

A Large-Scale Pre–Post Study for Multi-Component Active Learning Model

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ABSTRACT:

This study evaluates the effectiveness of a multi-component active learning approach using a pre-test/post-test design. The evaluation was conducted on first-year students to enhance their academic performance in a foundational mathematics course. Experience integrates task-based learning, inquiry-oriented activities, peer instruction, and continuous formative assessment. Each technique was used to address a specific learning goal. The learning was assessed using a Mathematics Competency Test (MCT). The results indicate moderate-to-high normalized gains and a high effect size. In addition, post-test scores and final course outcomes have a strong correlation between them. Which supports the validity of the assessment approach. These findings support the proposed multi-component active learning models, as an effective way to scale up educational.

Keywords: Normalized gain; Student-Centered Learning; Active Learning Strategies; Standardized Mean Difference, Pearson's correlation coefficient..

1. Introduction

Mathematics skills are a key pre-condition to achieving success in science, technology, engineering, and mathematics fields (STEM). Nevertheless, a high percentage of students joining higher education show shortfalls in basic mathematical skills, which impact adversely on academic achievement, advancement, and retention. The conventional approach of lecture-based teaching, which is still common in most of the institutions of higher learning, tends to foster passive learning and poor conceptual knowledge. Conversely, active learning strategies, where

students interact in problem solving, discussion, and collaborative tasks have been observed to be more successful in improving the learning outcomes in a significant way (Freeman et al. 2014). Active learning, although implemented in large-scale preparatory programs, is still unevenly distributed, especially in situations where varied student population and different degrees of prior knowledge are involved. This paper answers this question by looking at a data-driven, scalable active learning model within university mathematics course of large number of students.

1.1. Problem Statement

Numerous studies have been done to define the efficacy of active learning in improving the student engagement and performance (Freeman et al. 2014; Michael 2006; Prince 2004). However,

there are still several critical limitations. Most of the studies rely on single instructional interventions isolated instructional interventions rather than integrated multi-component models,

even though educational practice typically requires the simultaneous achievement of multiple learning objectives. In order to fill these gaps, this research will assess the efficacy of a multi-component active learning intervention that is applied in a preparatory year course in mathematics. The instructional model

suggested is a combination of task-based learning, inquiry-based activities, collaborative learning and peer instruction, constant formative assessment, and grouping of students by level. This combination design offers a framework that is structured and scalable to high enrollment courses see Figure 1.

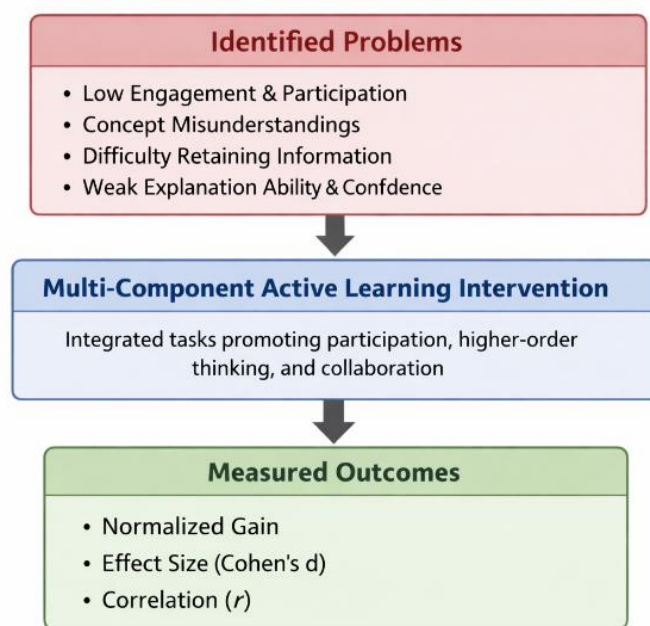


Figure 1

1.2. Research objectives

This study will aim to answer the following questions:

- What is the effect of the suggested multi-component active learning intervention? It will be measured by normalized gain **g**.
- How does the intervention put effect on student performance? That will be measured using the Cohen **d**.
- How are post-test competency scores and end-course performance related? That will be indicated by the Pearson correlation coefficient **r**.

