Does Active Learning Work? A Review of the Research

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ABSTRACT

This study examines the evidence for the effectiveness of active learning. It defines the common forms of active learning most relevant for engineering faculty and critically examines the core element of each method. It is found that there is broad but uneven support for the core elements of active, collaborative, cooperative and problem-based learning.

[QA1]

I. INTRODUCTION

Active learning has received considerable attention over the past several years. Often presented or perceived as a radical change from traditional instruction, the topic frequently polarizes faculty. Active learning has attracted strong advocates among faculty looking for alternatives to traditional teaching methods, while skeptical faculty regard active learning as another in a long line of educational fads.

For many faculty there remain questions about what active learning is and how it differs from traditional engineering education, since this is already "active" through homework assignments and laboratories. Adding to the confusion, engineering faculty do not always understand how the common forms of active learning differ from each other and most engineering faculty are not inclined to comb the educational literature for answers.

This study addresses each of these issues. First, it defines active learning and distinguishes the different types of active learning most frequently discussed in the engineering literature. A core element is identified for each of these separate methods in order to differentiate between them, as well as to aid in the subsequent analysis of their effectiveness. Second, the study provides an overview of relevant cautions for the reader trying to draw quick conclusions on the effectiveness of active learning from the educational literature. Finally, it assists engineering faculty by summarizing some of the most relevant literature in the field of active learning.

II. DEFINITIONS

It is not possible to provide universally accepted definitions for all of the vocabulary of active learning since different authors in the field have interpreted some terms differently. However, it is possible to provide some generally accepted definitions and to highlight distinctions in how common terms are used.

Active learning is generally defined as any instructional method that engages students in the learning process. In short, active learning requires students to do meaningful learning activities and think about what they are doing [1]. While this definition could include traditional activities such as homework, in practice active learning refers to activities that are introduced into the classroom. The core elements of active learning are student activity and engagement in the learning process. Active learning is often contrasted to the traditional lecture where students passively receive information from the instructor.

Collaborative learning can refer to any instructional method in which students work together in small groups toward a common goal [2]. As such, collaborative learning can be viewed as encompassing all group-based instructional methods, including cooperative learning [3–7]. In contrast, some authors distinguish between collaborative and cooperative learning as having distinct historical developments and different philosophical roots [8–10]. In either interpretation, the core element of collaborative learning is the emphasis on student interactions rather than on learning as a solitary activity.

Cooperative learning can be defined as a structured form of group work where students pursue common goals while being assessed individually [3, 11]. The most common model of cooperative learning found in the engineering literature is that of Johnson, Johnson and Smith [12, 13]. This model incorporates five specific tenets, which are individual accountability, mutual interdependence, face-to-face promotive interaction, appropriate practice of interpersonal skills, and regular self-assessment of team functioning. While different cooperative learning models exist [14, 15], the core element held in common is a focus on cooperative incentives rather than competition to promote learning.

Problem-based learning (PBL) is an instructional method where relevant problems are introduced at the beginning of the instruction cycle and used to provide the context and motivation for the learning that follows. It is always active and usually (but not necessarily) collaborative or cooperative using the above definitions. PBL typically involves significant amounts of self-directed learning on the part of the students.

III. COMMON PROBLEMS INTERPRETING THE LITERATURE ON ACTIVE LEARNING

Before examining the literature to analyze the effectiveness of each approach, it is worth highlighting common problems that engineering faculty should appreciate before attempting to draw conclusions from the literature.

A. Problems Defining What Is Being Studied

Confusion can result from reading the literature on the effectiveness of any instructional method unless the reader and author

take care to specify *precisely* what is being examined. For example, there are many different approaches that go under the name of problem-based learning [16]. These distinct approaches to PBL can have as many differences as they have elements in common, making interpretation of the literature difficult. In PBL, for example, students typically work in small teams to solve problems in a self-directed fashion. Looking at a number of meta-analyses [17], Norman and Schmidt [18] point out that having students work in small teams has a positive effect on academic achievement while self-directed learning has a slight negative effect on academic achievement. If PBL includes both of these elements and one asks if PBL works for promoting academic achievement, the answer seems to be that parts of it do and parts of it do not. Since different applications of PBL will emphasize different components, the literature results on the overall effectiveness of PBL are bound to be confusing unless one takes care to specify what is being examined. This is even truer of the more broadly defined approaches of active or collaborative learning, which encompass very distinct practices.

