

## **The Impact of Scaffolding Prompts on Students' Cognitive Interactions During Collaborative Problem Solving of Ill-structured Engineering Tasks**

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## **Introduction**

Ill-structured design tasks are an important feature of engineering education because they support collaborative problem solving, which is an essential element of STEM curricula in the 21<sup>st</sup> century [1]. These tasks are especially important because they pose teamwork-based design challenges that resemble authentic work students will encounter in their future workplaces [2]. Solving collaborative ill-structured tasks allows students to expand their learning beyond “drill-and-practice”-type problem solving and engage in higher order thinking [3]. In the past decade, studies have established how to design and implement ill-structured tasks in engineering curricula [4]. These studies have shown the need for scaffolding in ill-structured tasks and have identified two main roles for scaffolding: to guide students through the complexity of the task and to help them focus on the most relevant aspects [5]. As the implementation of open-ended learning formats tends to pose additional challenges to learners, especially in traditional course contexts that experience curricular and time-related limitations, there has recently been a focus in research on how to scaffold these tasks [6], [7].

Our previous work evaluated the impact of implementing a non-scaffolded ill-structured task on the collaborative problem-solving processes of undergraduate engineering students [8]. We also investigated the effect of manipulating explicit scaffolds in these tasks [7], finding that the presence of explicit scaffolds provided students with fruitful opportunities to execute necessary collaborative problem-solving processes throughout the task. In turn, participation in these opportunities led to higher-quality final task solutions. However, few studies have examined the effectiveness of these prompts on students' group interactions. In other words, we know that scaffolds can assist students as they solve ill-structured tasks, but we do not know how they influence group interactions, which in turn can impact final solution quality. This study addresses this gap in the literature by evaluating the influence of explicit scaffolding prompts on the cognitive dimension of groups' interactions to better inform the design of ill-structured engineering tasks for collaborative problem solving.

Collaborative problem-solving processes in ill-structured tasks

Ge and Land [9], [10] defined four problem-solving processes necessary for effectively solving an ill-structured task in groups: exploring the problem (P1), planning solutions (P2), attempting to solve (P3), and evaluating the solution and considering alternatives (P4). Researchers argue that these processes are associated with better learning outcomes; thus, it is important for students to engage in all four as they solve this type of task [11], [12]. Our previous work debuted a literature-based framework that outlines and defines these processes within the context of undergraduate engineering group work as demonstrated through verbal interactions among

group members [8]. To construct the framework, we relied on characteristics of engineering problem solving defined in literature [2]. Using our framework, we then introduced a method for characterizing verbal interactions within each of the problem-solving processes (P1, P2, P3, and P4) in the context of collaborative problem-solving engineering classrooms [8]. This allowed us to evaluate the effectiveness of tasks that had been given to students by characterizing the nature of their processes throughout their work on the task [7].

Findings from our research [13], [7] show that when solving a non-scaffolded ill-structured task, groups' collaborative problem-solving processes were significantly dominated by attempting to solve the task (P3) as compared to their processes when solving a scaffolded ill-structured task. They also show that when solving a scaffolded ill-structured task, groups evaluated the solution and considered alternatives (P4) significantly more than when they solved a non-scaffolded task. Furthermore, our findings indicate that groups had significantly higher scores on their final solution to the scaffolded task compared to their final solutions on the non-scaffolded task. This suggests that the presence of scaffolding prompts led to differences in the groups' collaborative problem-solving processes, which in turn may have resulted in better solutions to the task. However, in order to support this hypothesis, we need more evidence that relies on examining the interactions taking place as groups implemented each of the four processes during both types of task. Research shows that group interactions play a critical role in shaping group processes that allow students to think together and co-construct knowledge to solve a task during collaborative problem solving [12], [14], [15]. These interactions can be examined in three dimensions: collaborative, cognitive, and metacognitive [16], [17]. In this paper, we examine the cognitive dimension of group interactions to understand how students were presenting and handling ideas as they implemented the four problem-solving processes to solve a non-scaffolded and a scaffolded ill-structured task. This paper seeks to answer the following research questions:

- 1) What types of cognitive interactions did groups implement as they solved the non-scaffolded versus the scaffolded ill-structured task?
- 2) What are the differences among these types of interactions within each of the four problem-solving processes when solving the non-scaffolded versus the scaffolded ill-structured task?

