Synthesis of Research on Spaced Practice

Summary

The "spacing effect" is an overwhelmingly well-documented phenomenon that shows that learning is improved when the learning time is interrupted, or spaced, rather than being continuous, or *massed*. The effect has been observed in babies, in children and adults in numerous studies. The effect has been observed in learning mathematics, statistics, physics, languages, and such widely diverse skills as aircraft recognition and kayak rolls. Roughly speaking, as long as there is some latent memory of earlier learning of a skill, delaying the reinforcement by spacing improves both transfer and long-term learning.

There appear to be two principal reasons why this knowledge is not more widely applied in the classroom. First, little of the research has been done by educators. Most of the work has been done in psychology laboratories or for workplace training. Second—and this reason is probably more important for its lack of use—using spaced practice for learning rather than massed slows ***down the initial learning at the same time that it improves long-term retention and transfer***. Thus teachers often feel that when students struggle to learn a new skill it is a bad thing because knowledge is mastered more slowly. However, the research is overwhelmingly positive that certain kinds of carefully designed struggle are beneficial.

Spacing thus has three positive effects for learning mathematics:

- it helps students learn better
- • it helps students remember longer
- • it helps students transfer their knowledge more effectively

Introduction

In what follows, we will be using the term "skills" to include such different notions as acquisition of concepts, algorithms and rules. It should be clear that the acquisition of a concept with all of the transfer implications included is very different than the learning of a rule with the ability to apply it appropriately in a narrow realm. However, most of the literature either ignores concept acquisition entirely or subsumes it under rule acquisition so we will rarely make the distinction.

In the past 70 years, dozens of researchers from psychology, workplace training and education have validated the "spacing effect," that is, the observation that learning improves when the learning time is interrupted, or spaced, rather than being continuous, or massed. Researchers who study workplace training refer to "distributed practice" or "spaced practice" (as opposed to "massed practice") for the cause of the spacing effect as they seek methods of improving the effectiveness of training programs or workers. See Schmidt (1992) and Salas (2001) for good review articles about studies on distributed practice.

Psychologists have verified the phenomenon in babies as young as three months of age in one study (Roveecollier, 1995) and in numerous studies for school-age children up to adults and in areas as diverse as rolling kayaks (Smith, 1995), aircraft recognition (Goettl, 1996) and learning languages (Bahrick, 1987, 1993). Because the spacing effect appears in so many contexts, it appears as Raaijmakers (2003, p. 432) comments, "that basic principles of learning and retention are involved." No wonder, then, that Dempsey (1998) laments the minimal impact that this research has had on educational practice.

Discussion of literature on distributed practice

The major problem from our standpoint with the literature on the effectiveness of distributed practice is that few of the studies have been done in educational fields, and fewer still in classrooms. Far more of this research has been done in looking at effective ways to provide workplace training. The constraints of workplace training are, of course, very different from those of the classroom since most such training is done over a short time interval (a few days at most) and most of it is limited to training a single skill or a small complex of closely-related skills. In addition, a large fraction of the research papers done by psychologists deal with the acquisition of motor skills such as balancing on a beam or shooting free throws which calls their relevance into question. With these limitations in mind, Salas and Cannon-Bowers (2001) did a comprehensive review article of 79 papers and concluded that distributing practice provides an advantage in learning and retention in a wide set of knowledge, skills and attitudes.

The only article that deals directly with mathematics learning (Mayfield, 2002) has some serious limitations for our purposes. First, it deals with college-age students who are learning algebra, so they are likely to be students who failed to learn algebra in high school. Second, the authors' philosophy of learning is basically to drill to automaticity on a narrow rule (three sessions of 50 similar problems each) before investigating what kind of review works best. They conclude that cumulative practice, that is, having students practice solving a mixture of previously-learned different types of problems in the review periods, is better than simply additional blocks of practice.