Note that this point sheds a different light on some of the available meta-analyses that are naturally attractive to a reader hoping for a quick overview of the field. In looking for a general sense of whether an approach like problem-based learning works, nothing seems as attractive as a meta-analysis that brings together the results of several studies and quantitatively examines the impact of the approach. While this has value, there are pitfalls. Aggregating the results of several studies on the effectiveness of PBL can be misleading if the forms of PBL vary significantly in each of the individual studies included in the meta-analysis.

To minimize this problem, the analysis presented in Section IV of this paper focuses on the specific core elements of a given instructional method. For example, as discussed in Section II, the core element of collaborative learning is working in groups rather than working individually. Similarly, the core element of cooperative learning is cooperation rather than competition. These distinctions can be examined without ambiguity. Furthermore, focusing on the core element of active learning methods allows a broad field to be treated concisely.

B. Problems Measuring "What Works"

Just as every instructional method consists of more than one element, it also affects more than one learning outcome [18]. When asking whether active learning "works," the broad range of outcomes should be considered such as measures of factual knowledge, relevant skills and student attitudes, and pragmatic items as student retention in academic programs. However, solid data on how an instructional method impacts all of these learning outcomes is often not available, making comprehensive assessment difficult. In addition, where data on multiple learning outcomes exists it can include mixed results. For example, some studies on problem-based learning with medical students [19, 20] suggest that clinical performance is slightly enhanced while performance on standardized exams declines slightly. In cases like this, whether an approach works is a matter of interpretation and both proponents and detractors can comfortably hold different views.

Another significant problem with assessment is that many relevant learning outcomes are simply difficult to measure. This is particularly true for some of the higher level learning outcomes that are targeted by active learning methods. For example, PBL might naturally attract instructors interested in developing their students'

ability to solve open-ended problems or engage in life-long learning, since PBL typically provides practice in both skills. However, problem solving and life-long learning are difficult to measure. As a result, data are less frequently available for these outcomes than for standard measures of academic achievement such as test scores. This makes it difficult to know whether the potential of PBL to promote these outcomes is achieved in practice.

Even when data on higher-level outcomes are available, it is easy to misinterpret reported results. Consider a study by Qin et al. [21] that reports that cooperation promotes higher quality individual problem solving than does competition. The result stems from the finding that individuals in cooperative groups produced better solutions to problems than individuals working in competitive environments. While the finding might provide strong support for cooperative learning, it is important to understand what the study does *not* specifically demonstrate. It does not necessarily follow from these results that students in cooperative environments developed stronger, more permanent and more transferable problem solving skills. Faculty citing the reference to prove that cooperative learning results in individuals becoming generically better problem solvers would be over-interpreting the results.

A separate problem determining what works is deciding when an improvement is significant. Proponents of active learning sometimes cite improvements without mentioning that the magnitude of the improvement is small [22]. This is particularly misleading when extra effort or resources are required to produce an improvement. Quantifying the impact of an intervention is often done using effect sizes, which are defined to be the difference in the means of a subject and control population divided by the pooled standard deviation of the populations. An improvement with an effect size of 1.0 would mean that the test population outperformed the control group by one standard deviation. Albanese [23] cites the benefits of using effect sizes and points out that Cohen [24] arbitrarily labeled effect sizes of 0.2, 0.5 and 0.8 as small, medium and large, respectively. Colliver [22] used this fact and other arguments to suggest that effect sizes should be at least 0.8 before they be considered significant. However, this suggestion would discount almost every available finding since effect sizes of 0.8 are rare for any intervention and require truly impressive gains [23]. The effect sizes of 0.5 or higher reported in Section IV of this paper are higher than those found for most instructional interventions. Indeed, several decades of research indicated that standard measures of academic achievement were not particularly sensitive to any change in instructional approach [25]. Therefore, reported improvements in academic achievement should not be dismissed lightly.