## **Methods**

### **Design**

This study is part of a multi-year design-based implementation research project, Collaborative Support Tools for Engineering Problem Solving (CSTEPS) [18], [19] that has involved the design and implementation of authentic ill-structured tasks in actual undergraduate engineering discussion sections, where students worked in small groups to solve these tasks. Tasks were presented as digital worksheets on 11-inch tablets. The software use allowed for tablets of students in the same group to be synchronized to support the creation of joint representations. This study builds on previous work, which compared verbal interactions from the same groups

on a non-scaffolded and a scaffolded task, by adding a layer of analysis that investigates the cognitive processes associated with these interactions. The non-scaffolded and the scaffolded tasks were both designed using a literature-based framework developed by Authors [4]. The tasks included an introduction that contextualized the problem in a real-life scenario, a description of the task itself, and supplementary material that provided information useful for solving the task. Only the scaffolded task included scaffolding prompts that explicitly directed the students to set up the task, develop plans, draw diagrams, and evaluate solutions. The scaffolded task was given to students during the first half of the semester, and the non-scaffolded task was given during the second half. More detailed task descriptions and information regarding the course can be found in previous work [7].

### Participants

Participants were 40 undergraduate engineering students (mostly freshmen) of varied disciplines (6 females, 34 males), divided into 11 groups, who were registered for a required introductory engineering course at a large, public university. All students enrolled in the course were pre-organized by the instructor into groups of 3-4 that remained consistent throughout the entire semester. These groups were arranged such that neither gender was placed in a minority. After the completion of the semester-long data collection, researchers selected consented groups based on complete attendance, meaning that no group member was absent from a week of data collection. Participant demographics, such as age, race, and engineering major, were not controlled in this study. Groups were spread across four registered sections, each taught by three teaching assistants. In this paper, we analyze data from two weeks of 50-minute discussion sessions held in a laboratory classroom.

### Data Analysis

Groups' video and audio data were collected as they solved each task. This study analyzes data from 22 total video recordings, one from each of the eleven groups for each of the two weeks. In previous work, the recordings were transcribed using a playscript format. All turns of dialogue were then coded during the data cleaning process, in which on-task turns were marked for analysis. All on-task talk was then coded for type of problem-solving process: exploring the problem (P1), planning solutions (P2), attempting to solve (P3), and evaluating the solution and considering alternatives (P4). The coding scheme and procedures are described in previous work, which found no significant difference in the mean number of group turns per task for each process [7].

In this study, an additional coding scheme (Table 1) was applied to all turns that were previously coded for type of collaborative process to identify the types of cognitive interactions that took place per each process. The coding scheme was adapted from previous work [15]. To evaluate inter-rater reliability, two researchers coded two groups for each task. Cohen's kappa was .85 for the non-scaffolded task and .84 for the scaffolded task.

Table 1. Types of Cognitive Interactions Coding Scheme

<b>Code</b>	<b>Definition</b>	<b>Example</b>
Mentions a new idea	A student mentions a new idea not previously introduced	<i>"I think the one-eighth steel would work for this configuration"</i>
Modifies an idea	A student provides more details (elaboration, explanation, or clarification) about an idea, term, information, or relationship	<i>"Yeah, I've got the one-eighth steel as the cheapest material possible"</i>
Accepts an idea	A student indicates agreement with an idea	<i>"Yes, this is it"</i>
Rejects an idea	A student indicates disagreement with an idea	<i>"No, I don't think so"</i>
Asks a simple question	A student asks a clarifying question	<i>"Did you get 3?"</i>
Asks an open question	A student asks a question to stimulate further discussion	<i>"Can we assume that the weight of the object is evenly distributed?"</i>
Other	Statements that do not fit into the previous categories or are unintelligible	<i>"Are we gonna...."</i>

In this study, we present groups' mean proportions of cognitive codes per each problem-solving process on the scaffolded and non-scaffolded tasks. For purposes of this study, we relied only on non-parametric statistics given our small sample size.