1.3. Literature Review

In the past, a significant amount of literature highlighted the shortcomings of the traditional lecture-based learning in the field of STEM learning. Active learning on the other hand, has proven to be a great option that involves the students in the learning process, that might be applied through giving students structured tasks,

peer interaction and/or problem solving. There are multiple learning cases in which active learning has been studied, such as organized models of instruction in previous literature (El-Garaihy et al. 2024). Students in STEM fields have been shown to subserve from active learning, that enhance their academic level and increase their engagement in the studies (Freeman et al. 2014; Michael 2006; Prince 2004). One of the foundation works by Hake (Hake 1998) had proved that interactive methods of engagement are much better than traditional teaching in conceptual knowledge, as it was measured by normalized gain **g**. The article put normalized gain into practice as a standard of pre/post-test research to measure instructional effectiveness. Freeman et al. (Freeman et al. 2014) carried out a meta-analysis of STEM subjects (large-scale), which found that the active learning strategies positively affected student performance

and lowered failure rates over traditional lectures. The results strongly support the use of student-centered STEM teaching in higher education. Task-based learning methods such as inquiry-based learning (IBL) have been extensively identified to enhance higher-order cognitive processes and enhanced conceptual knowledge. These strategies transform the teaching emphasis on the delivery of information to the knowledge-building process in which students actively learn mathematical concepts by being guided in their work. Problem-based and inquiry-based types of learning fosters greater conceptual knowledge as students actively contribute towards knowledge building (Hmelo-Silver 2004). However, there are other research concluded that a small amount of guidance can be restrictive unless it is done correctly (Kirschner, Sweller, and Clark 2006). Moreover, structured in-class activities, i.e., problem solving tasks, conceptual tasks, guided discovery tasks, etc., may be considered as the key processes that will not only provide the students with the opportunity to be involved in the process but also be able to address the misconceptions on spot (Alanazi, Osman, and Halim 2025). These activity-centered strategies are one of the core elements of contemporary active learning models.

Normalized gain (Hake's **g**) is widely used to measure learning improvement in pre/post-test designs (Hake 1998). Other formulations like normalized change have been suggested to polish interpretation as well (Marx and Cummings 2007). More recent studies have, however, pointed out the need to interpret gain scores cautiously. Navarrete-Ulloa (Navarrete-Ulloa 2025). Suggested improvements to the calculation and meaning of learning gains, including the fact that methodological thoroughness is required when comparing interventions. Besides normalized gain, effect size (Cohen's **d**) is common to measure the impact of the implantation. He joint application Many active learning approaches have gained popularity, Usually studies focus on isolated strategies rather than integrated instructional models (Bishop and Verleger" 2013). A growing body of literature supporting active learning and

of **g** and **d** gives a detailed assessment of the relative improvement as well as absolute effect. Empirical studies of the effects of different instructional interventions on mathematic student performance at the university level have been carried out in recent years. Ben Hassen et al. . (Ben Hassen and others 2025) investigated the impact of teacher and peer-recorded videos in college algebra, finding that students' performance and retention improved significantly. Likewise, Nurmalitasari and Herman (Nurmalitasari and Herman 2025) investigated collaborative, cooperative, and traditional learning methods for linear algebra, showing that collaborative learning achieved better normalized gain and problem solving skills. Attempts to intervene for students with math difficulties have also been successful. Instructional interventions resulted in significant improvements in algebra problem solving (Namkung and Bricko 2021). All these studies confirm that active, student-centered interventions have a positive effect on mathematics performance and that they involve active participation, collaboration and feedback. This research is in line with earlier research showing that structured active learning interventions have a significant positive impact on student learning (Theobald et al. 2020). In addition to the design of instruction, other factors, including motivational and socio-cultural factors, influence mathematical performance. In several countries, gender differences in math learning motivation and performance highlighted by Wu and Zhang (Wu and Zhang 2025) show the importance of contextual and institutional factors in student learning. Although these studies do not assess the impact of specific instruction, they offer valuable insights into student performance variability and the importance of inclusive and responsive instruction.

