orono. Her research interests include educational technology, motivation, self-regulation, peer assessment, teacher education, STEM education, and artificial intelligence in education. At CSU, Dr. Liu is affiliated with TechHub and the Center for Integrated Modeling for Energy, Sustainability and Resiliency. She has worked on multiple interdisciplinary research projects as co-PI and evaluator for the development of innovative approaches to engineering education at various educational levels in such critical areas as modeling and simulation, cybersecurity, and AI.

Dr. Yong Tao P.E., Cleveland State University

Dr. Yong Tao holds the Betty L. Gordon Endowed Chair and Distinguished Professor of the Department of Mechanical Engineering and is the past department chair at CSU. He received his Ph.D. in mechanical engineering from the University of Michigan. Prior to joining CSU in 2019, Dr. Tao has served in higher education for three decades with different roles as professor, research director, chair, associate dean, and dean in several public or private research universities. He has been active in research of the fundamentals of thermal sciences, renewable energy applications in buildings and energy system modeling and simulations. His research at CSU involves collaboration with industries on district energy systems. Dr. Tao founded Center for Integrated Modeling for Energy, Sustainability and Resiliency (IERS Center) at CSU. His recent endeavors include a Department of Education grant to establish the experiential learning environment in modeling and simulation of energy system engineering, and coordination of development of professional microcredential and certification courses in microgrid and power engineering.

Peer Teaching in Engineering: An In-Depth Study

Abstract
In this paper, we present an in-depth study on incorporating peer teaching in graduate level engineering courses. Peer teaching is a form of active learning. It also incorporates elements of flipped classrooms. Unlike common practices of peer teaching, which usually focuses on tutoring, mentoring, and problem solving, students in our class were required to form teams and each team was required to give a mini-lecture on a pre-approved topic within the scope of the course. This design of peer teaching has two purposes. First, from the students' perspective, they get to experience what it takes to prepare and teach a mini-lecture on a topic that is relevant to the course. Second, from the instructor's perspective, the mini-lectures given by student teams could complement the lectures prepared and given by the instructor.

The assessment method is a survey consisting of a Teacher Perception Scale (TPS) (*i.e.,* eight questions regarding a student's perception serving as a peer teacher), a Learner Perception Scale (LPS) (*i.e.,* eight questions regarding a students' perception as a peer learner), and two open-ended questions. Basic analysis of the survey results confirmed that the findings of our study are consistent with those of previous studies on peer teaching. Furthermore, we report an in-depth analysis of the impact of the peer teaching module that is guided by the following research questions: (1) To what extent do students' perceptions of peer teaching as teachers align with their perceptions as learners? (2) How does participating in peer teaching influence students' engagement, confidence, and communication skills? (3) Are there distinct clusters of students based on their attitudes toward peer teaching? What characterizes each group? (4) How is perceived effectiveness shaped by the structure and preparedness of peer-teaching activities? (5) What suggestions do students offer to improve peer teaching experiences?

Both TPS and LPS demonstrate excellent reliability ($\alpha_{\mathrm{TPS}} = 0.946$, $\alpha_{\mathrm{LPS}} = 0.886$), and a strong TPS–LPS alignment (Spearman $\rho \approx 0.81$, Pearson $r \approx 0.83$). Clustering yields two coherent segments (*teamwork-focused* and *preparedness-focused*; silhouette ≈ 0.45). Open-ended recommendations emphasize interactive activities, clear objectives and rubrics, targeted training for peer teachers, topic uniqueness, pacing, and light-touch faculty oversight. Findings are interpreted within self-determination theory, social cognitive theory, and constructive alignment. Implications for instructional design and future research are also outlined.

Introduction
Peer teaching is widely adopted to promote active learning, communication, and collaboration. Yet student perceptions of peer teaching can vary across roles (peer-teacher vs. peer-learner), course contexts, and instructional designs. This paper investigates five research questions (RQs):

- RQ1: To what extent do students' perceptions of peer teaching as teachers align with their perceptions as learners?
- RQ2: How does participating in peer teaching influence students' engagement, confidence, and communication skills?
- RQ3: Are there distinct clusters of students based on their attitudes toward peer teaching? What characterizes each group?
- RQ4: How is perceived effectiveness shaped by the structure and preparedness of peer-teaching activities?
- RQ5: What suggestions do students offer to improve peer teaching experiences?

We combine structured Likert analysis with qualitative coding to develop actionable design guidance for future peer teaching implementations.

Related Work

Our approach to peer teaching, which is defined as group-based delivery of mini-lectures by students, is grounded in the principle of *active learning* [1], which emphasizes that students learn more effectively when they actively participate in class. This contrasts with traditional lecture-based instruction, often described as passive learning, where students primarily listen to the instructor. Over the past decades, numerous active learning strategies have emerged. To examine their relative popularity, we searched the Web of Science Core Collection using the terms "active learning," "problem-based learning," "peer teaching," and "flipped classroom." The results were striking: "problem-based learning" yielded 240,696 publications, "active learning" 80,818, "peer teaching" 17,274, and "flipped classroom" 6,767. These numbers indicate that all four methods have been widely studied. In the literature, peer teaching is sometimes referred to as *peer instruction* [2–4].

Active learning serves as an umbrella term for pedagogical strategies that promote student engagement and participation. Within this framework, problem-based learning is the most extensively published method. Its popularity may be due to its relatively low implementation barrier, especially when suitable textbooks or instructional resources are available [5–9]. Problem-based learning is largely independent of other active learning approaches and can be combined with peer teaching or flipped classroom techniques. Flipped classroom and peer teaching may also overlap and complement each other.

Although our course included problem-based learning, this study focuses on designing and evaluating the *peer teaching component*. Peer teaching has a long history in higher education [10, 11]. The earliest comprehensive review, published in 1976, categorized peer teaching into five types: (1) sessions led by teaching assistants; (2) the proctor model; (3) student learning groups; (4) learning cells; and (5) student counseling. The first three types typically involve student teachers who are not classmates of the learners and are often more senior, a practice sometimes referred to as *near-peer teaching* [12]. The latter two types—learning cells and student learning groups—consist of classmates who alternate roles as teachers and learners. In learning cells, two students study together, whereas student learning groups collaborate on assigned tasks.

Given the extensive literature on peer teaching—over 17,000 studies indexed in Web of Science—it is impossible to provide a comprehensive review here. Instead, we highlight select recent studies. Many focus on tutoring to support comprehension or assist struggling students outside class [13–17], while others emphasize active participation during class through problem-solving [3, 4]. For example, Adawi et al. [3] describe peer teaching in group discussions of multiple-choice questions, while Carroll [18] frames collaborative research assignments as a form of flipped classroom. Other studies involve peer assistance in laboratory settings [19, 20] or mentoring by postgraduate students in project-based courses [16, 17]. Some programs even formalize peer teaching through faculty mentorship and didactic training for high-performing students [21] or service-learning initiatives where undergraduates teach in high schools [22].

Two studies closely resemble our approach. Glassey [23] assigned specific topics to student teams for presentation, while Ramaswamy [24] required individual students to teach a 20–25-minute unit after mastering core concepts. Our design differs in that student teams select their own mini-lecture topics, granting greater autonomy and allowing them to explore areas of personal interest.

Study Design

The peer teaching component in our course (offered as a 500-level graduate course named ”Fundamentals of Modeling and Simulation”) involved four stages: (1) team formation; (2) topic proposal; (3) peer teaching signup; and (4) peer teaching presentation. At the start of the semester, the assignment was introduced and students were encouraged to form teams. A team formation assignment was posted on Blackboard for submission, and each team must designate a leader. After several weeks, teams submitted a topic they wish to explore and present as a mini-lecture, using a dedicated Blackboard assignment. To assist with topic selection, a list of suggested topics was provided, though students were free to propose alternatives. If a topic was deemed unsuitable, immediate feedback was given so the team can choose a more appropriate one. A total of 12 teams were formed. The team size varies between one to four.

Approximately four weeks before the semester ended, teams signed up for a time slot to deliver their mini-lecture. The length of each presentation depends on team size, with each member expected to present for about 10 minutes. The final two weeks of the semester were reserved for student-led mini-lectures.

A questionnaire was designed to collect student feedback regarding their peer teaching experience. The questionnaire is based on questionnaires proposed in [25]. The questionnaire contains a teacher perception scale (TPS), a learner perception scale (LPS), and two open-ended questions. Each scale consists of eight questions. The TPS consists eight questions about student experience as a student teacher:

- Q_1^t: Serving as a peer teacher increased my self-confidence in this course.
- Q_2^t: Serving as a peer teacher improved my course performance.
- Q_3^t: Serving as a peer teacher improved my communication and active listening skills.
- Q_4^t: I had the opportunity to consolidate my own knowledge through peer teaching.

- Q^t_5: I have a better understanding of teamwork and understanding roles within the team.
- Q^t_6: I gained many benefits from peer teaching experience and am willing to repeat it.
- Q^t_7: The students were actively engaged during the peer teaching sessions.
- Q^t_8: I think the students benefited from peer teaching experience.

The LPS consists of eight questions about student experience as a student learner:

- Q^l_1: The content of peer teaching sessions was appropriate for the student's level.
- Q^l_2: The Peer teacher's methods were helpful.
- Q^l_3: I understood the subject better after the peer teaching sessions.
- Q^l_4: I understood the content better when the peer teachers explained it.
- Q^l_5: I am more willing to engage in sessions taught by peers compared to faculty teachers.
- Q^l_6: The peer teaching sessions were better than I had expected.
- Q^l_7: The peer teachers were well-prepared and knowledgeable about the topic.
- Q^l_8: We should have more peer teaching sessions.