Note that while effect sizes are a common measure of the magnitude of an improvement, absolute rather than relative values are sometimes more telling. There can be an important difference between results that are statistically significant and those that are significant in absolute terms. For this reason, it is often best to find both statistical and absolute measures of the magnitude of a reported improvement before deciding whether it is significant.

As a final cautionary note for interpreting reported results, some readers dismiss reported improvements from nontraditional instructional methods because they attribute them to the Hawthorne effect whereby the subjects knowingly react positively to any novel intervention regardless of its merit. The Hawthorne effect is generally discredited, although it retains a strong hold on the popular imagination [26].

C. Summary

There are pitfalls for engineering faculty hoping to pick up an article or two to see if active learning works. In particular, readers must clarify what is being studied and how the authors measure and interpret what "works." The former is complicated by the wide range of methods that fall under the name of active learning, but can be simplified by focusing on core elements of common active learning methods. Assessing "what works" requires looking at a broad range of learning outcomes, interpreting data carefully, quantifying the magnitude of any reported improvement and having some idea of what constitutes a "significant" improvement. This last will always be a matter of interpretation, although it is helpful to look at both statistical measures such as effect sizes and absolute values for reported learning gains.

No matter how data is presented, faculty adopting instructional practices with the expectation of seeing results similar to those reported in the literature should be aware of the practical limitations of educational studies. Educational studies tell us what worked, on average, for the populations examined and learning theories suggest why this might be so. However, claiming that faculty who adopt a specific method will see similar results in their own classrooms is simply not possible. Even if faculty master the new instructional method, they can not control all other variables that affect learning. The value of the results presented in Section IV of the paper is that they provide information to help teachers "go with the odds." The more extensive the data supporting an intervention, the more a teacher's students resemble the test population and the bigger the reported gains, the better the odds are that the method will work for a given instructor.

Notwithstanding all of these problems, engineering faculty should be strongly encouraged to look at the literature on active learning. Some of the evidence for active learning is compelling and should stimulate faculty to think about teaching and learning in nontraditional ways.

IV. THE EVIDENCE FOR ACTIVE LEARNING

Bonwell and Eison [1] summarize the literature on active learning and conclude that it leads to better student attitudes and improvements in students' thinking and writing. They also cite evidence from McKeachie that discussion, one form of active learning, surpasses traditional lectures for retention of material, motivating students for further study and developing thinking skills. Felder et al. [27] include active learning on their recommendations for teaching methods that work, noting among other things that active learning is one of Chickering and Gamson's "Seven Principles for Good Practice" [28].

However, not all of this support for active learning is compelling. McKeachie himself admits that the measured improvements of discussion over lecture are small [29]. In addition, Chickering and Gamson do not provide hard evidence to support active learning as one of their principles. Even studies addressing the research base for Chickering and Gamson's principles come across as thin with respect to empirical support for active learning. For example, Scorcelli [30], in a study aimed at presenting the research base for Chickering and Gamson's seven principles, states that, "We simply do not have much data confirming beneficial effects of other (not cooperative or social) kinds of active learning."

Despite this, the empirical support for active learning is extensive. However, the variety of instructional methods labeled as active learning muddles the issue. Given differences in the approaches labeled as active learning, it is not always clear what is being promoted by broad claims supporting the adoption of active learning. Perhaps it is best, as some proponents claim, to think of active learning as an approach rather than a method [31] and to recognize that different methods are best assessed separately.