## Results

Figure 1 shows the mean proportions of the types of cognitive interactions for P1 and P2 (exploration and planning, respectively). P1 and P2 were combined because they both serve to set up the problem for the applied, actionable process (P3), where students implement plans and carry out calculations. When solving the scaffolded task, groups tended to have more acceptance of ideas, rejection of ideas, and open questions as they explored the problem and planned solutions as compared to solving the non-scaffolded task. This suggests that the scaffolds prompted students to discuss ideas and ask questions, resulting in the stimulation of further discussion to create joint representations (e.g., free body diagram), form a joint understanding of the problem, and plan for solving the task prior to actually attempting to solve (P3).

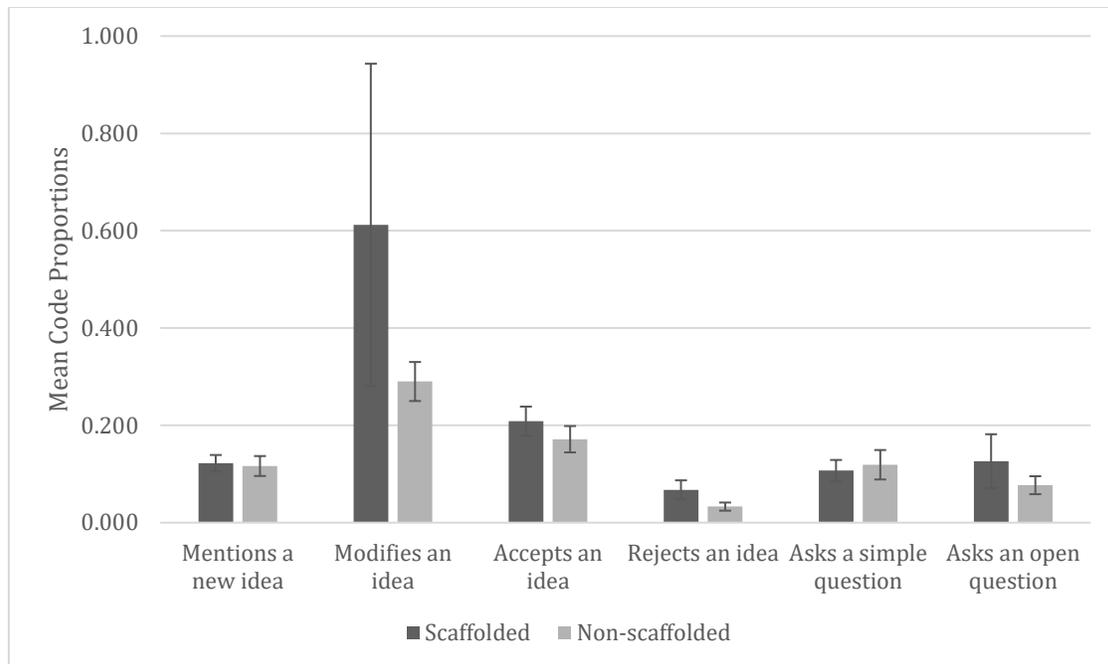


Figure 1. Types of Cognitive Interactions for P1 and P2 Coded Turns

Figure 2 shows that, during the scaffolded task, groups tended to have more acceptance of ideas and less rejection of ideas and open questions while they attempted to solve (P3) as compared to when they solved the non-scaffolded task. This indicates that when solving the scaffolded task, the groups were executing the plan upon which they had converged after discussing potential plans for solving the task (P2). In comparison, when solving the non-scaffolded task, the groups were not prompted to discuss plans to solve the task (P2) prior to attempting to solve the task (P3) and thus were still discussing issues related to how to solve the task as they executed different procedures of solving the task.