For each question, a 5-point Likert scale [26] is used, which includes strongly disagree (SD, with a numerical value of 1), disagree (D, with a numerical value of 2), neutral (N, with a numerical value of 3), agree (A, with a numerical value of 4), and strongly agree (SA, with a numerical value of 5). Furthermore, the questionnaire includes two open-ended questions:

- What do you think are the advantages and disadvantages of using peer teaching method in an engineering course?
- What suggestions do you have for improving student experience if peer teaching method is used in future courses?

Theoretical Foundation

The pedagogical design for incorporating peer teaching lies primary in two theories: self-determination theory and social cognitive theory. The two theories serve as the theoretical foundation for the current study. The basic idea is stronger motivation in learning and enhanced engagement.

Self-Determination Theory

The self-determination theory [27, 28] posits that learners flourish when three basic psychological needs are supported: *i.e.,* autonomy, competence, and relatedness. In the context of academic eduction, autonomy means that the curriculum design grants students sufficient degree of freedom for them to make their own choices that are consistent with their own volition. Competence often relates to students feeling effective and capable in their learning environment. Relatedness refers to students feeling connected to others, including peer students and the instructor. Relatedness also implies reciprocal respect and shared responsibility.

The incorporation of peer teaching in the curriculum design provides with students great opportunities to increase their self determination with respect to all three properties. To facilitate autonomy, each student team is free to choose a relevant topic and the way they present the mini-lecture on the topic (*i.e.,* student-led segments and topical agency). When a team is able to present their mini-lecture in front of the class and to interact with the class (through question and answer and quizzes), the students would directly feel the impact of their preparation and knowledge, which undoubtedly would improve their competence. By working in a team preparing for the mini-lecture, students would be more connected to each other. Students also get to observe and learn from the mini-lectures offered by other student teams, facilitating the relatedness with other teams. The guidance and feedback offered by the instructor would also increase the relatedness of students with the instructor.

Social Cognitive Theory and Self-Efficacy

Bandura's social cognitive theory holds that self-efficacy drives effort, resilience, and performance. Self-efficacy is a belief of an individual about his or her capability to organize and execute actions. Efficacy grows through mastery experience (*i.e.,* successful performance), vicarious experience (*i.e.,* observing peers), verbal persuasion (*i.e.,* credible encouragement and/or feedback from the instructor), and affective regulation [29]. In peer teaching, students who prepare and present (mastery), observe confident peers (vicarious), and receive supportive feedback from the instructor (persuasion) report higher confidence and engagement. Operationalization: teacher-side confidence (Q1_1), communication (Q1_3), engagement (Q1_7) and learner-side clarity/understanding (Q2_3–Q2_4) index efficacy-building processes; regression showing *clarity* and *preparedness* as strongest predictors of effectiveness accords with the central role of competence-beliefs in shaping outcomes.

RQ1: Alignment Between Peer-Teacher and Peer-Learner Perceptions

This section reports the findings for the first research question, which is about the alignment between peer-teaching and peer-learner perceptions. Peer teaching and peer learning have been investigated across a range of educational contexts, and a recurrent theme is the mutual reinforcement of students' experiences when they adopt both roles. Qualitative evidence suggests that peer teaching creates inclusive, interactive classrooms in which students report enjoyment both when teaching and when being taught by peers, alongside heightened metacognition and self-reflection [30]. These findings imply an underlying coherence between the perceived value of peer-led instruction and peer learning activities, even when alignment is not directly quantified.

At the same time, alignment can be nuanced. In a mixed-methods study of elementary science [31], it was found that while students and teachers endorsed peer teaching, their emphases diverged: teachers foregrounded cognitive goals, whereas students prioritized social-emotional and behavioral dimensions. This highlights that aligned positive valence across roles may coexist with differences in the aspects students find most salient, an observation relevant to item-level patterns in perception instruments.

Directly within higher education language classrooms, it is reported consistently positive attitudes toward peer teaching and learning, though students appeared comparatively more enthusiastic about their role as peer teachers than as peer learners [32]. Such role-specific differences suggest that perception alignment can vary by context, instrument, and task demands, but the broader empirical signal remains favorable toward peer-led pedagogies.

Theoretically, the construct of "alignment" resonates with the framework of constructive alignment [33], wherein coherence between intended learning outcomes, teaching activities, and assessments is posited to support deep learning and engagement. Student-facing alignment in how teaching and learning are experienced has been linked to more active and deeper approaches to study [34]. In peer teaching, alignment can also be interpreted through social interdependence theory: when learners perceive mutual goals and positive interdependence, cooperative structures yield cognitive and socioemotional gains, and perceptions of value converge across roles [35]. Complementary evidence from feedback research shows that orchestrating peer and teacher feedback can enhance behavioral engagement and performance, reinforcing the idea that aligned social learning processes strengthen outcomes [36].

Taken together, prior work motivates the examination of perception alignment across the two roles students inhabit in peer teaching: as peer teachers and as peer learners. It supports the expectation that positive perceptions will be correlated, while leaving room for item-level emphasis differences that reflect role-specific salience.

In our data, we operationalized the two perspectives as composite scales, *i.e.,* TPS and LPS. Both scales demonstrated excellent reliability (TPS $\alpha = 0.946$; LPS $\alpha = 0.886$), indicating internally consistent measurement of their respective constructs. Most critically for RQ1, TPS and LPS were strongly and significantly correlated (Spearman $\rho \approx 0.81$, Pearson $r \approx 0.83$, $p < .001$), evidencing robust alignment between students' perceptions of peer teaching as teachers and as learners. Figure 1 visualizes the TPS-LPS alignment, *i.e.,* students who rate peer teaching highly as teachers also rate it highly as learners.

Item-level alignment for peer teaching and peer learning is shown in Figure 2. The item-level correlation matrix reveals that some pairs of teacher-perspective items (Q_i^t) and learner-perspective items (Q_j^l) exhibit relatively low Spearman correlations, often below $r = 0.40$. Two learner-side items—Q_5^l (*"I am more willing to engage in sessions taught by peers compared to faculty teachers."*) and Q_7^l (*"The peer teachers were well-prepared and knowledgeable about the topic."*)—appear most frequently among these low-correlation pairs. Several factors may explain this pattern.

First, construct misalignment plays a significant role. Items such as Q_5^l use a comparative frame (peer versus faculty), whereas most TPS items assess absolute self-development, such as confidence or communication skills. These differences in reference frames naturally reduce covariance. Second, perspective asymmetry is evident in Q_7^l, which reflects learners' judgments of peer preparedness, while TPS items emphasize perceived benefits for the peer teachers themselves. A peer teacher may feel confident and gain skills even if learners perceive limited preparedness, leading to weak associations. Third, wording heterogeneity contributes to the problem. Some TPS items combine multiple facets—for example, teamwork and role clarity—diluting alignment with single-facet LPS items. Measurement effects also matter: restricted variance and ties in Likert responses, combined with rank-based correlation, can attenuate item-level associations. Finally, contextual variability affects items such as Q_6^l (*"Sessions were better than expected."*), which capture situational factors like expectations and

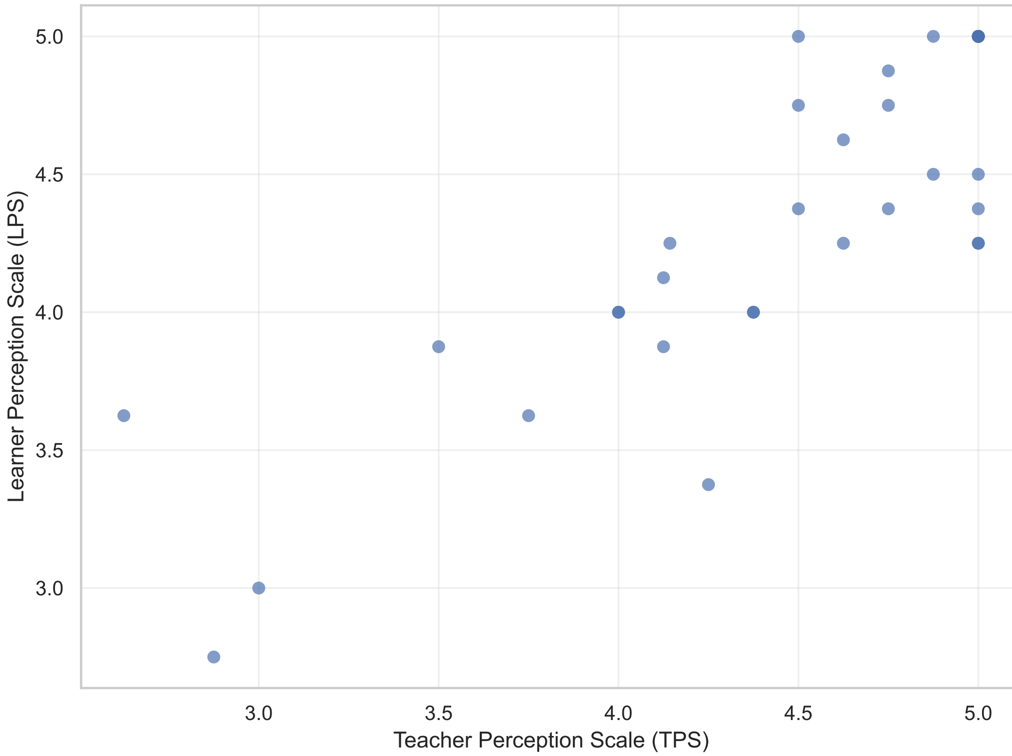

Figure 1: Alignment between teacher and learner perspectives (TPS vs. LPS).

topic difficulty that may not correspond to teachers' self-reported gains.

