Journal of East-West Thought
ISSN: ***2168-2259 (online)***
(https://jetjournal.us/)
Volume 14, Issue 3 – Sep 2024

JOURNAL OF EAST-WEST THOUGHT

UGC CARE I

INVESTIGATING THE INFLUENCE OF INDIVIDUAL PREPARATION ON PERFORMANCE IN COLLABORATIVE LEARNING ENVIRONMENTS

Dr. Neeta Patil, Associate Professor, Thakur College of Engineering and Technology, Mumbai, Maharashtra, India.

Dr. Amol Dapkekar, Associate Professor, Thakur College of Engineering and Technology, Mumbai, Maharashtra, India.

Abstract

Collaborative learning of students facilitates efficient and meaningful information processing. Individual learning or solo learning is equally valuable it has the potential to amplify the benefits of collaborative learning. However, previous research has not clearly demonstrated how this type of preparation contributes to learning or how it differs from simply studying alone. Moreover, most of those studies focused on short-term outcomes and were limited to fields like history or literature, rather than areas like engineering or technical education. The study has two experiments that explored the direct and delayed effects of individual preparation before collaboration, as a way to address those gaps. In the first experiment, 79 undergraduate participants participated in groups that either, learned individually, worked collaboratively with no preparation, or made both an individual and a collaborative contribution. The participants involved in individual preparation and collaborating had better performances than the other groups, both immediate and delayed exams. The second experiment involved 101 participants studying without the benefit of any prior teaching, and used real teaching materials from technical education. Again participants' performance was examined, in both the short- and long-terms and was found that the participants who prepared individually first and then collaboratively, outperformed the other groups, both in the short- and longer-term assessments. Overall, the results illustrate that individual learning prior to collaboration makes collaborative learning more effective and can be considered in other methods of teaching, especially in engineering professional education context.

Keywords: Collaborative Learning, Individual Learning, Engineering Education, Problem-based learning, Instructional strategy

I INTRODUCTION AND BACKGROUND

In today's fast-changing world, engineering education should focus on helping students apply what they learn, not just memorizing facts. To meet this goal, engineering schools are using teaching methods that encourage students to use their knowledge in practical ways [1–3]. One popular method is collaborative learning, where students work together on projects or problems. This approach can improve critical thinking, problem-solving, and the ability to use engineering concepts [3–6]. However, group work isn't always better than studying alone. It can be complex and mentally demanding, which sometimes makes it harder for students to learn or apply knowledge [7–10]. To make group work more effective, study suggest, students prepare on their own first by doing tasks or solving problems before joining group activities

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[11–16]. While this idea has been studied in general education, it is not explored much in engineering, where solving technical problems is key. This study looks at how individual preparation helps students learn better in group settings, both right away and over time.

Individual preparation helps because group work can be tough on the brain. When students work together, they need to solve problems, share ideas, and check materials all at once, which can feel overwhelming [17]. Group discussions can also cause interruptions, like when someone's ideas get blocked or strategies clash, making it harder to focus [9, 11, 12, 17]. Preparing alone first, let's students study the material ahead of time. This makes group work easier because they're already familiar with the concepts, so they can focus better and contribute more during discussions [9, 15]. That's why individual preparation is seen as a good way to make group learning more successful in engineering [16].

There are still some unanswered questions about using individual preparation for group learning. Most studies compare it to jumping straight into group work, but it's hard to know exactly what makes it special [1, 15, 18, 19]. This makes it tricky for engineering teachers to decide whether to use it instead of solo study. Students came up with more ideas when they prepared alone before working in a group, compared to starting group work right away [20]. But the number of ideas from individual preparation wasn't much different from group work after preparation. This means individual preparation might not always be better than studying alone, which could make teachers hesitant to use it. We need to learn more about what makes individual preparation unique compared to both group and solo learning.

It can be believed that individual preparation for group learning could be really helpful in engineering education. Engineers today need more than just technical knowledge—they need to think critically and solve complex problems. Group work with preparation could help build these skills. But most studies have looked at short-term results in subjects like humanities or social sciences [11, 12, 15, 16], so we're not sure how well it works for engineering. This study checks if preparing individually helps engineering students learn and remember technical concepts and solve problems better, both now and in the long run.

This study seeks to:

1. Explore the short- and long-term benefits of individual preparation using materials from engineering professional education.
2. Prove that preparing alone before group work has a distinct effect compared to solo or group learning.

II METHODOLOGY AND ANALYSIS

To investigate the impact of individual preparation on collaborative learning in engineering education, we designed two experiments. Experiment 1, builds on prior research by examining individual preparation with structured tasks. Its results are informed to Experiment 2, which used complex, open-ended engineering problems to assess individual preparation in problem-based learning scenarios. By increasing task complexity in Experiment 2, we aimed to mirror real-world engineering challenges and evaluate how individual preparation enhances learning outcomes. Together, these experiments seek to understand the short- and long-term effects of individual preparation in engineering education. This study aims to provide evidence to support the use of individual preparation in collaborative learning within engineering education.

