Research Base Excerpt: Synthesis of Research on Problem-Based Learning, 2013

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2013 Introduction to Problem-Based Learning

The research of the last seven years on Problem- Based Learning (PBL) has also accepted the view that PBL is a good strategy to help students from first grade through college, to ***retain more knowledge*** from their instruction than they do when they are simply lectured to and told a rule or procedure. It seems to be especially true for students learning mathematics or science.

Additional research has simply confirmed this fact. Relatively few of the results are useful to CPM, however, as a large fraction of current research is devoted to understanding what happens in a computer-based PBL setting. Such studies have the significant advantage of being easier and much, much cheaper to carry out than classroom-based research. Science and medical education are also the beneficiaries of many of these studies.

New results relevant to CPM that are worth noting, however, are that assisted PBL is the most useful variant of the technique, that it is important to do PBL in a cooperative learning environment, and that students of virtually all learning abilities can profit from a PBL curriculum.

What is Problem- Based Learning?

In the simplest terms, PBL means working on problems in order to *develop an understanding* together with a *procedure for solving* them rather than *practicing a procedure* after being told. Trying to learn something in the first place is a very different goal than trying to imitate a practice and needs different methods. No single method is superior for all children and all topics and all cases. Every successful program needs a mix of the methods, and every student needs both. No one can be asked to discover the definition of a trapezoid, and no one can be told the concept of an unknown. The former is a matter of social convention while the latter is such a deep concept that words are inadequate. At different times, students need different opportunities, and learning different topics requires different methods and different time frames.

But two very different classroom activities have been done under the name PBL for some time. In a meta-analysis, Alfieri et al. (2011) looked at the results of 164 different studies that compared different types of PBL with a traditional direct instruction format. One group of studies involved *unassisted* discovery (here is a problem of a kind you have never seen before; figure out how to solve it in any way you can) while the other group of studies used *assisted* discovery, where problems are organized in a sequence to promote discovery of the answer. The conclusion was that assisted discovery was better than direct instruction, which, in turn, was better than unassisted discovery. CPM has always used assisted instruction. See also Hmelo-Silver (2004) or Prince & Felder (2006) for more extensive discussions of types of PBL.

Why use Problem- Based Learning?

Unfortunately, there is a strong belief on the part of many educators that students need only to be told what to do and, if they are told properly and practice, they will learn the fact, skill or concept. It certainly ***seems*** efficient at conveying knowledge. The trouble with this belief is that **it is not true** except when one is dealing with very young children or for topics that have no unifying structure such as names of state capitals. It is certainly not true in mathematics.

The problems with teaching by telling have been amply documented by many researchers in mathematics and science at all levels and for most types of students, for almost as long as cooperative learning has been studied. Carpenter et al. (1998) followed students in grades 1-3 for three years and found that "students who used invented strategies before they learned standard algorithms demonstrated better knowledge of base-ten number concepts and were more successful in extending their knowledge to new situations than were students who initially learned standard algorithms." Similar results were reported for students this age by Hiebert & Wearne (1996) and Cauley (1998). Some research even indicates that being told rules before attempting to forge a personal understanding can interfere with deeper learning.

For sixth graders, Hmelo et al. (2000) found that science design activities, which allow deeper explorations of how systems work, helped students "learn more than students receiving direct instruction." For eighth graders, Woodward (1994) reported that students who learned the reasons for earth science phenomena "had significantly better retention of facts and concepts and were superior in applying this knowledge in problem-solving exercises." Azer (2009) reported that "Saudi students from the fifth, sixth and seventh grades perceived PBL in a positive way" following up on other work that he had done with medical students.

In a survey article McDermott & Redish (1999) have demonstrated that college level physics students do not learn some very basic content by lecture and this result has been duplicated with thousands of students at many institutions ranging from very selective private institutions and large state universities down through high schools. The work of Crouch & Mazur (2001) reporting on ten years using Peer Instruction (an interactive method of teaching) for the introductory physics courses at Harvard shows "increased student mastery of both conceptual reasoning and quantitative problem solving upon implementing Peer Instruction."

The work of Capon and & Kuhn (2004) with adult students contrasting the outcomes of problem-based learning with lecture and discussion showed that six weeks after instruction the lecture group was superior in the understanding of one concept and the two groups were equivalent in understanding of the other. After 12 weeks concept retention was equal, but the problem-based learning group was superior in being able to explain what they had learned. Masek & Yamin (2012) showed that electrical engineering students learned more about the principles and procedures in their first electrical technology module.