This empirical result coheres with qualitative reports of mutual enjoyment and metacognitive gains in peer-teaching contexts [30] and aligns with theory that constructively aligned instructional experiences foster deep engagement [34]. At the same time, our item-level correlation matrix indicates that alignment is not monolithic; certain bridges are stronger than others (e.g., teacher-side communication and engagement items pair closely with learner-side helpfulness and understanding). That texture mirrors the role-emphasis differences observed in mixed-methods work [31], suggesting that while overall valence is aligned, different facets may be differentially salient to students depending on whether they are teaching or learning.

From a theoretical standpoint, our TPS–LPS alignment supports the premise that peer teaching leverages social interdependence mechanisms—shared goals, positive interdependence, and promotive interaction—yielding convergent perceptions across roles [35]. It also dovetails with evidence that aligned social learning processes (e.g., peer and teacher feedback) are associated with increases in engagement and performance [36]. Practically, these findings justify treating perception alignment as a design target: interventions that strengthen clarity of peer explanations and preparedness (shown in our RQ5 analysis to predict perceived effectiveness) can be understood as levers that support alignment across roles and thereby reinforce deep, active learning consistent with constructive alignment.

Our analysis also exposed that the LPS requires refinement to improve the alignment between

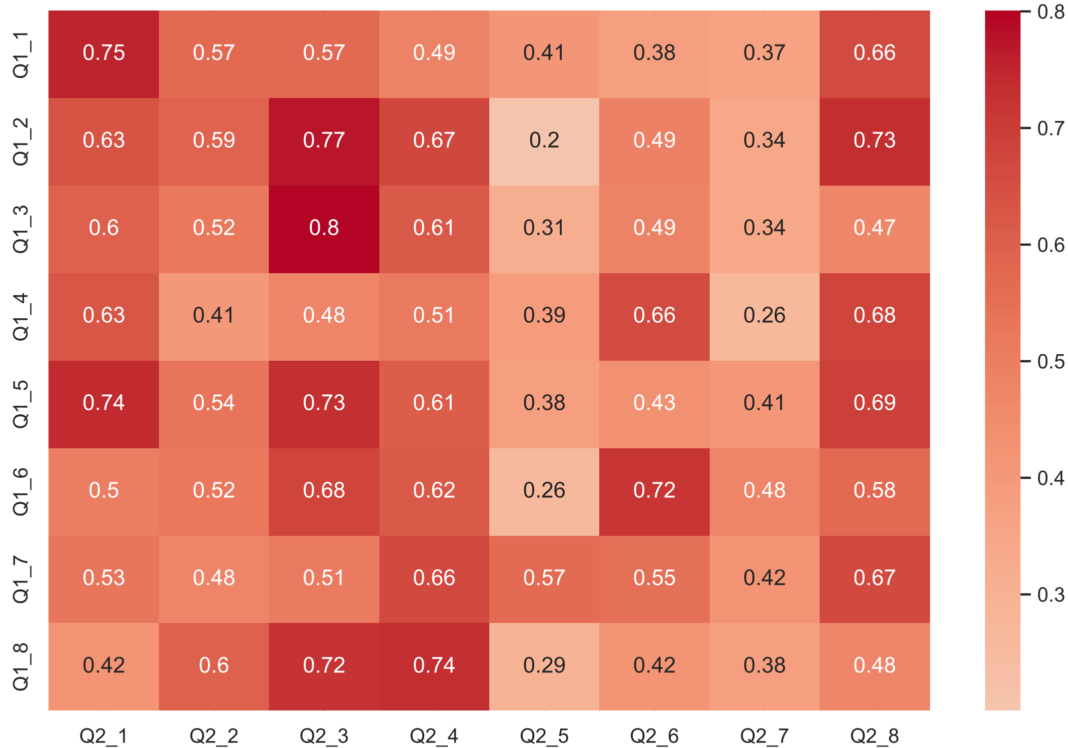

Figure 2: Item-level Spearman correlations between teacher-side items (Q_i^t) and learner-side items (Q_i^l).

teacher and learner perspectives. Comparative items such as Q_5^l should be reworded to focus on absolute engagement (e.g., *"I was engaged during peer-taught sessions."*), while a separate item can capture comparisons with faculty-led sessions if needed. Learner-side judgments of preparedness (Q_7^l) would benefit from corresponding TPS items that directly assess perceived preparedness, such as *"I felt well-prepared to teach the topic."*. Multi-facet TPS items should be split into distinct constructs to reduce ambiguity, and additional items should be introduced to strengthen coverage of key dimensions such as engagement, preparedness, and self-development. Finally, psychometric validation through confirmatory factor analysis and item-total correlation checks will ensure dimensional alignment and guide iterative improvements to item wording and structure.

RQ2: Impact on Engagement and Confidence

As shown in Figure 3, teacher-side engagement and confidence are consistently high. Q_1^t (about confidence) and Q_3^t (about communication skills) are in the 4.4–4.6 range, and Q_7^t (about engagement) is comparably strong. Learner-side perceptions are similarly positive as indicated in Figure 4. Item-level cross-domain correlations show that teacher-side communication skills and engagement align with learner-side helpful methods and understanding, as shown in Figure 2, reinforcing a coherent social-cognitive and sociocultural account of how peer teaching raises confidence and deepens engagement through active explanation, modeling, and scaffolding [37–39].

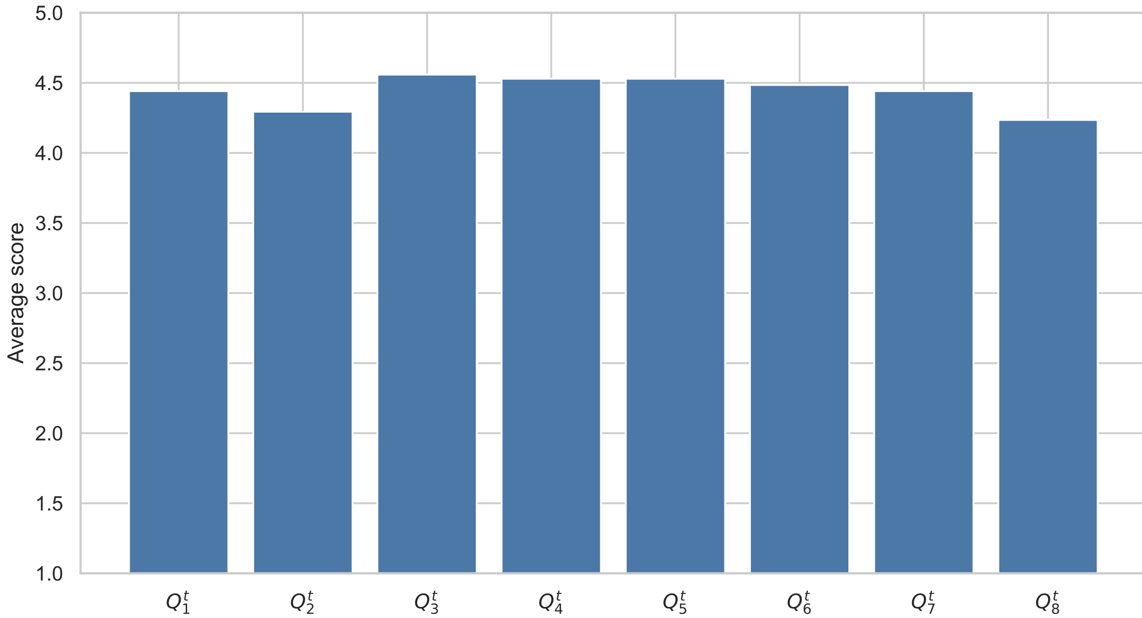

Figure 3: Mean score for each question in the TPS.

Open-ended feedback from students corroborate these quantitative findings. Students frequently cite increased confidence, improved communication, and active learning as advantages, and recommend more interactive formats, clearer objectives, targeted training for peer teachers. Furthermore some students expressed the desire for more faculty oversight. These recommendations map directly onto needs-supportive design in the self-determination theory, *i.e.,* autonomy via student-led segments, competence via training and feedback, relatedness via structured interaction [27, 40].

The findings of our study corroborate with prior related studies, which showed that peer-centered pedagogies increase student engagement, conceptual understanding, and transferable skills when the social and cognitive design of activities is well aligned. In physics and across STEM, peer Instruction research demonstrated sustained gains in conceptual mastery and engagement when lectures were interleaved with structured peer discourse and instructor debriefs because these practices involved every student, increasing emotional investment, and improving subsequent performance on near and far transfer items [37, 41–43]. Meta-analyses and reviews of peer learning demonstrated cognitive benefits for both tutors and tutees, and highlighted social-emotional improvements such as confidence, communication, and collaborative problem solving [39, 44]. Qualitative and mixed-methods studies in peer teaching also reported increased metacognition, self-reflection, and enjoyment on both the teaching and learning sides [30]. More recent higher-education studies underlined the role of peer and teacher relationships in fostering engagement, effort, and performance over time [40, 45, 46].