This assessment is done in the following sections, which look at the empirical support for active, collaborative, cooperative and problem-based learning. As previously discussed, the critical elements of each approach are singled out rather than examining the effectiveness of every possible implementation scheme for each of these distinct methods. The benefits of this general approach are twofold. First, it allows the reader to examine questions that are both fundamental and pragmatic, such as whether introducing activity into the lecture or putting students into groups, is effective. Second, focusing on the core element eliminates the need to examine the effectiveness of every instructional technique that falls under a given broad category, which would be impractical within the scope of a single paper. Readers looking for literature on a number of specific active learning methods are referred to additional references [1, 6, 32].
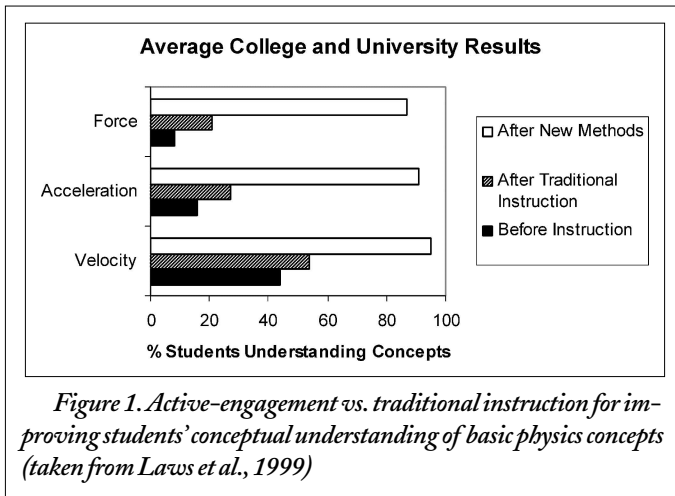
A. Active Learning

We have defined the core elements of active learning to be introducing activities into the traditional lecture and promoting student engagement. Both elements are examined below, with an emphasis on empirical support for their effectiveness.

1) Introducing student activity into the traditional lecture: On the simplest level, active learning is introducing student activity into the traditional lecture. One example of this is for the lecturer to pause periodically and have students clarify their notes with a partner. This can be done two or three times during an hour-long class. Because this pause procedure is so simple, it provides a baseline to study whether short, informal student activities can improve the effectiveness of lectures.

Ruhl et al. [33] show some significant results of adopting this pause procedure. In a study involving 72 students over two courses in each of two semesters, the researchers examined the effect of interrupting a 45-minute lecture three times with two-minute breaks during which students worked in pairs to clarify their notes. In parallel with this approach, they taught a separate group using a straight lecture and then tested short and long-term retention of lecture material. Short-term retention was assessed by a free-recall exercise where students wrote down everything they could remember in three minutes after each lecture and results were scored by the number of correct facts recorded. Short-term recall with the pause procedure averaged 108 correct facts compared to 80 correct facts recalled in classes with straight lecture. Long-term retention was assessed with a 65 question multiple-choice exam given one and a half weeks after the last of five lectures used in the study. Test scores were 89.4 with the pause procedure compared to 80.9 without pause for one class, and 80.4 with the pause procedure compared to 72.6 with no pause in the other class. Further support for the effectiveness of pauses during the lecture is provided by Di Vesta [34].

Many proponents of active learning suggest that the effectiveness of this approach has to do with student attention span during lecture. Wankat [35] cites numerous studies that suggest that student

Figure 1. Active-engagement vs. traditional instruction for improving students' conceptual understanding of basic physics concepts (taken from Laws et al., 1999)

attention span during lecture is roughly fifteen minutes. After that, Hartley and Davies [36] found that the number of students paying attention begins to drop dramatically with a resulting loss in retention of lecture material. The same authors found that immediately after the lecture students remembered 70 percent of information presented in first ten minutes of the lecture and 20 percent of information presented in last ten minutes. Breaking up the lecture might work because students' minds start to wander and activities provide the opportunity to start fresh again, keeping students engaged.

2) Promoting Student Engagement: Simply introducing activity into the classroom fails to capture an important component of active learning. The type of activity, for example, influences how much classroom material is retained [34]. In "Understanding by Design" [37], the authors emphasize that good activities develop deep understanding of the important ideas to be learned. To do this, the activities must be designed around important learning outcomes and promote thoughtful engagement on the part of the student. The activity used by Ruhl, for example, encourages students to think about what they are learning. Adopting instructional practices that engage students in the learning process is the defining feature of active learning.

