Cooperative Classroom Problem-Solving

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Abstract

This paper describes a relatively simple technique for engaging engineering students in solving closed-end problems in class by working in small groups. Ideally, students work in groups of 2 to 4 to solve problems in a relatively short amount of time on content that has just been covered in class. Students mentor each other while the instructor monitors the groups and provides further instruction as appropriate. Some examples are given for how the technique may be implemented. This cooperative learning method has many benefits as well as a few challenges which are briefly considered. Some conclusions and recommendations are provided.

Keywords

problem-based learning, active learning, small groups, problem-solving, teamwork, collaboration, cooperative learning

Introduction[1]

It is widely recognized that the ability to solve problems and work effectively on teams are critical skills for engineers [1]. These are briefly considered next.

<u>Problem-Solving</u>

Engineering is often described as problem-solving [2, p. 3]. The National Academy of Engineering report *The Engineer of 2020* [3, p. 43] describes engineering as "problem recognition, formulation, and solution." The ABET requirements for the 2024-2025 accreditation cycle [4] include Student Outcomes 1 and 2 which directly address problem-solving where students should have:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics,
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Singer et al. [5, p. 75) wrote, "problem solving may be the quintessential expression of human thinking." Problem-solving may be one of the most fundamental processes for engineers [6]. Jonassen [7, p. 103] wrote, "Learning to solve workplace problems is an essential learning outcome for any engineering graduate. Every engineer is hired, retained, and rewarded for his or her ability to solve problems." One goal of engineering education is to produce effective

[1] This section has been adapted from [1].

problem-solvers which is central to the practice of engineering [8]. Karabulut-Ilgu et al. ([9], pp. 514-515) argued that "engineers of tomorrow need to be prepared to solve workplace problems in collaborative environments."

Teamwork[2]

ABET [4] Student Outcome 5 directly addresses teamwork:

5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

While this Student Outcome is more concerned with significant projects such as capstone projects, students need to learn how to work effectively in teams well before their capstone projects.

Teamwork, sometimes referred to as collaboration, is critical in most engineering positions because many problems are larger and more complex than can be handled by single individuals. Lahdiji made a relevant observation, "Today's engineers are becoming an integrator, and a coordinator of information, technology, and people" [10]. This clearly requires teamwork. A survey of Malaysian employers of engineers from a private university ranked teamwork as the number one employability skill [11]. A different survey of Malaysian employers showed they have high expectations that engineering graduates will work well as leaders and as members of teams [12]. A survey of 420 engineers and engineering managers in the aerospace industry showed that an ability to function on multi-disciplinary teams ranked highly as an industry expectation [13]. In a survey of Australian employers, teamwork was ranked in the top five out of 23 desirable attributes for engineering graduates [14]. A large survey of 2115 engineering alumni from a large Midwestern university found that participants ranked teamwork as the highest of the old ABET a-k Student Outcomes [15].

An increasing number of engineering projects are cross-disciplinary. Communication is further complicated by multiple time zones, cultures, and sometimes even languages. Engineers must learn to work in teams; however, they do not get a lot of practice doing that as undergraduates, except for labs and capstone projects. Part of the reason for this is that many engineering courses are theory-based where problems have a single correct answer, with faculty trying to assess the performance of individual students. Back and Sanders wrote, "engineers at all levels must be able and willing to function in a team environment, and to accept that the team, not the individual, will succeed or fail" [16].

Learning how to work effectively in teams is a skill that is not as straightforward as solving an engineering problem. If someone is brilliant but cannot communicate their ideas to their teammates, then they are not likely to be very effective as an engineer. People with expertise in different disciplines may not speak the same technical language. Teammates may be from very different generations, ethnic backgrounds and cultures. Gender and personality types can also impact how teams function. These factors and others complicate communication.

[2] This section has been adapted from [29].