RQ3: Clustered Attitudes Toward Peer Teaching

In this section, we report our findings regarding the clustered attitudes towards peer teaching. We choose to use the k-means clustering algorithm for creating the clusters. Normally, the number of

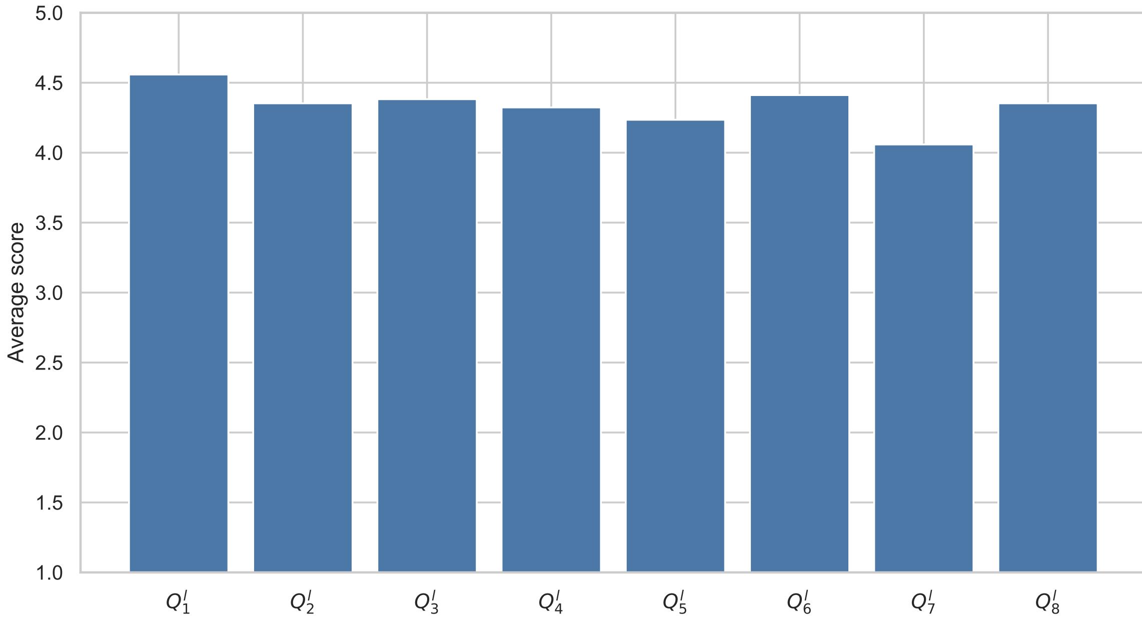

Figure 4: Mean score for each question in the LPS.

clusters is heuristically determined. In this study, we follow a method to objectively determine the number of clusters based on the silhouette score. The silhouette score is a widely used internal validation metric for clustering quality. It evaluates how well each data point fits within its assigned cluster compared to other clusters, balancing cohesion and separation [47]. For a given observation i, let $a(i)$ denote the average distance to all other points in the same cluster (intra-cluster distance), and let $b(i)$ represent the smallest average distance to points in any other cluster (nearest-cluster distance). The silhouette coefficient for observation i is defined as:

$$s(i) = \frac{b(i) - a(i)}{\max\{a(i), b(i)\}}, \quad -1 \leq s(i) \leq 1. \tag{1}$$

A silhouette value close to $+1$ indicates that the observation is well matched to its own cluster and poorly matched to neighboring clusters, whereas values near 0 suggest that the observation lies on the boundary between clusters. Negative values imply potential misclassification. The overall silhouette score for a clustering solution is the mean of $s(i)$ across all observations. When determining the optimal number of clusters k, one typically computes the silhouette score for a range of k values and selects the k that maximizes this score [48]. High silhouette scores (e.g., > 0.5) indicate well-separated clusters, while scores below 0.25 suggest weak or overlapping cluster structures. For clustering our structured survey data, we experimented with four different number of clusters, 2, 3, 4, and 5. The silhouette scores are summarized in Table 1.

It is clear that a cluster of 2 provides the best separation between the clusters. The first cluster has 28 samples and the second cluster has 5 samples. As shown in Figure 5, the first cluster is formed by the samples that are highly positive about the peer teaching experience and the second cluster is formed by those who have more reservations about the experience.

Table 1: Silhouette scores for 2, 3, 4, and 5 clusters using k-means.

k	Silhouette Score	Interpretation
2	0.4514	Highest score (best clustering)
3	0.3563	Moderate separation
4	0.2251	Weak structure
5	0.1983	Poor structure

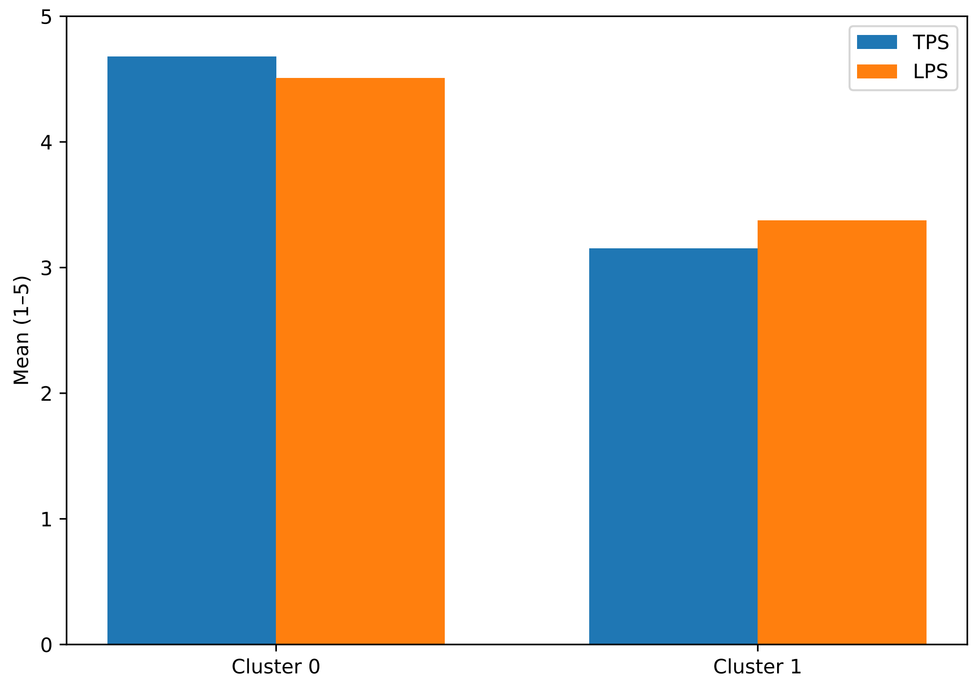

Figure 5: Cluster profiles of TPS and LPS.

We are interested in using the large language model (LLM) to discover deeper semantics for the two clusters as their labels. While we could have constructed prompts for cloud-based LLM services such as Chatgpt and Copilot, we decided to set up a local LLM computing environment (*i.e.,* Ollama) so that we can develop an LLM agent to automate the workflow. Deploying LLMs locally offers significant advantages in terms of privacy, latency, and control over computational resources. Ollama is an open-source framework that enables efficient on-device inference of state-of-the-art LLMs without reliance on cloud services, providing a unified interface for model management and prompt-based interaction [49, 50]. This approach is particularly appealing for research environments where data sovereignty and reproducibility are critical.

Recent open-source LLMs such as LLaMA [51] and Mistral [52] have demonstrated strong performance at practical scales, making them suitable for local deployment. LLaMA provides efficient foundation models trained on publicly available data, while Mistral introduces architectural improvements like grouped-query and sliding-window attention to outperform larger models. Together with Ollama, these models allow researchers to experiment with advanced language capabilities in offline or self-hosted settings, ensuring both flexibility and security. For semantic labeling of the two clusters, we chose to use Mistral.

Early tries proved that finding a thoughtful semantic label for each cluster is challenging. Using a simply and naive prompt such as ”Please provide semantic labels for each cluster based on the given information” led to uninspiring labels ”High Peer Teaching Effectiveness” for the first cluster and ”Low Peer Teaching Effectiveness” for the second cluster. We enhanced the prompt by adding more constraints and the question keys. Essentially, we followed the best practice in LLM-guided clustering and cluster naming studies, which recommend prompt variation and small pilot validations for best performance [53–56]: (a) summarize per-cluster item means and distinctive items; (b) generate candidate labels and short narratives; (c) human-validate with exemplar responses (when respondent-level linkage is available) and adjust labels.

The following box shows the prompt used for deriving the semantic label for cluster 0. The prompt for cluster 1 is rather similar and therefore is omitted.

LLM Prompt for Cluster Labeling

Task: You are labeling survey respondent clusters in a peer-teaching study. Be concise, neutral, and strictly grounded in the provided data.
Constraints:

- Disallowed phrases: `'High Peer Teaching Effectiveness'`, `'Low Peer Teaching Effectiveness'`, `'Mixed Feelings'`, `'General Satisfaction'`, `'General Dissatisfaction'`.
- Label must be 2–4 words, theme-specific (e.g., `Preparedness-Focused`, `Engagement-Confident`), and reflect TPS/LPS asymmetry if present.
- Use at least one theme inferred from item texts (e.g., confidence, engagement, preparedness, teamwork).
- Return **STRICT JSON only**.