The importance of student engagement is widely accepted and there is considerable evidence to support the effectiveness of student engagement on a broad range of learning outcomes. Astin [38]

reports that student involvement is one of the most important predictors of success in college. Hake [39] examined pre- and post-test data for over 6,000 students in introductory physics courses and found significantly improved performance for students in classes with substantial use of interactive-engagement methods. Test scores measuring conceptual understanding were roughly twice as high in classes promoting engagement than in traditional courses. Statistically, this was an improvement of two standard deviations above that of traditional courses. Other results supporting the effectiveness of active-engagement methods are reported by Redish et al. [40] and Laws et al. [41]. Redish et al. show that the improved learning gains are due to the nature of active engagement and not to extra time spent on a given topic. Figure 1, taken from Laws et al., shows that active engagement methods surpass traditional instruction for improving conceptual understanding of basic physics concepts. The differences are quite significant. Taken together, the studies of Hake et al., Redish et al. and Laws et al. provide considerable support for active engagement methods, particularly for addressing students' fundamental misconceptions. The importance of addressing student misconceptions has recently been recognized as an essential element of effective teaching [42].

In summary, considerable support exists for the core elements of active learning. Introducing activity into lectures can significantly improve recall of information while extensive evidence supports the benefits of student engagement.

B. Collaborative Learning

The central element of collaborative learning is collaborative vs. individual work and the analysis therefore focuses on how collaboration influences learning outcomes. The results of existing meta-studies on this question are consistent. In a review of 90 years of research, Johnson, Johnson and Smith found that cooperation improved learning outcomes relative to individual work across the board [12]. Similar results were found in an updated study by the same authors [13] that looked at 168 studies between 1924 and 1997. Springer et al. [43] found similar results looking at 37 studies of students in science, mathematics, engineering and technology. Reported results for each of these studies are shown in Table 1, using effect sizes to show the impact of collaboration on a range of learning outcomes.

What do these results mean in real terms instead of effect sizes, which are sometimes difficult to interpret? With respect to academic achievement, the lowest of the three studies cited would move a

Reference	Learning Outcome	Effect Size
Johnson, Johnson and Smith [12]	Improved academic achievement	0.64
	Improved quality of interpersonal interactions	0.60
	Improved self-esteem	0.44
	Improved perceptions of greater social support	0.70
Johnson, Johnson and Smith [13]	Improved academic achievement	0.53
	Improved liking among students	0.55
	Improved self-esteem	0.29
	Improved perceptions of greater social support	0.51
Springer et al. [43]	Improved academic achievement	0.51
	Improved student attitudes	0.55
	Improved retention in academic programs	0.46

Table 1. Collaborative vs. individualistic learning: Reported effect size of the improvement in different learning outcomes.

Reference	Learning Outcome	Effect Size
Johnson, Johnson and Smith [12]	Improved academic achievement	0.67
	Improved interpersonal relationships	0.82
	Improved perceptions of greater social support	0.83
	Improved self-esteem	0.67
Johnson, Johnson and Smith [13]	Improved academic achievement	0.49
	Improved liking among students	0.68
	Improved perceptions of greater social support	0.60
	Improved self-esteem	0.47

Table 2. Collaborative vs. competitive learning: Reported effect size of the improvement in different learning outcomes.

student from the 50th to the 70th percentile on an exam. In absolute terms, this change is consistent with raising a student's grade from 75 to 81, given classical assumptions about grade distributions.* With respect to retention, the results suggest that collaboration reduces attrition in technical programs by 22 percent, a significant finding when technical programs are struggling to attract and retain students. Furthermore, some evidence suggests that collaboration is particularly effective for improving retention of traditionally underrepresented groups [44, 45].