Cooperative Learning

While cooperative, sometimes referred to as *collaborative* or *group*, learning is related to teamwork, they are distinct from each other. Cooperative learning is where students work together in the pursuit of knowledge. It may be considered a subset of teamwork that encompasses more than just learning. Gauvain (2018) also called cooperative learning “social learning” [17]. Cooperative problem solving (CPS) is gaining attention because of the increasingly more complex problems in the modern world [18]. Cohen (1996) wrote of the many potential benefits of cooperative learning including learning gains, development of higher-order thinking, prosocial behavior, interracial acceptance, and improved management of academic heterogeneity in classrooms with a wide range of achievement in basic skills [19].

Johnson et al. (1998) identified three types of cooperative learning groups: formal, informal, and base [20]. Informal is the group of interest here. These are ad-hoc groups that last from a few minutes to one class period. The purposes of informal cooperative learning include:

- focuses student attention on the material to be learned,
- sets a mood conducive to learning,
- ensures that students cognitively process the material being taught,
- provides closure to an instructional session,
- allows for identifying and correcting misconceptions, incorrect misunderstanding, and gaps in comprehension, and
- personalizes learning experiences.

Solving problems in small groups is not new. However, engineering students solving problems in small groups in the context considered here (i.e., not in a laboratory or capstone project) has received little attention in the literature. At least until the time of their article, Springer et al. (1999) argued that small-group learning for undergraduate engineering students was not commonly practiced, even though many studies have shown a statistically significant and positive effect on achievement, persistence, and attitude on undergraduate STEM students [21]. They strongly recommended it be used, although they did not specify a particular implementation. Sternberg recommended a more formal approach to collaborative learning for engineering students than is advocated here [22]. His groups consisted of three students where each was assigned a specific role in the problem-solving process: Thinker, Writer, and Source of Information. Only the Source of Information was given the problem statement and had access to the class notes and text. The Thinker described to the Writer how to find the problem solution. The Writer documented the process. This is a much more time-intensive process for the instructor than the method considered here. Zhu et al. (2023) argued that one reason higher education instructors do not use small-group learning activities is due to management burdens [23]. The technique described here has minimal instructor management requirements.

Group problem-solving is an active learning technique that helps eliminate the illusion of understanding and can be motivating for students [24]. In the former, students sometimes believe they understand a subject after listening to a lecture or reading a text. However, when they actually try to solve problems, they find out they actually did not understand as well as they thought which comes out in the group problem-solving. Regarding motivation, group problem-solving is usually considered to be more interesting than a traditional lecture. Further, the joy of correctly solving problems can be very motivating.

Implementation Examples

There are two common settings where students work in small groups to solve problems: projects and labs. In both of these, students are expected to work together for a sustained period of time as short as a classroom period for labs to as long as two semesters for senior capstone projects. Neither of these is the type of setting considered here. The focus here is on the traditional face-to-face lecture setting which is usually in a classroom or lecture hall. The context here is not a project or design, but rather solving traditional math and engineering problems. The concern here is not the methodologies used to solve problems (e.g., [25]), nor with the particular problems being solved, but on students working together to solve well-defined, closed-ended problems. Many books have been written on the mechanics of solving engineering problems (e.g., [26]), which is not the focus here. The type of problem-solving of interest here is also different than small group discussions where students may have differing opinions; here the problems have only one correct answer. These are the types of problems engineering students typically solve for homework and exams in most of their math, science, and engineering classes.

The technique promulgated here can be used with pre-determined or self-selected groups. The former requires more work for the instructor. The groups formed with the latter approach may consist of friends or acquaintances, or simply students near each other. To encourage teamwork and working with as many colleagues as possible, students could be required to work with a minimum number of different students during the semester. If a class is small enough and there are enough opportunities to work in small groups, students could be required to work with every student in the class at least once. This can be particularly advantageous in classes where students do not know many other students, such as in first-semester freshmen classes, as it forces the students to get to know their colleagues. From personal experience, there must be some type of grade associated with collaboration where a student would get full credit if they worked with the required minimum number of students and a reduced grade proportional to the number they worked with below the minimum requirement. Besides learning to work with others who may not be like them, students also get to see how other students solve problems.