Item texts: (Full question keys included in the actual prompt but omitted here for brevity.)
Cluster profile:

- cluster: 0
- Indices: TPS=4.68, LPS=4.51, EffectivenessIdx=4.51, OverallMean=4.57; alignment=balanced (TPS-LPS gap=+0.17)
- Top discriminators: `[ {"code":"Q1_5","mean":4.86,"z":0.35}, {"code":"Q1_7","mean":4.71,"z":0.33}, ... ]`
- Bottom discriminators: `[ {"code":"Q2_7","mean":4.21,"z":0.14}, {"code":"Q2_2","mean":4.50,"z":0.17}, ... ]`

Expected Output:

```
{"cluster": 0,
 "label": "<2-4 words>",
 "rationale": "<one sentence grounded in indices, gap, and top/
    bottom themes>"}
```

The response for cluster 0 is shown below:

```
{
  "cluster": 0,
```

```
  "label": "Teamwork-Focused",
  "rationale": "Higher mean scores for teamwork understanding (Q1_5) and peer
     teaching session engagement (Q1_7), with a balanced alignment and higher
      preference for more peer teaching sessions (Q2_8)."
}
```


The response for cluster 1 is shown below:


```
{
  "cluster": 1,
  "label": "Preparedness-Focused",
  "rationale": "Higher agreement with questions about peer teacher preparation
      and helpful methods, lower agreement with questions about student
     engagement during sessions."
}
```


Our clustering reveals two segments consistent with theory and literature. The first cluster (with label ”teamwork-focused”) suggests strong needs-support and efficacy-building. The second cluster (with label ”preparedness-focused”) suggests that students seek explicit scaffolds and cooperative structures to optimize the benefits of peer teaching. Practically, the cluster insights imply differentiated design levers: maintain high-agency, high-interaction formats for the first cluster; and increase preparedness, clarity rubrics, and structured activities for the second cluster, a design choices that will elevate engagement and confidence across segments [27, 57].

RQ4: Student Perception on the Effectiveness Shaped by the Structure and Preparedness of Peer-Teaching Activities

Preparedness and structural clarity are repeatedly cited as critical determinants of peer teaching success. Studies on peer-assisted learning emphasize that well-prepared peer instructors and clearly articulated objectives enhance both cognitive and affective outcomes [39, 44]. In cooperative learning literature, structured interaction and role clarity are associated with higher engagement and achievement [35]. Peer Instruction research underscores the importance of scaffolding and sequencing: structured questioning, time for peer discussion, and instructor debriefs significantly improve conceptual understanding and student satisfaction [37, 41]. Conversely, poorly organized sessions risk uneven quality and reduced perceived effectiveness, as documented in qualitative evaluations of peer-led activities [30].

Recent work in instructional design highlights that clarity of expectations and preparedness are not merely logistical concerns but motivational levers. When students perceive structure and competence support, they report higher engagement and confidence, consistent with Self-Determination Theory (SDT) and sociocultural scaffolding principles [27, 38]. Open-ended feedback in higher education contexts often calls for clearer rubrics, topic guidelines, and rehearsal opportunities for peer teacher, which is echoed in our study.

To study the impact of preparedness and structure of peer teaching, we first construct an effectiveness index, computed as the mean of Q^l_5, Q^l_6, and Q^l_8, which capture endorsement and perceived impact at the course level, which capture global endorsement of peer teaching: willingness to engage with peer-led sessions, perception that sessions exceeded expectations, and desire for more sessions. These items reflect overall acceptance and perceived impact rather than item-level mechanics.

We model perceived effectiveness of peer teaching as a function of session preparedness and design. The dependent variable is the effectiveness index. The predictors represent preparedness and design factors: Q^l_1 (content appropriateness),Q^l_2 (helpfulness of methods), Q^l_4 (clarity of content via peer explanations), and Q^l_7 (peer teacher preparedness and knowledge). Ordinary Least Squares (OLS) is applied with an intercept to estimate the linear relation between these factors and the effectiveness index:

$$\text{EffectivenessIdx}_i = \beta_0 + \beta_1\, Q^l_{1i} + \beta_2\, Q^l_{2i} + \beta_3\, Q2^l_{4i} + \beta_4\, Q^l_{7i} + \varepsilon_i.$$

where Q^l_j denotes preparedness items (session design), and i indexes respondents. This specification emphasizes a conceptual distinction between the *outcome* (global endorsement) and the *antecedents* (preparedness and delivery). We excluded Q^l_3, which measures subject understanding, to avoid redundancy with Q^l_4 and to maintain conceptual separation between predictors (preparedness) and outcome (endorsement).

The overall significance of the preparedness regression is assessed using the F-test, which evaluates whether the set of predictors jointly explains variation in the outcome. The null hypothesis states that all slope coefficients are zero, implying no linear relationship between preparedness factors and perceived effectiveness. The alternative hypothesis asserts that at least one predictor contributes to explaining the outcome. The observed F-test p-value (< 0.001) strongly rejects the null, indicating that the four preparedness items collectively exhibit a statistically significant association with the effectiveness index, *i.e.,* the likelihood of all slope coefficients being zero is extremely low [58].

The preparedness regression explains a substantial portion of the variability in the effectiveness index, achieving an R^2 of 0.42 and an adjusted R^2 of 0.39. The coefficient of determination (R^2) indicates that 42% of the total variance in endorsement is accounted for by the preparedness predictors, while the adjusted R^2 corrects for model complexity [59]. The model's F-statistic yields a $p < 0.001$, confirming that the predictors jointly have a statistically significant association with the outcome—the likelihood of all slope coefficients being zero is extremely low [58].

Table 2: Statistics for the preparedness regression fitness.

Statistic	Value	Interpretation
R^2	0.42	42% of variability in endorsement explained by preparedness factors
Adjusted R^2	0.39	Accounts for model complexity; indicates robust explanatory power
F-test p-value	< 0.001	Model is statistically significant overall

The statistics for preparedness regression is summarized in Table 2. These statistics confirm that content appropriateness, helpfulness of methods, clarity of peer explanations, and peer teacher preparedness together explain a meaningful portion of endorsement variability. Our findings corroborate with peer instruction implementation research emphasizing structured questioning, peer discourse, and instructor debriefs as levers that heighten engagement and confidence [41, 42]. In terms of the self-determination theory, these design features support competence (clear explanations), autonomy (students reason and choose), and relatedness (peer interaction), jointly producing higher-quality motivation and sustained engagement [27, 28].

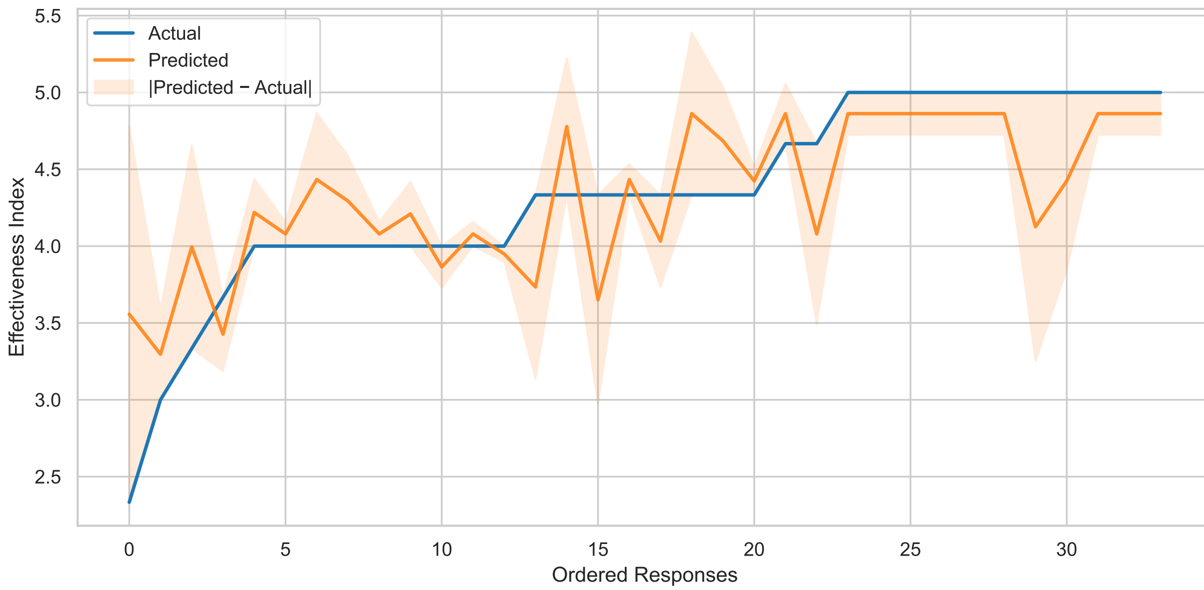

Figure 6: Preparedness regression line fit: Actual effectiveness index versus predicted values from preparedness predictors (Q_1^l, Q_2^l, Q_4^l, Q_7^l). Observations are ordered by the actual index.

Figure 6 presents an intuitive visualization of the OLS fit by overlaying the actual effectiveness index and the model's predicted values as a line chart, with observations ordered by the actual index. The following cues guide interpretation:

- Line proximity: The closer the orange (*Predicted*) line tracks the blue (*Actual*) line across the ordered responses, the better the model captures variation in perceived effectiveness.
- Shaded error band: The translucent band encodes absolute deviations ($|\text{Predicted} - \text{Actual}|$) around the predicted line. Narrow bands indicate small errors (strong fit); wider bands highlight where the model under- or over-predicts.
- Local departures: Segments where the predicted line diverges from the actual line point to response regions where preparedness factors alone may not fully explain endorsement, suggesting potential influence from unmodeled elements (e.g., cohort preferences, topic novelty, scheduling).
- Global trend: If the two lines move in tandem across the range of the actual index, the predictors jointly explain not only levels of endorsement but also its ordering across respondents.

Together, the plot complements coefficient tables and fit statistics (e.g., R^2, adjusted R^2) by providing a direct visual sense of how well the model reproduces observed endorsement patterns and where it departs from them.