In Experiment 1, the study compared the effects of individual learning followed by collaborative learning (ILC) to collaborative learning alone (CL) and individual learning alone (IL). Participants were divided into three groups based on these conditions, and their performance was evaluated using a final test with comprehension and problem-solving questions.

A pilot test with 27 participants indicated a medium effect size (Cohen's f = 0.25). Using Cohen's effect size guidelines and a power analysis tool (with an alpha of 0.05 and power of 0.90), a sample size of approximately 79 participants was determined. Further, 68 undergraduate engineering students from an engineering school in Mumbai, India participated for course credit. All participants used learning materials and were recruited through the Engineering Department's online system. Five participants with prior knowledge were excluded, leaving 63 participants (average age = 20 years, SD = 2.01) for analysis. Students were randomly assigned to one of three groups: ILC (n = 26), CL (n = 28), or IL (n = 25). The ILC and CL groups worked in teams of three or four, while the IL group worked individually.

The students studied subject "Research Methodology" learning material which is not part of the university's undergraduate curriculum. A background knowledge survey using a 7-point scale (1 = no knowledge, 7 = expert knowledge) was conducted. Five participants, who scored above 4, indicating prior exposure to the topic, were excluded from the analysis. Students, in the three groups (ILC, CL, IL) made a concept map summarizing the material and added at least three related questions. In the Individual Learning (IL) group, participants created a concept map alone for 7 minutes, and then worked in groups of three or four for 9 minutes to combine their maps. In the Collaborative Learning (CL) group, three or four participants built a concept map together from the start for 16 minutes. In the Individual Learning (IL) group, participants worked solo for 16 minutes to create their concept map. The final test had comprehensive questions transfer questions. Raters were trained with a scoring guide and practiced on five sample responses, discussing differences to ensure consistent scoring.

Experiment 1: Procedure

1. **Background Knowledge Survey**: Students took a survey to check prior knowledge.
2. **Study Phase**: Students reviewed pre-requisite material for 10 minutes.
3. **Concept Map Creation (20 minutes)**:
   ILC Group: Worked alone for 7 minutes, then in groups of 3–4 for 9 minutes.
   CL Group: Worked in groups of 3–4 for 16 minutes.
   IL Group: Worked alone for 16 minutes.
   Students could use the material during this step.
4. **Final Test**: Participants took a 15-minute test (10 questions, 40 points) without the material.

Analysis: One-way ANOVA followed by Bonferroni post-hoc tests was used to evaluate the learning effects across the three conditions. To ensure reliable grading, two raters scored the

Journal of East-West Thought
ISSN: 2168-2259 (online)
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participants' responses. The first rater, an expert in educational psychology, scored all responses. A second rater, an engineering education specialist, independently scored over 50% of the responses (42 responses). We calculated the interrater reliability using the Cohen's kappa coefficient, which yielded a value of 0.91, indicating high agreement between raters and confirming the reliability of the first rater's scores. Statistical significance was set at $p < 0.05$. Effect sizes for ANOVA were measured using partial eta squared (ηp^2).

Overall Scores: ANOVA: $F(2, 80) = 9.12$, $p < 0.001$, $\eta p^2 = 0.19$.

Bonferroni post-hoc: ILC outperformed I ($p < 0.001$) and CL ($p = 0.028$); no difference between CL and IL ($p = 0.195$).

Comprehension Scores: ANOVA: $F(2, 80) = 7.25$, $p = 0.001$, $\eta p^2 = 0.16$.

Transfer Scores: ANOVA: $F(2, 80) = 3.48$, $p = 0.035$, $\eta p^2 = 0.09$.

Individual Learning followed by collaborative learning (ILC) led to better outcomes than collaborative (CL) or individual (IL) learning alone. Findings support using individual learning in engineering education need validation with engineering-specific materials and students

Experiment 2: Investigated the short-term and long-term learning effects of individual learning among engineering students, using problem-solving tasks instead of the concept mapping used in Experiment 1. The learning material focused on research methodology relevant to engineering education. Students were divided into three conditions (ILC, CL, IL), consistent with Experiment 1, based on their learning activities. Outcomes were measured by scores on immediate and delayed tests, which included comprehension and transfer questions.