The simplest and most straightforward implementation is to assign all students in a group the same grade. Some might argue this may not always be fair as some students may do most or maybe all of the work while others sit back and watch, which is referred to as *social loafing* [18]. While that is almost certainly true in some cases, a particular purpose of this technique is to have students who better understand a topic to teach those who do not understand it as well. Almost by definition, this means the more knowledgeable students will be doing more of the work compared to those who are still trying to make sense of a subject. In this scenario, it is this author’s opinion that widely varying efforts receiving the same grade is acceptable, assuming all students are making at least a good faith effort.

As with most types of learning opportunities, these small-group problem-solving activities should be assessed. Without grades, there is often a lack of effort and a sense of urgency. Groups should have a reasonably short amount of time, depending on the problem, so students will work diligently to get a solution in a timely manner. These formative assessments are also an opportunity for instructors to get a sense of how well specific content is being learned, both while they are interacting with students during problem-solving and when they grade the solutions. Smith et al. (1981) recommended that all students in a group receive the same grade [27]. Partial credit is recommended as it encourages students to work out problems even if they are unable to get the correct answer. However, this activity should generally not be worth a significant portion of the overall course grade. In-class problems can also encourage class attendance if there are no make-up opportunities for missed quizzes.

The technique can be used in any class involving problem-solving, typically after a particular topic has been covered so students can immediately apply what they have learned. It has been used in many different classes taught by the author including statistics, thermodynamics, experimental methods, heat transfer, and combustion. This technique also helps students when they work on homework problems as they will already have had some experience solving similar problems. While it can be used for any type of problem, those with a numerical answer are in mind here. While it could be and has been used to discuss scenarios that emphasize student opinions, engineering is rarely based on opinion [28], so those are not the types of problems in mind here.

Ideally, students would have read the text covering the subject prior to coming to class so the lecture is not the first time they are learning the material. In general, the problems selected should be solvable by the majority of the students in a relatively short amount of time. However, on occasion, it may be beneficial to assign a problem that is more difficult for most students so students in a group can see that some problems are challenging even for the students who have shown to be knowledgeable in the subject area. It is at the instructor's discretion whether the problems are open- or closed-book. The instructor might even provide key equations and hints needed for the solution. The problems should not have solutions that can be looked up in the text or online.

Only one solution is turned in by each group with all necessary work shown and the appropriate number of significant digits. Points should be deducted if those are lacking even if the solution is correct. This teaches students the necessity of good documentation for engineers [29]. All students in the group should be listed on the group solution. This can even be used to take class attendance, although a caution is that students have been known to put their friends' names on the solution sheet even when those friends are absent. For a smaller class where the instructor knows the students, this is easy to detect. For very large classes, this may be more problematic.

Group size depends on time limits, students' experience working in groups, students' age, and the materials and equipment available [20]. The size of each group is recommended to be no more than 4 and must be a minimum of 2 (or else it would not be a group!). Spencer Kagan believed teams of 4 are optimum [30]. If the groups are too small, there is a greater risk that no one in the group will know how to solve a given problem. If the groups are too large, then it is more likely not all students will actively participate.

The timing of the activity is flexible but generally would be in the middle to the end of the class, after a particular topic has been covered. Problems assigned at the end of class have the advantage of a hard time deadline and also give students who finish more quickly the opportunity to leave class early rather than waiting for other groups to finish.

Benefits

Small group problem solving is an interactive problem-based learning (PBL) technique that has several potential advantages in the engineering classroom. The first and probably most important is that it has the potential to help students who do not understand a particular topic as explained by the instructor but may understand it when it is explained by a fellow student. It is sometimes challenging for an instructor to explain a topic that is so easy to them but quite challenging to students. Hearing an explanation from a fellow student can sometimes help students understand the material better than listening to an instructor or reading a textbook. Students, especially freshmen and sophomores, are often reluctant to ask instructors questions, particularly in larger classes, for fear of looking stupid. They are much more likely to ask questions in a small group of their peers than they are in larger classes. They are also more likely to ask the instructor questions in a small group compared to in front of the entire class.