RQ5: Student Recommendations to Improve Peer Teaching Experiences
Student-generated recommendations offer critical insights for refining peer teaching practices. Prior research on peer-assisted learning and cooperative learning consistently emphasizes the importance of incorporating learner feedback into instructional design [39, 44]. Qualitative studies reveal that students often advocate for clearer objectives, structured guidelines, and interactive formats to maximize engagement and learning outcomes [30]. In higher education, recommendations frequently target scaffolding strategies, training for peer teachers, and mechanisms for quality assurance to mitigate variability in peer-led sessions [35]. Recent work on participatory design in education underscores that integrating student voice enhances autonomy and competence support, aligning with Self-Determination Theory principles [27, 28].

To analyze student recommendations that we have collected, we choose to use a codebook with 12 themes, which is constructed to capture widely documented dimensions of peer teaching and active learning in higher education. Each theme operationalizes constructs supported by meta-analyses, critical reviews, and design frameworks. Together, these themes convert well-cited constructs into observable patterns in student text, enabling reproducible coding while remaining closely aligned with established evidence in higher education and engineering education.

Training for Peer Teachers. Structured training for peer tutors improves session quality and learning outcomes [60]. The theme Training for Peer Teachers reflects student recommendations for pre-session preparation, workshops, and rehearsal.

Feedback Mechanisms. Feedback is one of the strongest influences on learning when it is timely, specific, and information-rich [61, 62]. Peer feedback can be valid and reliable under well-structured conditions [63]. The theme Feedback Mechanisms operationalizes these principles by detecting calls for rubrics, reviews, and constructive comments.

Clear Objectives and Expectations. Clarity of objectives, guidelines, and expectations is a core principle of effective course design [64]. This informs the theme Clear Objectives and Expectations, which surfaces student requests for coherent structure, explicit criteria, and organized delivery.

Interactive and Active Learning. Active learning, including peer-mediated explanations, structured interaction, and collaborative problem solving, is associated with improved examination performance and reduced failure rates in undergraduate STEM courses [65, 66]. These findings provide a foundation for the theme Interactive Active Learning, which flags student calls for discussion, collaboration, and engagement.

Topic Selection and Uniqueness. Peer learning design often highlights reciprocal learning and student agency while cautioning that topic selection requires coordination to avoid duplication and uneven coverage [67]. The theme Topic Selection and Uniqueness captures preferences for curated lists, novelty, and balanced distribution of topics.

Faculty Oversight and Approval. Effective peer learning benefits from instructor scaffolding, oversight, and assessment alignment to ensure accuracy and coherence [67]. The theme Faculty Oversight and Approval registers student calls for supervision and verification of content, consistent with quality assurance concerns.

Pacing, Scheduling, and Time on Task. Time on task and distributed practice are core to effective learning environments [64]. Students frequently request spreading sessions biweekly or weekly to maintain attention and reduce overload; the theme Pacing and Scheduling formalizes these signals.

Attendance, Demonstrations, and Code. Requests for mandatory attendance, demonstrations, and runtime evidence such as showing simulations or code reflect active-learning practices that combine performance with prompt feedback [64]. The theme Attendance and Demonstrations captures these implementation preferences.

Optional Presentation Pathways. Respecting diverse talents and ways of learning is a core design principle [64]. The theme Optional Presentation Pathways maps to student suggestions for alternative assessment modes such as homework equivalence to reduce performance anxiety and broaden participation.

Risk of Misinformation and Quality Variance. Unmoderated peer teaching can propagate misconceptions, underscoring the need for faculty review and verification [67]. The theme Risk of Misinformation and Quality Variance captures student concerns about uneven quality and incorrect information, aligning with the literature's calls for safeguards.

Confidence, Communication, and Teamwork. Reviews of peer learning consistently report gains in confidence, communication, and teamwork as prominent outcomes [68, 69]. The theme Confidence, Communication, and Teamwork formalizes these recurrent benefits.

Understanding, Clarity, and Overall Benefit. Students often attribute improved understanding to peer explanations and collaborative engagement, echoing findings from active learning and peer instruction [65]. The theme Understanding and Overall Benefit aggregates statements of perceived learning gains.

Figure 7 presents the frequency distribution of themes identified from the two open-ended survey questions on the advantages, disadvantages, and suggested improvements of peer teaching. The plot highlights which aspects of the peer teaching experience were most salient to students, independent of how themes may co-occur within individual responses.

For the advantages and disadvantages question, student responses are dominated by themes related to *confidence, communication, and teamwork*, *understanding and clarity benefits*, and *topic selection uniqueness*. The high frequency of these themes indicates that students most saliently associate peer teaching with improved conceptual understanding and more engaging classroom dynamics. References to *confidence, communication, and teamwork* suggests that students perceive peer teaching as supporting broader skill development beyond content mastery, including public speaking, collaboration, and self-efficacy.

In contrast, themes reflecting potential drawbacks, such as *risk of misinformation or uneven content quality*, appear with noticeably lower frequency. This asymmetry suggests that, while students are aware of possible risks inherent to peer-led instruction, these concerns are secondary to perceived learning and engagement benefits. Overall, the distribution of themes in Question 3 indicates that students' spontaneous reflections focus primarily on experiential advantages, with disadvantages occupying a comparatively minor role.

The pattern for the suggestions and feedback question is qualitatively different. Here, frequently mentioned themes shift away from experiential benefits toward pragmatic design and implementation considerations. Prominent themes include *interactive active learning*, *clear objectives and expectations*, and *training for peer teachers*, indicating that students view structural scaffolding as critical to improving peer teaching effectiveness.

Additional themes such as *pacing and distribution of sessions*, *feedback mechanisms*, and *topic selection and uniqueness* highlight students' desire for refinement rather than fundamental change. Rather than questioning the value of peer teaching itself, responses in Question 4 emphasize adjustments that would enhance consistency, fairness, and instructional quality. This shift suggests that students separate their evaluation of peer teaching as a learning experience from their evaluation of how it should be organized and supported institutionally.

Taken together, the two panels reveal a coherent narrative: students associate peer teaching primarily with learning gains, engagement, and personal development when asked to reflect on advantages and disadvantages, but turn to issues of structure, preparation, and guidance when asked how the experience could be improved. The frequency-based patterns thus suggest that perceived benefits motivate acceptance of peer teaching, while suggested improvements focus on optimizing its delivery rather than questioning its pedagogical legitimacy.

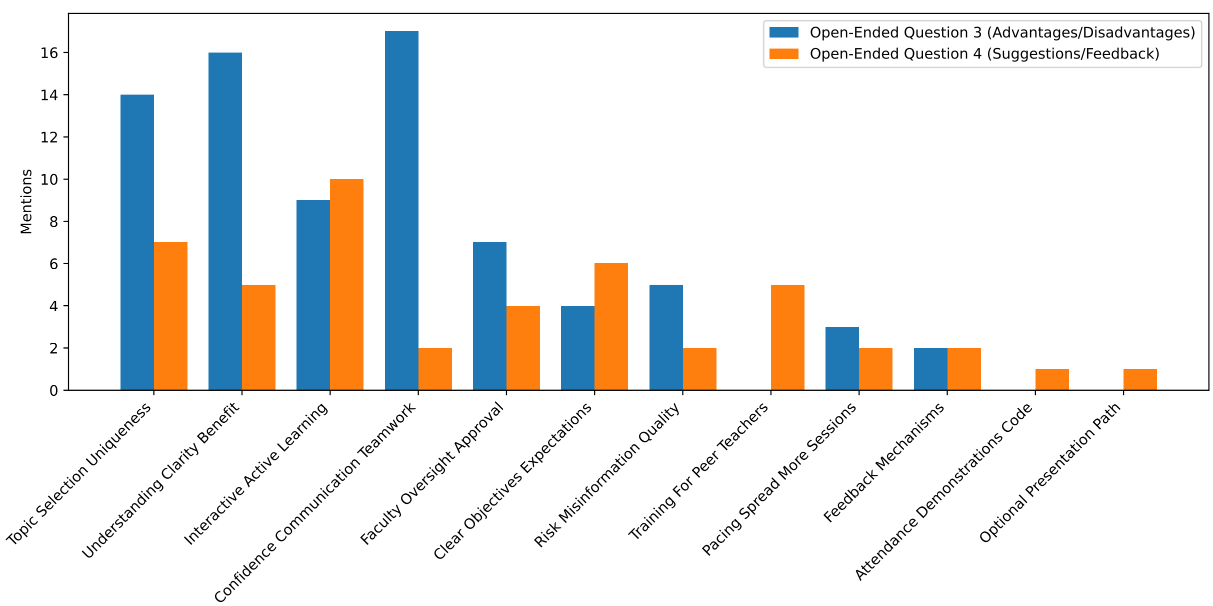

Figure 7: Co-occurrence heatmap for the open-ended question regarding the advantages and disadvantages of peer teaching.

Conclusive Remarks and Future Work

Across the five research questions, three cross-cutting insights emerge: (*i*) TPS–LPS alignment is strong, indicating mutual reinforcement between teaching and learning roles; (*ii*) clarity and preparedness are pivotal, predicting perceived effectiveness and appearing in student recommendations; (*iii*) clustered attitudes suggest differentiated design levers. Taken together, peer teaching is most effective when activities are needs-supportive, scaffolded, and cooperative within constructively aligned courses. Findings confirm that structured peer-teaching is a practical lever to raise engagement, confidence, and perceived effectiveness.

The current study has a number of limitations. This study uses a single course (N=33) and self-report Likert items; no student selected “Strongly Disagree,” which reduces scale spread. Comparative Likert items capture preferences but not causality. Furthermore, regression establishes correlates rather than causal effects. Qualitative coding uses regex/LLM-assisted pipelines and human-in-the-loop validation was applied, but coding may still reflect sampling or prompt-design biases. Row-level linkage between structured items and open-ended responses may be partial.