A related question of practical interest is whether the benefits of group work improve with frequency. Springer et al. looked specifically at the effect of incorporating small, medium and large amounts of group work on achievement and found the positive effect sizes associated with low, medium and high amount of time in groups to be 0.52, 0.73 and 0.53, respectively. That is, the highest benefit was found for medium time in groups. In contrast, more time spent in groups did produce the highest effect on promoting positive student attitudes, with low, medium and high amount of time in groups having effect sizes of 0.37, 0.26, and 0.77, respectively. Springer et al. note that the attitudinal results were based on a relatively small number of studies.

In summary, a number of meta-analyses support the premise that collaboration "works" for promoting a broad range of student learning outcomes. In particular, collaboration enhances academic achievement, student attitudes, and student retention. The magnitude, consistency and relevance of these results strongly suggest that engineering faculty promote student collaboration in their courses.

C. Cooperative Learning

At its core, cooperative learning is based on the premise that cooperation is more effective than competition among students for producing positive learning outcomes. This is examined in Table 2.

The reported results are consistently positive. Indeed, looking at high quality studies with good internal validity, the already large effect size of 0.67 shown in Table 2 for academic achievement increases to 0.88. In real terms, this would increase a student's exam score from 75 to 85 in the "classic" example cited previously, though of course this specific result is dependent on the assumed grade distribution. As seen in Table 2, cooperation also promotes interpersonal relationships, improves social support and fosters self-esteem.

Another issue of interest to engineering faculty is that cooperative learning provides a natural environment in which to promote

effective teamwork and interpersonal skills. For engineering faculty, the need to develop these skills in their students is reflected by the ABET engineering criteria. Employers frequently identify team skills as a critical gap in the preparation of engineering students. Since practice is a precondition of learning any skill, it is difficult to argue that individual work in traditional classes does anything to develop team skills.

Whether cooperative learning effectively develops interpersonal skills is another question. Part of the difficulty in answering that question stems from how one defines and measures team skills. Still, there is reason to think that cooperative learning is effective in this area. Johnson et al. [12, 13] recommend explicitly training students in the skills needed to be effective team members when using cooperative learning groups. It is reasonable to assume that the opportunity to practice interpersonal skills coupled with explicit instructions in these skills is more effective than traditional instruction that emphasizes individual learning and generally has no explicit instruction in teamwork. There is also empirical evidence to support this conclusion. Johnson and Johnson report that social skills tend to increase more within cooperative rather than competitive or individual situations [46]. Terenzini et al. [47] show that students report increased team skills as a result of cooperative learning. In addition, Panitz [48] cites a number of benefits of cooperative learning for developing the interpersonal skills required for effective teamwork.

In summary, there is broad empirical support for the central premise of cooperative learning, that cooperation is more effective than competition for promoting a range of positive learning outcomes. These results include enhanced academic achievement and a number of attitudinal outcomes. In addition, cooperative learning provides a natural environment in which to enhance interpersonal skills and there are rational arguments and evidence to show the effectiveness of cooperation in this regard.

D. Problem-Based Learning

As mentioned in Section II of this paper, the first step of determining whether an educational approach works is clarifying exactly what the approach is. Unfortunately, while there is agreement on the general definition of PBL, implementation varies widely. Woods et al. [16], for example, discuss several variations of PBL.

"Once a problem has been posed, different instructional methods may be used to facilitate the subsequent learning process: lecturing, instructor-facilitated discussion, guided decision making, or cooperative learning. As part of the problem-solving process, student groups can be assigned to

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*Calculated using an effect size of 0.5, a mean of 75 and a normalized grade distribution where the top 10 percent of students receive a 90 or higher (an A) and the bottom 10 percent receive a 60 or lower (an F).

complete any of the learning tasks listed above, either in or out of class. In the latter case, three approaches may be adopted to help the groups stay on track and to monitor their progress: (1) give the groups written feedback after each task; (2) assign a tutor or teaching assistant to each group, or (3) create fully autonomous, self-assessed "tutorless" groups."

The large variation in PBL practices makes the analysis of its effectiveness more complex. Many studies comparing PBL to traditional programs are simply not talking about the same thing. For meta-studies of PBL to show any significant effect compared to traditional programs, the signal from the common elements of PBL would have to be greater than the noise produced by differences in the implementation of both PBL and the traditional curricula. Given the huge variation in PBL practices, not to mention differences in traditional programs, readers should not be surprised if no consistent results emerge from meta-studies that group together different PBL methods.