These results are not only true in mathematics and the sciences. Cobb (1999) reports on a study of students learning English in the Sultanate of Oman who learned vocabulary in two ways: by memorizing dictionary definitions or by constructing their own definitions using the tools of lexicographers. "After 12 weeks, both groups were equal in definitional knowledge of target words, but lexicography group students were more able to transfer their work knowledge to novel contexts."

Who should be taught using PBL?

At the same time that studies have demonstrated the failure of direct instruction for average students, other studies have shown the advantages of PBL. Most of these studies have been done with gifted students in K-12 or with older students studying engineering or medicine. See, for example, Albanese & Mitchell (1993) for an extensive review of the medical literature on PBL, Prince (2004) for a briefer summary on its uses with engineering students, and Dods (1997) or Gallagher & Stepien (1996) for studies about gifted children learning with PBL.

These results confirm what has long been believed, that something akin to problem-based learning is superior for learning, when it is appropriate for the students involved. These earlier studies focused on students of ability—gifted elementary students or students in rigorous college programs. The implicit assumption was that only a small minority of students could benefit from such an approach.

In the past 15 years, however, studies have found that well-designed PBL courses can benefit most, if not all, students. Songer et al. (2002) reported on a study of 19 urban sixth-grade classes showing that students in all classrooms made significant content and inquiry gains. Kahle et al. (2000) studied eight middle schools in Ohio and showed that teachers who used PBL or a modified form of it for teaching science "positively influenced urban, African-American science achievement."

The study of Marx et al. (2004) on approximately 8000 middle school students in the Detroit public schools showed (1) statistically significant increases on test scores and (2) an increased effect for each of the three years that students were in the program. At the college level, Hake (2002) reported on the pre- and post-test gains for more than 6500 students in introductory physics classes, demonstrating the large positive effect of interactive engagement.

In smaller studies, Sendag & Odabasi (2009), in a study of online learning for future mathematics primary teachers, found that knowledge acquisition was not different for students in PBL experience, but that *critical thinking skills* were significantly improved. Similarly, Schneider et al. (2002) reported the performance of 10th and 11th grade students enrolled in Problem-Based Science was significantly better than matched groups on the National Assessment of Educational Progress science items, while Gallagher & Stepien (1996) reported that gifted students in a PBL class acquired as much content as students in a traditionally-taught class and acquired additional skills as well.

More recently, a small Singapore study of a seventh-grade mathematics class by Kapur (2010) concluded that the students who engaged the "productive failure" of working on a complex problem followed by a summary lecture by the teacher "significantly outperformed their counterparts" who had been taught by a traditional "lecture and practice" method. But the students did not like the class as much. A somewhat different result was found in another small study of sixth-grade students in Turkey by Demirel & Turan (2010) which showed that PBL students both learned more and liked the experience better.

Dods (1997) reported that lecture tended to widen the coverage as compared to a PBL class for gifted students in biochemistry, but "*understanding and retention [were] promoted by PBL* [emphasis added]." A similar result was reported in the meta-analysis of studies by Dochy et al. (2003), which concluded that "students in PBL gained slightly less knowledge, but remember[ed] more of the acquired knowledge."

What these research pieces show is that the goals of long-term learning are better achieved by PBL and that virtually all students can profit from this form of education. In particular, there is no need to restrict this superior form of learning to the academically elite. This is why CPM structures its lessons so that students are told as much as necessary for learning a topic, but based on the research cited above, assumes that most of the learning—the quality learning—will take place while they are working on problems.

How is Problem- Based Learning Best Implemented?

The research in the past seven years has done nothing to contradict the earlier support of the central concept of PBL, but in the intervening years the emphasis has changed to looking more carefully at what other components must be present for a successful problem-based class. Furtak et al. (2012) has done a comprehensive meta-analysis of various studies in science education, concluding that *social interaction* (some form of cooperative learning or with a tutor) is an important component of problem-based learning, a finding echoed by DeCaro & Rittle-Johnson (2012), which emphasized the role of teacher control of activities. (Note: "teacher control" in this context means that the teacher is responsible for ensuring that students are working well and on the mathematical topic—not that the teacher is telling the students what to do.) The same results were found in an extensive German study of 100 mathematics classrooms at the eighth grade level. Gruehn (2000) studied results from the 1997 TIMMS international comparison. In a very small, intense study, Yew & Schmidt (2012) found that for college freshmen, "collaborative learning is significant in the PBL process, and may be more important than individual study in determining students' achievement." For medical students, Schmidt et al. (2011) concluded that learning in a PBL classroom requires both the social interaction of teams and also individual learning.

So while PBL has been done with students working alone, it is clear that most students benefit by collaboration.

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