In the future, we plan to conduct a multi-course replication with larger, diverse samples; inclusion of objective learning outcomes (concept inventories, performance assessments); quasi-experimental designs that compare peer-led vs. faculty-led segments; longitudinal tracking to assess persistence; and targeted interventions per cluster (A vs. B) to test differentiated design effects. For qualitative analysis, extend human-in-the-loop workflows with inter-rater reliability (*e.g.,* Cohen’s κ) and compare LLM-supported coding with manual baselines.

References

[1] P. Doolittle, K. Wojdak, A. Walters *et al.*, “Defining active learning: A restricted systemic review,” *Teaching and Learning Inquiry*, vol. 11, 2023.

[2] W. A. Kitch, “Evaluation of effectiveness of just-in-time teaching and peer instruction methods in civil engineering courses,” in *2011 ASEE Annual Conference & Exposition*, 2011, pp. 22–651.

[3] T. Adawi, H. Burden, D. Olsson, and R. Mattiasson, “Characterizing software engineering students’ discussions during peer instruction: Opportunities for learning and implications for teaching,” *International Journal of Engineering Education*, vol. 32, no. 2, pp. 927–936, 2016.

[4] J. Rivadeneira and E. Inga, “Interactive peer instruction method applied to classroom environments considering a learning engineering approach to innovate the teaching–learning process,” *Education Sciences*, vol. 13, no. 3, p. 301, 2023.

[5] W. Zhao, X. Luo, C. Luo, and Y. Peng, “Design and implementation of project-based courses on cutting-edge computer technologies,” in *2017 ASEE Annual Conference & Exposition*, 2017.

[6] J. Wang, C. Luo, W. Zhao, and X. Li, “Empowering students with self-regulation in a project-based embedded systems course,” in *2017 ASEE Annual Conference & Exposition*, 2017.

[7] C. Luo, J. Wang, L. Wang, and W. Zhao, “Multi-lab-driven learning method used for robotics ros system development,” in *2017 ASEE Annual Conference & Exposition*, 2017.

[8] W. Zhao, “Enhancing undergraduate research experience with cutting edge technologies,” *International Journal of Information and Education Technology*, vol. 7, no. 7, pp. 495–501, 2017.

[9] ——, “Enriching engineering curricula with a course on cutting-edge computer technologies,” in *2015 IEEE Integrated STEM Education Conference*. IEEE, 2015, pp. 44–48.

[10] B. Goldschmid and M. L. Goldschmid, “Peer teaching in higher education: A review,” *Higher education*, vol. 5, no. 1, pp. 9–33, 1976.

[11] M. Stigmar, “Peer-to-peer teaching in higher education: A critical literature review,” *Mentoring & Tutoring: partnership in learning*, vol. 24, no. 2, pp. 124–136, 2016.

[12] S. Irvine, B. Williams, and L. McKenna, “Near-peer teaching in undergraduate nurse education: An integrative review,” *Nurse education today*, vol. 70, pp. 60–68, 2018.

[13] J. Secomb, “A systematic review of peer teaching and learning in clinical education,” *Journal of clinical nursing*, vol. 17, no. 6, pp. 703–716, 2008.

[14] H. Zhang, A. W. X. Liao, S. H. Goh, X. V. Wu, and S. Q. Yoong, “Effectiveness of peer teaching in health professions education: A systematic review and meta-analysis,” *Nurse Education Today*, vol. 118, p. 105499, 2022.

[15] M. A. Tanveer, T. Mildestvedt, I. G. Skjærseth, H. H. Arntzen, E. Kenne, A. Bonnevier, T. Stenfors, and M. Kvernenes, “Peer teaching in undergraduate medical education: what are the learning outputs for the student-teachers? a systematic review,” *Advances in Medical Education and Practice*, pp. 723–739, 2023.

[16] D. Reith, T. Haedecke, E. Schulz, L. Langel, L. Gemein, and I. Groß, “Practical undergraduate projects within the brsu race academy: An example for conducting a new tutored peer-teaching learning approach,” in *2017 IEEE Global Engineering Education Conference (EDUCON)*. IEEE, 2017, pp. 146–151.

[17] D. Reith, M. Grein, D. Röthgen, J. Behrendt, T. Held, M. Malschützky, and I. Gross, “How self-reliant peer teaching can be set up to augment learning outcomes for university learners,” in *2022 IEEE Global Engineering Education Conference (EDUCON)*. IEEE, 2022, pp. 57–62.

[18] A. J. Carroll, N. Tchangalova, and E. G. Harrington, “Flipping one-shot library instruction: using canvas and pecha kucha for peer teaching,” *Journal of the Medical Library Association: JMLA*, vol. 104, no. 2, p. 125, 2016.

[19] M. A. Muñoz-García, G. P. Moreda, N. Hernández-Sánchez, and V. Valiño, “Student reciprocal peer teaching as a method for active learning: An experience in an electrotechnical laboratory,” *Journal of Science Education and Technology*, vol. 22, pp. 729–734, 2013.

[20] E. M. Kim, T. F. Schubert, and F. G. Jacobitz, “Student peer teaching in engineering laboratory situations,” in *2014 ASEE Annual Conference & Exposition*, 2014, pp. 24–1117.

[21] I. Gross, M. Malschützky, T. Held, J. Behrendt, D. Röthgen, M. Grein, and D. Reith, “Self-reliant peer teaching as an additional dimension of university-level education for high potentials,” in *2022 IEEE Global Engineering Education Conference (EDUCON)*. IEEE, 2022, pp. 333–338.

[22] H. E. Chrispeels, J. M. Chapman, C. L. Gibson, and G. K. Muday, “Peer teaching increases knowledge and changes perceptions about genetically modified crops in non–science major undergraduates,” *CBE—Life Sciences Education*, vol. 18, no. 2, p. ar14, 2019.

[23] R. Glassey, O. Bälter, P. Haller, and M. Wiggberg, “Addressing the double challenge of learning and teaching enterprise technologies through peer teaching,” in *Proceedings of the ACM/IEEE 42nd International Conference on Software Engineering: Software Engineering Education and Training*, 2020, pp. 130–138.

[24] S. Ramaswamy, I. Harris, and U. Tschirner, “Student peer teaching: An innovative approach to instruction in science and engineering education,” *Journal of science education and technology*, vol. 10, pp. 165–171, 2001.

[25] C. C. Dosoftei and L. Alexa, “Students’ perception of peer teaching in engineering education: a mixed–method case study,” *Humanities and Social Sciences Communications*, vol. 11, no. 1, pp. 1–9, 2024.

[26] A. Joshi, S. Kale, S. Chandel, and D. K. Pal, “Likert scale: Explored and explained,” *British journal of applied science & technology*, vol. 7, no. 4, pp. 396–403, 2015.

[27] R. M. Ryan and E. L. Deci, “Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being,” *American Psychologist*, vol. 55, no. 1, pp. 68–78, 2000. [Online]. Available: https://selfdeterminationtheory.org/SDT/documents/2000_RyanDeci_SDT.pdf

[28] ——, “Self-determination theory,” in *Encyclopedia of Quality of Life and Well-Being Research*. Springer, 2022, pp. 1–7. [Online]. Available: https://link.springer.com/rwe/10.1007/978-3-319-69909-7_2630-2

[29] A. Bandura, *Self-Efficacy: The Exercise of Control*. New York: W. H. Freeman, 1997. [Online]. Available: https://psycnet.apa.org/psycinfo/1997-08589-000

[30] J. J. Velez, J. Cano, M. S. Whittington, and K. J. Wolf, “Cultivating change through peer teaching,” *Journal of Agricultural Education*, vol. 52, no. 1, pp. 40–49, 2011. [Online]. Available: https://files.eric.ed.gov/fulltext/EJ955665.pdf

[31] A. Gal and O. Fallik, “Learn from each other: A peer-teaching model,” *Interdisciplinary Journal of Environmental and Science Education*, vol. 17, no. 3, p. e2242, 2021. [Online]. Available: https://www.ijese.com/download/learn-from-each-other-a-peer-teaching-model-10896.pdf

[32] S. Shaikh, “Peer teaching for peer learning and sharing: A study on students’ attitudes towards implementing peer teaching and learning in the esl classroom at the university of technology and applied sciences,” *International Journal of English Language Teaching*, vol. 12, no. 5, 2024. [Online]. Available: https://eajournals.org/ijelt/vol12-issue-5-2024/ peer-teaching-for-peer-learning-and-sharing-a-study-on-students-attitudes-towards-implementing-peer-teaching-and-learning-in

[33] J. Biggs, “Enhancing teaching through constructive alignment,” *Higher education*, vol. 32, no. 3, pp. 347–364, 1996.

