Synthesis of Research on Problem-based Learning

Summary

Traditional instruction with its emphasis on telling does not work well for long-term retention of knowledge for most children. Studies of students studying mathematics or science from first grade through college show that students ***retain more knowledge*** when they are taught using problem-based learning (PBL) than when they are simply told what to do. Problems engage the mental energies of students and allow them to develop cognitive understanding in a way that is more effective in the long term than simply being told a rule or procedure. Some research indicates that being told rules before attempting to forge a personal understanding can even interfere with deeper learning.

Teaching for understanding

Everyone seems to agree that mathematics students should understand what they do when they learn math. As Skemp (1986, especially Chapter 12) has pointed out, however, there are two very different views about what constitutes "understanding."

The first, which he terms "instrumental understanding," seems implicit in most mathematics textbooks—a student can carry out known procedures or solve standard problems according to a memorized method. An example would be how to subtract with borrowing which most students can memorize, but too few understand ***why*** it works.

The second, deeper, kind of understanding, Skemp terms "relational understanding," and refers to the ability of the individual to see the relations among the different parts of knowledge. This type of knowledge is more robust since the learner will have a sense of how things should work and be able to repair his or her own memory missteps with an understanding of the big picture. It is not the goal of relational understanding to create learners who respond automatically in narrow situations, but rather learners who see several different options for solving a problem and can make a reasoned choice among the alternatives. [We prefer the terms "procedural knowledge" and "conceptual knowledge" as used by Rittle-Johnson et. al. (2001) for the same ideas.]

The distinction is, of course, not precise. Different kinds of knowledge are important at different times. Some facts need to be acquired automatically so that the interesting work can proceed. No middle-school student should have to think to compute 5 + 9 or 17 x 10. At the same time, a student should understand that 3 x 4 = 4 x 3 with a better reason than "that is what the rule says[1] ." Advanced students may also want to know that a formula exists for tan(2x).

What is most important, however, is that the learning persists beyond the end of the chapter and beyond the end of the year. ***If the learning does not persist so that it can be used in the future and cannot be utilized outside of a homework set, in what sense have students learned anything?*** The problem for most students with memorizing and then practicing procedures is that this kind learning does not persist. It must be integrated with conceptual knowledge for permanence.

1 A formally taught student might cite the Commutative Law. Terminology aside, they still should know why.

CPM is emphatically on the side of long-term learning which of necessity implies both kinds of understanding/ knowledge. The question is—what are the most effective ways to help students achieve real understanding?

Focus on Students

The answer is both simple and true across all disciplines: a successful program must focus its energies on ***what students learn*** rather than measuring what teachers teach or what topics appear in the textbook or how many standards are met on paper. No matter what else happens—if the students do not learn, the teaching is not successful.

So how do we get students to learn and understand? Gardner (1983, 2000) has documented different learning styles for students. Similarly, different goals need different methods and no one method is superior for all children and all topics and all cases. Every successful program needs a mix of the methods. No one can be asked to discover what the definition of a trapezoid is 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 barely help. At different times, students need different opportunities and different topics require different methods and different time frames.

Unfortunately, there is a strong belief on the part of many educators that students only need to be told what to do and, if they are told properly, they will learn the fact/skill/concept. It certainly *seems* efficient at conveying knowledge. The trouble with this belief is that ***it is not true*** except at a very young age or for students for whom the goal is merely procedural knowledge.

The problem with telling

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. 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).

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."

Problem-Based Learning

At the same time that studies have demonstrated the failure of direct instruction for average students, other studies have shown the advantages of problem-based learning (PBL). Most of these studies have been done with gifted students in K-12 or with engineering or medical students. 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 has been that only a small minority of students can benefit from such an approach.

In the past decade, however, studies have found that well-designed PBL courses can benefit most, if not all, students. Songer, Lee & Kam (2002) report on a study of 19 urban sixth-grade classes showing students in all classrooms made significant content and inquiry gains. Kahle, Meece & Scantlebury's (2000) report on eight middle schools in Ohio 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) that the effect increased for each of the three years that students were in the program. At the college level, Hake (2002) reports on the pre/post-test gains for more than 6500 students in introductory physics classes demonstrating the large positive effect of interactive engagement.

In smaller studies, Schneider et. al (2002) report 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. This last result was sharpened in two further studies. Dods (1997) reports 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 by in the meta-analysis of studies by Dochy et.al. (2003) who 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 maximized by problem-based learning and that virtually all students can profit from this form of education. In particular, we need not restrict this superior form of learning to the academically elite. Thus CPM structures its lessons so that students are told as much as necessary for learning a topic, but assumes based on the research cited above that most of the learning—the quality learning—will take place while working on problems.

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