Methodology

intervention-based approaches exists, although several gaps remain:

- Most studies focus on single interventions rather than integrated multi-component models

- Many studies are conducted on small sample sizes,
- Not so much research is conducted on first year students, because they usually need a large-scale institutional setting
- Few studies combine multiple evaluation metrics (normalized gain, effect size, and correlation)

2.1 Contribution of This Study

To address these gaps, the present study proposes and evaluates a multi-component active learning intervention model Figure 1

This model integrates:

- Task-based in-class activities
- Collaborative and peer instruction
- Inquiry-based learning strategies
- Continuous formative assessment

Applied to a large cohort (1900 students), the study provides robust empirical evidence using normalized gain **g**, strong impact measurement via effect size **d**, and additional validation through correlation analysis **r**.

The method application is as follows, a Mathematics Competency Test (MCT) was taken at the start (pre-test) and at the conclusion (post-test) of the course, then the learning gains assessed. The tests cover two academic years (2023-2024 and 2024-2025), where there is a chance to verify the findings in cohorts.

The experiment was operationalized in terms of a series of task-based structured instruction. Table 1 provides an overview of the connection between the instructional issues mentioned, the tasks implemented, and the literature used to support these problems.

Identified Problem	Implementation (Task-Based)	Supporting Literature
Passive learning and low engagement	Build small in-class tasks to actively involve students during lectures	(Freeman et al. 2014)
Lack of immediate feedback	Integrate think-pair-share tasks after each concept	(Freeman et al. 2014; Hake 1998)
Low participation	Use real-time response systems (clickers, voting apps)	(Freeman et al. 2014)
Superficial understanding	Design guided discovery and inquiry-based tasks	(Alanazi et al. 2025; Hake 1998)
Instructor-centered learning	Shift to student-led problem-solving activities	(Freeman et al. 2014)
Insufficient practice	Organize structured group problem-solving sessions	(Nurmalitasari and Herman 2025)
Weak explanation skills	Assign peer-led solution presentations	(Ben Hassen and others 2025)
Persistent misconceptions	Include collaborative error analysis tasks	(Hake 1998)
Low confidence	Implement group discussion and peer validation activities	(Wu and Zhang 2025)

The primary instrument used in this study is the Mathematics Competency Test (MCT), designed to assess students' understanding of key mathematical concepts.

- Administered as both pre-test and post-test

- Covers core topics aligned with course learning outcomes
- Standardized across all student groups

Three statistical measures were used to evaluate learning outcomes:

Normalized Gain (Hake's g)

$$g = \frac{\text{Post} - \text{Pre}}{100 - \text{Pre}}$$

$$d = \frac{M_{\text{Post}} - M_{\text{Pre}}}{SD_{\text{pooled}}}$$

Effect Size (Cohen's d), Effect size quantifies the magnitude of the intervention's impact:

Pearson Correlation r , Pearson correlation evaluates the relationship between:

- Post-test scores
- Final exam performance

2. Results

The Mathematics Competency Test (MCT) scores were analyzed for both pre-test and post-test across two academic years (2023-2024 and 2024-2025). The results show a clear increase in mean post-test scores compared to pre-test scores in both cohorts.

This improvement was observed across:

Together, these metrics provide a comprehensive evaluation of both learning improvement and instructional effectiveness.

- Engineering and Science tracks
- Different student performance levels (Level 1 and Level 2)

Figure 2 illustrates the difference between pre-test and post-test mean scores across both academic years.