[34] T. Hailikari, V. Virtanen, M. Vesalainen, and L. Postareff, “Student perspectives on how different elements of constructive alignment support active learning,” *Active Learning in Higher Education*, vol. 23, no. 3, pp. 217–231, 2022, first published online 2021. [Online]. Available: https://journals.sagepub.com/doi/pdf/10.1177/1469787421989160

[35] M. Cockerill, N. Craig, and A. Thurston, “Teacher perceptions of the impact of peer learning in their classrooms: Using social interdependence theory as a model for data analysis and presentation,” *Education and Practice*, vol. 6, no. 1, pp. 14–27, 2018. [Online]. Available: https://files.eric.ed.gov/fulltext/EJ1210038.pdf

[36] T. Liu and V. Aryadoust, “Orchestrating teacher, peer, and self-feedback to enhance learners’ cognitive, behavioral, and emotional engagement and public speaking competence,” *Behavioral Sciences*, vol. 14, no. 8, p. 725, 2024. [Online]. Available: https://www.mdpi.com/2076-328X/14/8/725

[37] A. P. Fagen, C. H. Crouch, and E. Mazur, “Peer instruction: Results from a range of classrooms,” *The Physics Teacher*, vol. 40, no. 4, pp. 206–209, 2002. [Online]. Available: https://www.physics.utoronto.ca/~key/PHY1600/PER%20Papers/Mazur%20Peer%20Instruction%20results.pdf

[38] L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes*, M. Cole, V. John-Steiner, S. Scribner, and E. Souberman, Eds. Cambridge, MA: Harvard University Press, 1978. [Online]. Available: https://home.fau.edu/musgrove/web/vygotsky1978.pdf

[39] K. J. Topping, “Trends in peer learning,” *Educational Psychology*, vol. 25, no. 6, pp. 631–645, 2005. [Online]. Available: https://psycnet.apa.org/record/2005-14479-005

[40] J. S. Parmar, S. K. Mistry, S. Micheal, T. Dune, D. Lim, S. Alford, and A. Arora, “Peer support for improving student engagement and learning outcomes in postgraduate public health and health sciences: A qualitative study,” *Education Sciences*, vol. 15, no. 5, p. 602, 2025. [Online]. Available: https://www.mdpi.com/2227-7102/15/5/602

[41] C. H. Crouch, J. Watkins, A. P. Fagen, and E. Mazur, “Peer instruction: Engaging students one-on-one, all at once,” *Reviews in PER*, vol. 1, 2007. [Online]. Available: https://www.researchgate.net/profile/Adam-Fagen/publication/216743159_Peer_Instruction_Engaging_students_one-on-one_all_at_once/links/53ece18d0cf26b9b7dbff4a8/Peer-Instruction-Engaging-students-one-on-one-all-at-once.pdf

[42] E. Mazur, C. H. Crouch, and J. Watkins, “Peer instruction: Why it engages students and how to implement it,”

Center for Teaching & Learning Innovation (CTLI) resource, 2024. [Online]. Available: https://ctli.vermontstate.edu/teaching-effectiveness-framework/student-motivation/peer-instruction/

[43] University of Newcastle, Australia, "Peer instruction – mazur method (teaching resource)," 2024. [Online]. Available: https://www.newcastle.edu.au/current-staff/teaching-and-research/teaching-resources/ldti/ldti-teaching-resources/resources/peer-instruction-mazur-method

[44] K. J. Topping, "Peer assessment between students in colleges and universities," *Review of Educational Research*, vol. 68, no. 3, pp. 249–276, 1998. [Online]. Available: https://www.jstor.org/stable/1170595

[45] S. G. A. van Herpen, F. Hilverda, and M. Vollmann, "A longitudinal study on the impact of student–teacher and student–peer relationships on academic performance: The mediating effects of study effort and engagement," *European Journal of Higher Education*, 2024. [Online]. Available: https://www.tandfonline.com/doi/pdf/10.1080/21568235.2024.2414760

[46] G. Di Lisio, A. Milá Roa, A. Halty, A. Berástegui, A. Couso Losada, and C. Pitillas, "Nurturing bonds that empower learning: A systematic review of the significance of teacher–student relationship in education," *Frontiers in Education*, vol. 10, 2025. [Online]. Available: https://www.frontiersin.org/journals/education/articles/10.3389/feduc.2025.1522997/full

[47] P. J. Rousseeuw, "Silhouettes: a graphical aid to the interpretation and validation of cluster analysis," *Journal of Computational and Applied Mathematics*, vol. 20, pp. 53–65, 1987.

[48] L. Kaufman and P. J. Rousseeuw, *Finding Groups in Data: An Introduction to Cluster Analysis*. John Wiley & Sons, 1990.

[49] S. Tavakkol, "Your guide to local llms: Ollama deployment, models, and use cases," DEV Community Blog, Feb. 2025. [Online]. Available: https://dev.to/sina14/your-guide-to-local-llms-ollama-deployment-models-and-use-cases-2jng

[50] N. Bits, "The complete guide to ollama: Local llm inference made simple," *Neural Bits (Substack)*, Oct. 2025. [Online]. Available: https://multimodalai.substack.com/p/the-complete-guide-to-ollama-local

[51] H. Touvron, T. Lavril, G. Izacard *et al.*, "Llama: Open and efficient foundation language models," *arXiv preprint arXiv:2302.13971*, 2023.

[52] A. Q. Jiang, A. Sablayrolles, A. Mensch *et al.*, "Mistral 7b," *arXiv preprint arXiv:2310.06825*, 2023.

[53] A. J. Preiss, C. A. Arbeit, A. Berghammer *et al.*, "Evaluation of text cluster naming with generative large language models," *Journal of Data Science*, vol. 22, no. 3, pp. 376–392, 2024. [Online]. Available: https://jds-online.org/journal/JDS/article/1385

[54] Y. Zhang, Z. Wang, and J. Shang, "Clusterllm: Large language models as a guide for text clustering," in *Proceedings of EMNLP 2023*, 2023, pp. 13 903–13 920. [Online]. Available: https://aclanthology.org/2023.emnlp-main.858/

[55] Z. Feng, L. Lin, L. Wang, H. Cheng, and K.-F. Wong, "Llmedgerefine: Enhancing text clustering with llm-based boundary point refinement," in *Proceedings of EMNLP 2024*, 2024, pp. 18 455–18 462. [Online]. Available: https://aclanthology.org/2024.emnlp-main.1025/

[56] S. Tipirneni, R. Adkathimar, N. Choudhary, G. Hiranandani, R. A. Amjad, V. N. Ioannidis, C. Yuan, and C. K. Reddy, "Context-aware clustering using large language models," *arXiv*, 2024. [Online]. Available: https://arxiv.org/abs/2405.00988

[57] K. Shabani, M. Khatib, and S. Ebadi, "Vygotsky's zone of proximal development: Instructional implications and teachers' professional development," *English Language Teaching*, vol. 12, no. 11, pp. 10–23, 2015. [Online]. Available: https://files.eric.ed.gov/fulltext/EJ1081990.pdf

[58] J. Frost, "How to interpret the f-test of overall significance in regression analysis," 2025, accessed: 2026-01-06. [Online]. Available: https://statisticsbyjim.com/regression/interpret-f-test-overall-significance-regression/

[59] DataCamp, “R-squared explained: Measuring model fit,” 2025, accessed: 2026-01-06. [Online]. Available: https://www.datacamp.com/tutorial/r-squared

[60] J. L. Arco-Tirado, F. D. Fernández-Martín, and M. Hervás-Torres, “Evidence-based peer-tutoring program to improve students’ performance at the university,” *Studies in Higher Education*, vol. 45, no. 11, pp. 2190–2202, 2020. [Online]. Available: https://www.tandfonline.com/doi/pdf/10.1080/03075079.2019.1597038

[61] J. Hattie and H. Timperley, “The power of feedback,” *Review of Educational Research*, vol. 77, no. 1, pp. 81–112, 2007. [Online]. Available: https://journals.sagepub.com/doi/pdf/10.3102/003465430298487

[62] B. Wisniewski, K. Zierer, and J. Hattie, “The power of feedback revisited: A meta-analysis of educational feedback research,” *Frontiers in Psychology*, vol. 10, p. 3087, 2020. [Online]. Available: https://www.frontiersin.org/journals/psychology/articles/10.3389/fpsyg.2019.03087/full

[63] N. Falchikov and J. Goldfinch, “Student peer assessment in higher education: A meta-analysis comparing peer and teacher marks,” *Review of Educational Research*, vol. 70, no. 3, pp. 287–322, 2000. [Online]. Available: https://www.jstor.org/stable/1170785

[64] A. W. Chickering and Z. F. Gamson, “Seven principles for good practice in undergraduate education,” *AAHE Bulletin*, pp. 3–7, March 1987. [Online]. Available: https://www.lonestar.edu/multimedia/SevenPrinciples.pdf

[65] S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth, “Active learning increases student performance in science, engineering, and mathematics,” *Proceedings of the National Academy of Sciences*, vol. 111, no. 23, pp. 8410–8415, 2014. [Online]. Available: https://www.williams.edu/teaching-center/files/2023/09/Freeman-et-al.-2014.pdf

[66] M. Prince, “Does active learning work? a review of the research,” *Journal of Engineering Education*, vol. 93, no. 3, pp. 223–231, 2004. [Online]. Available: https://engr.ncsu.edu/wp-content/uploads/drive/1smSpn4AiHSh8z7a0MHDBwhb_JhcoLQmI/2004-Prince_AL.pdf

[67] D. Boud, R. Cohen, and J. Sampson, Eds., *Peer Learning in Higher Education: Learning from and with Each Other*. London: Routledge, 2001. [Online]. Available: https://www.taylorfrancis.com/books/edit/10.4324/9781315042565/peer-learning-higher-education-boud-david-ruth-cohen-sampson-jane-university-technology-sydney-australia

[68] K. J. Topping, “Trends in peer learning,” *Educational Psychology*, vol. 25, no. 6, pp. 631–645, 2005. [Online]. Available: https://andymatuschak.org/files/2005%20Topping.pdf

[69] ——, “Advantages and disadvantages of online and face-to-face peer learning in higher education: A review,” *Education Sciences*, vol. 13, no. 4, p. 326, 2023. [Online]. Available: https://www.mdpi.com/2227-7102/13/4/326