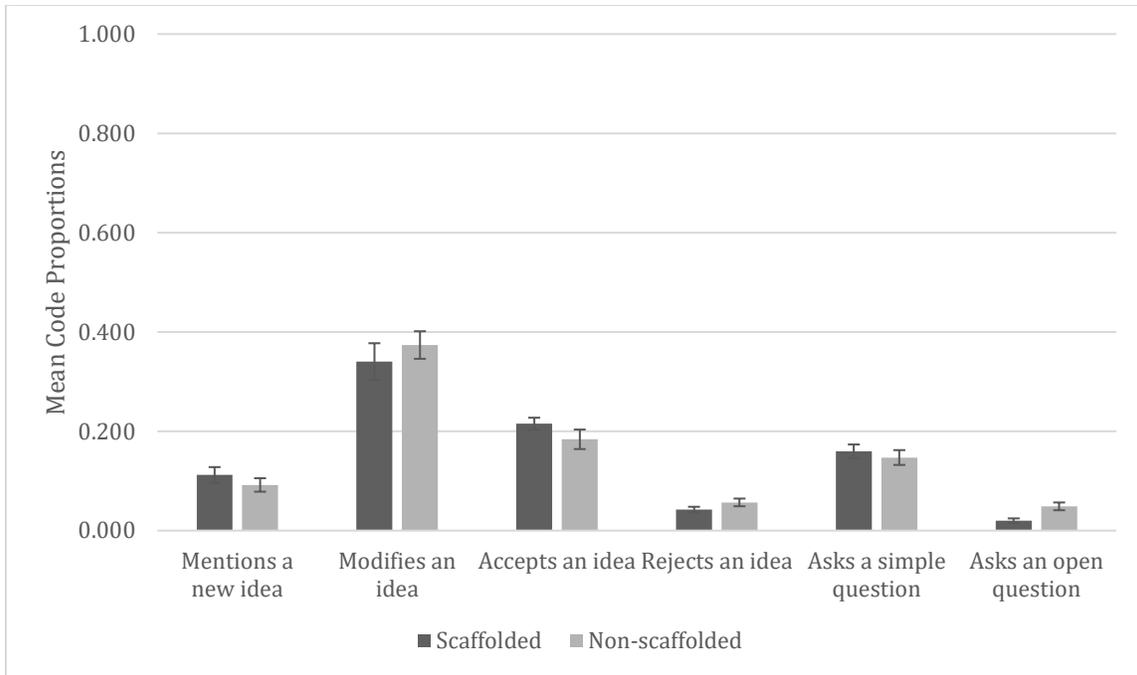


Figure 2. Types of Cognitive Interactions for P3 Coded Turns

Figure 3 shows that when solving the scaffolded task, groups tended to have more new ideas, acceptance of ideas, rejection of ideas, simple questions, and open questions as compared to solving the non-scaffolded task. This suggests that the scaffolds prompted the groups to discuss new ideas and ask questions that served to stimulate further discussion to evaluate solutions and come up with alternative solutions.