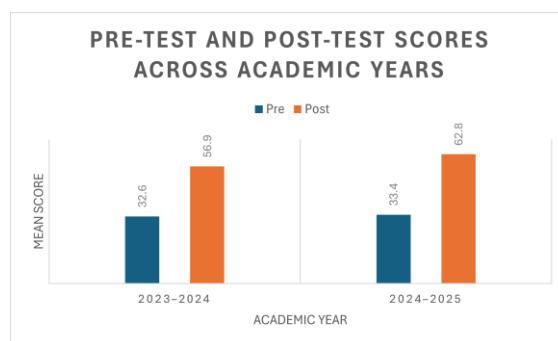


Figure 2

Normalized gain g was calculated to measure learning improvement relative to initial knowledge levels.

- 2023-2024: $g = 0.36$
- 2024-2025: $g = 0.44$

These values fall within the medium to high gain range as defined by Hake (Hake 1998). Figure 3 presents the normalized gain values across the two academic years.

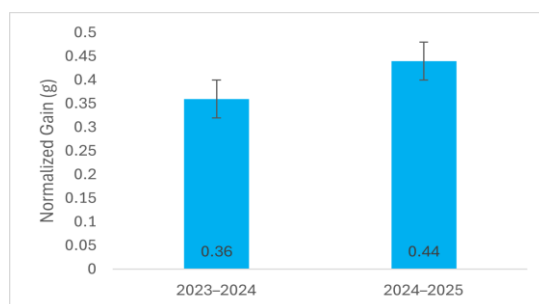


Figure 3

Cohen's **d** was calculated to assess the magnitude of the intervention's impact. **Effect size: $d > 1.2$**

According to conventional benchmarks, this value exceeds the threshold for a large effect size **$d = 0.8$** , indicating a substantial difference between pre-test and post-test performance.

Pearson correlation coefficients were computed to examine the relationship between competency test scores and final exam performance

- Engineering Track: $r = 0.842$
- Science Track: $r = 0.782$

Both values indicate a strong positive correlation between post-test scores and final course outcomes.

Summary of Key Findings

Metric	Result	Interpretation
Normalized Gain (g)	0.36 → 0.44	Moderate to high improvement
Effect Size (d)	> 1.2	Very large impact
Correlation (r)	0.78–0.84	Strong relationship

3. Discussion

The normalized gain values (**$g = 0.36$ and $g = 0.44$**) are associated with moderate-to-high learning gains, which is in line with the effectiveness of interactive engagement methods reported by Hake (Hake 1998). The fact that the normalized gain increased between the two academic years shows that the effectiveness of the intervention was increased over time. This indicates that the gradual

improvement of instructional practices, as well as the gradual increase in the familiarity of the instructor with active learning strategies, is a critical factor in improving the learning results. The present study uses systematic multi-component intervention, i.e., it involves both task-based activities and inquiry-based learning, peer instruction and continuous formative assessment within the coherence of an overall. The current study assessed a multi-component program of active learning that was developed to enhance mathematics competence in first-year university students. Results were remarkable in terms of massive improvements in performance in terms of moderate-to-high normalized gains, high effect size, and high association, on the competency measures as well as the final course outcomes, according to the findings on pre- and post-design over two academic years and nearly 1,900 students. In general, the results lead to

pedagogy. Interestingly, this was achieved in a large and heterogeneous population of students thus demonstrating how the proposed intervention can be successfully scaled and how robust it can be. The results are consistent with prior research demonstrating the effectiveness of active learning in improving student outcomes (Freeman et al. 2014; Theobald et al. 2020). The high correlation between post-test scores and final exam results (**$r = 0.78–0.84$**) show that there is a strong relationship between competency-based assessment and overall academic performance. Such multi-metric solution enhances the trustworthiness of the results and conforms to the latest suggestions in educational measurement research, as shown in (Navarrete-Ulloa 2025).

4. Conclusion

robust empirical data that systematized active learning model can significantly enhance learning in foundational mathematics, especially in diverse and large-scale education settings. These findings justify the wider implementation of the structured multi-component active learning models as a scalable and viable solution to enhance the outcomes in the foundational STEM education. The integrated character of the intervention does not allow determining the contribution of separate components. Future studies are required

to add in the use of controlled designs, analysis of comparative effectiveness of strategies, and

implementation of fidelity to help further develop scalable active learning frameworks.

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