Despite this, there is at least one generally accepted finding that emerges from the literature, which is that PBL produces positive student attitudes. Vernon and Blake [19] looking at 35 studies from 1970 to 1992 for medical programs found that PBL produced a significant effective size (0.55) for improved student attitudes and opinions about their programs. Albanese and Mitchell [20] similarly found that students and faculty generally prefer the PBL approach. Norman and Schmidt [18] argue "PBL does provide a more challenging, motivating and enjoyable approach to education. That may be a sufficient raison d'etre, providing the cost of the implementation is not too great." Note that these and most of the results reported in this section come from studies of medical students, for whom PBL has been widely used. While PBL has been used in undergraduate engineering programs [49, 50] there is very little data available for its effectiveness with this population of students.

Beyond producing positive student attitudes, the effects of PBL are less generally accepted, though other supporting data do exist. Vernon and Blake [19], for example, present evidence that there is a statistically significant improvement of PBL on students' clinical performance with an effect size of 0.28. However, Colliver [22] points out that this is influenced strongly by one outlying study with a positive effect size of 2.11, which skews the data. There is also evidence that PBL improves the long-term retention of knowledge compared to traditional instruction [51–53]. Evidence also suggests that PBL promotes better study habits among students. As one might expect from an approach that requires more independence from students, PBL has frequently been shown to increase library use, textbook reading, class attendance and studying for meaning rather than simple recall [19, 20, 53, 54].

We have already discussed the problems with meta-studies that compare non-uniform and inconsistently defined educational interventions. Such studies are easily prone to factors that obscure results. The approach for handling this difficulty with active, collaborative and cooperative learning was to identify the central element of the approach and to focus on this rather than on implementation methods. That is more difficult to do with PBL since it is not clear that one or two core elements exist. PBL is active, engages students and is generally collaborative, all of which are supported by our previous analysis. It is also inductive, generally self-directed, and often includes explicit training in necessary skills. Can one or two elements be identified as common or decisive?

Norman and Schmidt [18] provide one way around the difficulty by identifying several components of PBL in order to show how they impact learning outcomes. Their results are shown in Table 3, taken directly from Norman and Schmidt using the summary of meta-studies provided by Lipsey and Wilson [17]. The measured learning outcome for all educational studies cited by Lipsey and Wilson was academic achievement.

Norman and Schmidt present this table to illustrate how different elements of PBL have different effects on learning outcomes. However, the substantive findings of Table 3 are also worth highlighting for faculty interested in adopting PBL because there seems to be considerable agreement on what works and does not work in PBL.

Looking first at the negative effects, there is a significant negative effect size using PBL with non-expert tutors. This finding is consistent with some of the literature on helping students make the transition from novice to expert problem solvers. Research comparing experts to novices in a given field has demonstrated that becoming an expert is not just a matter of "good thinking" [42]. Instead, research has demonstrated the necessity for experts to have both a deep and broad foundation of factual knowledge in their fields. The same appears to be true for tutors in PBL.

There is also a small negative effect associated with both self-paced and self-directed learning. This result is consistent with the findings of Albanese and Mitchell [20] on the effect of PBL on test results. In seven out of ten cases they found that students in PBL programs scored lower than students in traditional programs on tests of basic science. However, in three out of ten cases, PBL students actually scored higher. Albanese and Mitchell note that these three PBL programs were more "directive" than others,

Characteristic	Effect Size
(a) Individualized	0.23
(b) Cooperative	0.54
(c) Small group	0.31
(d) With non-expert tutors	-0.74
(e) Self-paced	-0.07
(f) Self-directed	-0.05
(g) Using problems	0.20
(h) Inquiry based	0.16
(i) Instruction in problem solving	0.54
(j) Inductive	0.06

Table 3. Effect sizes associated with various aspects of problem-based learning.

indicating that this element might be responsible for the superior exam performance for students in those programs. Therefore, faculty might be advised to be cautious about the amount of self-direction required by students in PBL, at least with regard to promoting academic achievement as measured by traditional exams.