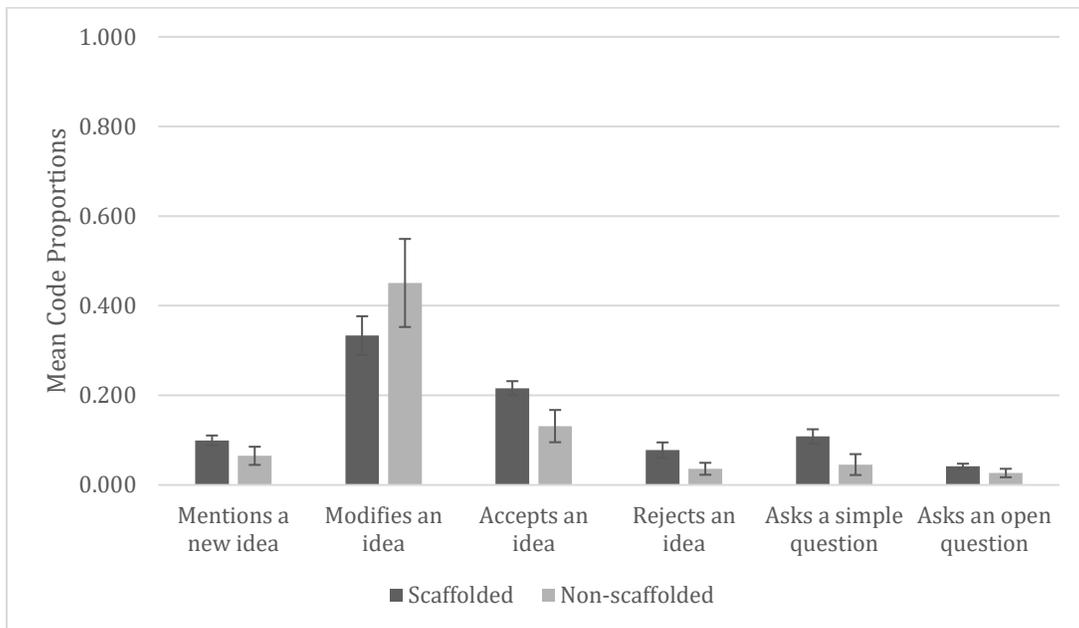


Figure 3. Types of Cognitive Interactions for P4 Coded Turns

## Discussion

The purpose of this paper was to examine the cognitive dimension of groups' interactions to understand how students were presenting and handling ideas as they implemented the four problem-solving processes to solve a non-scaffolded and a scaffolded ill-structured task. Findings show that the cognitive interactions that groups implemented within each process when solving the scaffolded task were different from those they implemented when solving the non-scaffolded task. It seems that the scaffold prompts guided groups through the complexity of the task by supporting them in following a structure conducive to implementing cognitive interactions effective for participating in each of the four collaborative processes.

In previous research, we established that all four processes are necessary for the collaborative problem solving of ill-structured tasks. Insight from observing students' behaviors as they implemented each of these four processes suggests that each process can be considered as a problem-solving space with unique characteristics. Thus, students need to implement all four spaces in order to effectively solve the task.

Using characteristics pulled from literature, we have found a clear difference between the nature of the attempting-to-solve space (P3) and the other three spaces. Where P3 can be thought of as the applied, actionable problem-solving space in which students perform computations and carry out plans, the other three spaces encompass more complex processes like planning, reflection, and conceptual problem solving. Thus, it is within these three spaces that the majority of metacognitive processes take place. We know from previous work that without scaffolds, collaborative problem-solving interactions are dominated by attempting to solve the problem (P3) [8], meaning that most of the problem solving during the task is computational. However, when provided with explicit scaffolds that supported the implementation of other problem-solving spaces, groups tended to score higher on the task [7]. Thus, while scaffolds themselves do not cause higher-order thinking, they can support students' implementation of all four problem-solving processes.

On the non-scaffolded task, groups' cognitive interactions do not distribute as well across the four spaces because the spaces themselves do not naturally occur as often. In other words, the students do not tend to give themselves opportunities to enter all four spaces, but instead jump to P3 and then try to experience all cognitive interactions in one space. There are more open (i.e. complex) questions happening in P3, which means that students are deviating from using P3 as a computational space and therefore not using the other spaces efficiently. The groups' tendency to score lower on the non-scaffolded task suggests that this reliance on P3 as a catch-all space is counterintuitive to effective engagement with the task.

On the scaffolded task, groups had manufactured opportunities to enter each space, resulting in a distribution of cognitive interactions that is seemingly better suited to the nature of each space. Groups also tended to score higher on the scaffolded task, indicating that experiencing fitting cognitive interactions within the proper space can result in better learning outcomes. Thus, we can suggest why these scaffolds are effective: they provide fruitful

opportunity for students to enter each space at strategic moments during the task such that they experience corresponding cognitive interactions in the proper space. The scaffolds themselves do not cause groups to problem solve correctly or experience desired cognitive interactions, but they provide opportunity to do so, making these outcomes more likely.

## **Conclusion and Implications**

This study analyzed the cognitive interactions from eleven groups as they solved a scaffolded and a non-scaffolded engineering task. It was hypothesized that the presence of explicit scaffolding prompts caused differences in the groups' collaborative problem-solving processes, which in turn resulted in better solutions to the task. Cognitive interactions were examined within each of the four processes, which were considered as unique spaces. Findings indicated that the scaffolds provided fruitful opportunity for groups to enter each space at a strategic point along the task solution path, allowing them to participate in cognitive interactions suited to that point in the task. These opportunities supported groups' deeper engagement with the task, leading them to produce higher average final solution scores than on the non-scaffolded task [7].

This study was limited by a small sample size. Additionally, our sample population was 85% male, which may have impacted group dynamics. Future work should consider participant demographics as they relate to effects of task design on group outcomes. Future work can also investigate the quality of the cognitive interactions per each process by adding an additional layer of analysis that measures the complexity of the cognitive processes, as well as pursue other dimensions of students' dialogue, such as their metacognitive interactions. Groups' experiences can also be further investigated through qualitative excerpts. This study supports the evolution of collaborative problem solving by demonstrating why task scaffolding can effectively engage students in processes and interactions that lead to higher-quality work.

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