Based on Experiment 1 results, we conducted a sample size calculation using Cohen's effect size guidelines ($f = 0.40$, derived from an average effect size of $\eta p^2 = 0.16$ for total and comprehension scores), with an alpha of 0.05 and power of 0.90. Using a power analysis tool, we determined a need for 78 students (26 per condition). We recruited 10 undergraduate engineering students, the average age was 20 years ($SD = 2.01$). Participants were randomly assigned to one of three conditions. To reduce bias from familiarity, we obtained anonymized student lists from class instructors and randomly grouped participants into teams of three or four. Participants in the IL condition worked individually on the problem-solving tasks.

Analysis: One-way ANOVA with Scheffé post-hoc tests to assess the learning effects across the three conditions (ILC, CL, IL) in engineering education. The first author, an educational psychology expert, initially scored all responses. To ensure scoring consistency, a second rater, a trained master's student in engineering education, independently evaluated over 50% of the responses (42 responses). The Cohen's kappa coefficient was 0.93, indicating strong interrater reliability. ANOVA found no significant differences in perceived efficiency or difficulty across conditions (efficiency: $F(2, 68) = 0.04$, $p = 0.965$, $\eta^2 = 0.00$; difficulty: $F(2, 68) = 1.40$, $p = 0.255$, $\eta^2 = 0.04$). Despite the IP condition requiring more effort, perceived difficulty was comparable across groups.

ANOVA revealed significant differences in immediate test total scores among the conditions ($F(2, 68) = 5.70$, $p = 0.005$, $\eta p^2 = 0.14$). Scheffé post-hoc tests showed a significant difference between the ILC and IL conditions ($p = 0.004$), but no differences between the CL and IL conditions ($p = 0.365$) or the ILC and CL conditions ($p = 0.120$). The ILC condition still performed better than the CL condition.

To explore score differences, we conducted ANOVA on comprehension and transfer questions. Significant differences were found (comprehension: $F(2, 68) = 4.20$, $p = 0.019$, $\eta p^2 = 0.11$; transfer: $F(2, 68) = 3.80$, $p = 0.027$, $\eta p^2 = 0.10$), suggesting that individual preparation for collaborative learning boosts short-term learning outcomes. ANOVA indicated significant differences in total scores across conditions ($F(2, 57) = 6.10$, $p = 0.003$, $\eta p^2 = 0.18$). Scheffé post-hoc tests confirmed a significant difference between the ILC and IL conditions ($p = 0.002$), but no differences between the C and I conditions ($p = 0.225$) or the ILC and CL conditions ($p = 0.110$). The ILC condition outperformed the others. Further ANOVA on comprehension and transfer scores showed significant differences (comprehension: $F(2, 57) = 5.40$, $p = 0.006$, $\eta p^2 = 0.16$; transfer: $F(2, 57) = 3.35$, $p = 0.042$, $\eta p^2 = 0.10$).

These results demonstrate that individual preparation for collaborative learning enhances both short-term and long-term academic performance for engineering students.

III DISCUSSION

The study carried out two experiments to compare individual preparation for collaborative learning with standalone collaborative and individual learning in engineering education. In Experiment 1, participants who prepared individually before collaborating outperformed those in only collaborative or individual learning on tests about Research Methodology. In Experiment 2, engineering students worked on problem-solving tasks related to engineering topics. Those in the individual preparation (ILC) condition scored higher on immediate and long-term tests compared to the individual (IL) condition and showed slightly better results than the collaborative (CL) condition, though not significantly.

These results suggest that individual learning strengthens prior knowledge and enhances engagement in collaborative learning, leading to improved understanding and application of engineering concepts [12, 15–17]. This approach shows promise for engineering education, surpassing the benefits of purely collaborative or individual learning.

Implications for Engineering Education: i) Improved Performance: Individual preparation boosts comprehension and problem-solving skills in engineering, as seen in both experiments. ii) Sustained Learning: Higher long-term test scores indicate lasting knowledge retention, essential for engineering practice. iii) Simple to Apply: This method requires only a short preparation phase, making it an easy, low-effort strategy for engineering instructors.

Unlike studies like in [20], which focused on idea generation, our research emphasizes academic outcomes, making it highly relevant to engineering education. However, the experiments used controlled settings with unfamiliar peers. Future studies should test this approach in real classrooms with familiar teams and diverse tasks, such as design projects. Analyzing group interactions could further explain how preparation improves collaboration.

IV CONCLUSION

This study establishes that individual preparation for collaborative learning significantly improves both short-term and long-term academic outcomes in engineering education. In two

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experiments, participants who prepared individually before collaborating outperformed those using only individual or collaborative learning, particularly in grasping engineering design principles. The findings highlight how individual preparation builds foundational knowledge and enhances collaborative engagement, leading to stronger comprehension and problem-solving skills. As a practical and low-effort approach, it is well-suited for engineering curricula. We recommend its wider adoption and encourage further research in real classroom settings with diverse engineering tasks to confirm and broaden these findings.

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