Looking at what seems to work, there are significant positive effect sizes associated with placing students in small groups and using cooperative learning structures. This is consistent with much of the literature cited previously in support of cooperative learning. While PBL and cooperative learning are distinct approaches, there is a natural synergy that instructors should consider exploiting. That is, real problems of the sort used in PBL require teams to solve effectively. At the same time, the challenge provided by realistic problems can provide some of the mutual interdependence that is one of the five tenets of cooperative learning.

Table 3 also shows that positive results come from instruction in problem solving. This is consistent with much of the advice given by proponents of problem-based learning [55]. While practice is crucial for mastering skills such as problem solving, greater gains are realized through explicit instruction of problem solving skills. However, traditional engineering courses do not generally teach problem solving skills explicitly. Table 3 suggests that faculty using PBL consider doing just that.

In conclusion, PBL is difficult to analyze because there is not one or two core elements that can be clearly identified with student learning outcomes. Perhaps the closest candidates for core elements would be inductive or discovery learning. These have been shown by meta-studies to have only weakly positive effects on student academic achievement [56, 57] as measured by exams. This might explain why PBL similarly shows no improvement on student test scores, the most common measure of academic achievement.

However, while no evidence proves that PBL enhances academic achievement as measured by exams, there is evidence to suggest that PBL "works" for achieving other important learning outcomes. Studies suggest that PBL develops more positive student attitudes, fosters a deeper approach to learning and helps students retain knowledge longer than traditional instruction. Further, just as cooperative learning provides a natural environment to promote interpersonal skills, PBL provides a natural environment for developing problem-solving and life-long learning skills. Indeed, some evidence shows that PBL develops enhanced problem-solving skills in medical students and that these skills can be improved further by coupling PBL with explicit instruction in problem solving. Similarly, supporting arguments can be made about PBL and the important ABET engineering outcome of life-long learning. Since self-directed learning and meta-cognition are common to both PBL and life-long learning, a logical connection exists between this desired learning outcome and PBL instruction, something often not true when trying to promote life-long learning through traditional teaching methods.

IV. CONCLUSIONS

Although the results vary in strength, this study has found support for all forms of active learning examined. Some of the findings, such as the benefits of student engagement, are unlikely to be controversial although the magnitude of improvements resulting from active-engagement methods may come as a surprise. Other findings challenge traditional assumptions about engineering education and these are most worth highlighting.

For example, students will remember more content if brief activities are introduced to the lecture. Contrast this to the prevalent content tyranny that encourages faculty to push through as much material as possible in a given session. Similarly, the support for collaborative and cooperative learning calls into question the traditional assumptions that individual work and competition best promote achievement. The best available evidence suggests that faculty should structure their courses to promote collaborative and cooperative environments. The entire course need not be team-based, as seen by the evidence in Springer et al. [43], nor must individual responsibility be absent, as seen by the emphasis on individual accountability in cooperative learning. Nevertheless, extensive and credible evidence suggests that faculty consider a nontraditional model for promoting academic achievement and positive student attitudes.

Problem-based learning presents the most difficult method to analyze because it includes a variety of practices and lacks a dominant core element to facilitate analysis. Rather, different implementations of PBL emphasize different elements, some more effective for promoting academic achievement than others. Based on the literature, faculty adopting PBL are unlikely to see improvements in student test scores, but are likely to positively influence student attitudes and study habits. Studies also suggest that students will retain information longer and perhaps develop enhanced critical thinking and problem-solving skills, especially if PBL is coupled with explicit instruction in these skills.

Teaching cannot be reduced to formulaic methods and active learning is not the cure for all educational problems. However, there is broad support for the elements of active learning most commonly discussed in the educational literature and analyzed here. Some of the findings are surprising and deserve special attention. Engineering faculty should be aware of these different instructional methods and make an effort to have their teaching informed by the literature on "what works."

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