A second benefit is that it helps students who do understand a particular topic because it boosts their confidence when they can explain it to their colleagues. Again, students may be reluctant to answer questions or solve problems in front of the instructor and the entire class even when they know the answer. There is still a fear of being wrong even when a student is fairly sure they are correct. Rather than risk embarrassment, students often keep quiet in class and defer to other students.

A third important benefit is that this technique engages students in the course content and is another alternative to lecture. Students move around and talk to each other. The instructor also moves around the class and helps individual groups. This helps the instructor get a better sense of student understanding by listening to the conversations within groups. The technique requires relatively minimal instructor management.

Challenges

One important potential challenge is that some students will dominate their groups. This is particularly prevalent when high-achieving students do not trust their fellow students to get the correct answer. That is why this activity should not constitute too much of a student’s final grade which should reduce the pressure to get the correct answer. Additionally, high-achieving students may view the activity as a waste of time if they are providing all the answers in their groups. Ideally, they would view it as helping their fellow students and building their own confidence in the course content.

The opposite challenge is that some students will sit back and let other students solve the problems and still get full credit. This could be because the non-participating students truly do not understand the material and are unable to participate. It could also be because they did not read the text before class and were not paying attention in class. Those students may be tempted to talk to the other students in their group about other unrelated topics or to be texting instead of working on the problem. The observant instructor can handle those situations assuming the class is not too large. In larger classes, teaching assistants can not only help students solve problems but also monitor for any undesired activities. If the class is small enough and the instructor knows the students, the non-participating students can be dealt with individually either during problem-solving or outside of class, whichever is more appropriate.

Problem selection is important because the activity described here is designed for shorter problems that can be completed usually in 10 – 15 minutes. That limits the types of problems that can be solved as more complicated problems may take too long to solve in a lecture environment. While the cooperative learning activity described here reduces the time in class available for lecture, it has proven to be very beneficial for student understanding. Felder (2011) strongly recommended cooperative learning and suggested publishing class notes to make up for lecture time lost to small group work in class [31].

Conclusions and Recommendations

Felder et al. [28] suggested the following criteria for effective instructional methods for teaching engineering students:

- They are relevant to engineering education.
- They can be implemented within the context of the ordinary engineering classroom.
- Most engineering professors should feel reasonably comfortable with them after a little practice.
- They are consistent with modern theories of learning and have been tried and found effective by many educators.

It is argued here that the method presented meets those criteria.

Johnson et al. (1981) compared cooperative, competitive, and individualistic learning in a meta-analysis of 122 studies [32]. They found that cooperation is superior to both competition and individualistic efforts in promoting achievement and productivity. Svinicki and McKeachie (2014) believed that cooperative peer learning is one of the "most valuable tools for effective teaching" [24].

It is strongly recommended that students be required to rotate partners and work with as many of their colleagues during the semester as possible. This gives them the opportunity to work with students of various backgrounds and abilities. They are likely to encounter that type of environment in the workplace when they collaborate with a wide range of people including non-engineers. They also get to observe how others solve problems so they can modify their own problem-solving techniques accordingly.

While this technique could be adapted for online classes, the author has no personal experience doing that. Collaboration in general is more difficult online but with today's technology, it is easier than ever. For example, collaboration software such as Zoom has features for dividing groups into smaller groups. Video streaming is usually fast enough to have multiple participants online simultaneously so everyone can see each other. While some things, such as body language, may be more challenging, the general methodology would be nearly the same.

A potentially larger challenge is implementation in large lecture classes. This can be effective if there are multiple instructors and/or teaching assistants available to help students, but it probably would be much less effective with a single instructor and many students. Another potential challenge is the layout of the classroom where some rooms are much more suited to collaboration than others. Large lecture halls with stadium seating are not as amenable as smaller classrooms with movable chairs and tables or desks. The author has employed the technique in both scenarios, but usually less frequently in classes with stadium seating.

Anecdotally, the author has seen the value of the methodology, especially for students who may be struggling with the course content. However, it is recommended that a more formal research program investigate the educational value to see if there is a statistically significant improvement in learning using the technique.

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