Other classroom studies about the effects of distributed practice include those of Grote (1995) who studied the effects of distributed practice on high-school physics students, Smith (1995) who studied college statistics students and Bahrick (1987, 1993) who studied distributed practice in learning languages. Regardless of the direct relevance to K-12 mathematics learners, each of these studies concludes the same thing: ***distributed classroom practice improves learning*** and Grote specifically found that it improves transfer.

The question thus is not "Can the learning of mathematics be improved by making use of distributed practice?" but rather: "What are the most effective ways to distribute the practice in order to improve learning mathematics?"

The research article that seems to have the most to say about this question for typical 7-12 students in typical classrooms deals with something completely different: college students learning the game of Go, the classical Japanese board strategy game (Schilling, 2003). It is a beautifully designed study that gave 90 students, working in groups of three, ten hours in five-hour blocks over two consecutive days to learn the game of Go.

This research reports that these groups of students learn to play Go best when they are also required to learn a related game, Reversi. The authors see Reversi as related to Go because both games involve placing pieces and controlling territory. In particular, what the study showed is that students who spent all of their sessions learning Go were less well able to play the game than students who spent about half of their time playing Reversi. The need for a related game was evidenced by the fact that students who had enforced interspersed time playing the game Cribbage played at about the same level as students who only played Go.

Retention and transfer of knowledge

Schmidt & Bjork (1992) point out that "the goal of training in a real-world setting is, or should be, to support … (a) the level of performance in the long term and (b) the capability to transfer that training to related tasks and altered contexts." Fisher (1996) and his colleagues summarize their position as:

> *"Schmidt & Bjork (1992) have argued that in many circumstances it is a mistake to focus solely on the speed with which a given method of training leads to the desired level of proficiency. In particular, they argue that in some cases the method which speeds learning in the short term may actually hinder learning in the long term. …Shea & Morgan (1979) found that subjects were much faster throughout training [on motor tasks] in blocked practice. Yet, when subjects were returned for retention testing 10 days after the end of training, subjects trained using random practice performed much better in random testing than did subjects trained using blocked practice. Furthermore,* **subjects trained using random practice performed significantly better** *in blocked testing than did subjects trained using blocked practice." [emphasis added]*

Since long-term retention of mathematical knowledge and the capability to transfer learning to related tasks are goals of CPM, it is clear that spaced practice is extremely desirable. At the same time, it is here that the problem occurs: spacing practice improves ***long-term learning and transfer while it decreases immediate acquisition***.

This trade-off was found not only for motor skills (Shea, 1979), but for many other learning situations as well. Pashler (2003) and his colleagues found that for learning vocabulary the spacing effect increased the number of errors during the learning phase, but improved later retention. Similarly, in a 9-year longitudinal study about retaining foreign vocabulary words, Bahrick (1993) and his colleagues found that 13 retraining sessions spaced at eight-week intervals was about as effective as 26 retraining sessions spaced at two-week intervals.

In their abstract, they state, "The longer intersession intervals slowed down acquisition slightly, but this disadvantage during training was offset by ***substantially higher retention***." Smith (1984) showed that spreading out a single 8-hour statistics class over four days was significantly more effective than presenting the material in one day.

Transfer of Learning

In their summary of the literature on transfer of learning of cognitive tasks, Gick and Holyoak (1987) concluded that some conditions that enhance and facilitate performance during the training period have a negative effect on retention or related tasks. Following up on this research, Schroth (1997) found that two different methods of delaying immediate learning improved long-term retention. Hesketh (1997) dealt specifically with transfer with college undergraduates and concluded that "methods of training that maximize immediate outcomes may do so at the cost of the longer-term benefits of developing transferable skills."

A related effect was described by Chen & Mo (2004) who found that "Exposure to less variant problems led to faster initial learning, but narrower and fixed schemas (mental set), whereas exposure to variant procedures led to slower initial learning, but broader and more flexible schemas." (Flexible schemas allow students to tackle kinds of problems they have not seen before.)

Implications for textbook design in mathematics

The sources cited above make it clear that for students in regular classrooms long-term learning and the ability to transfer this learning is facilitated by distributed practice and by using different kinds of problems built around the same theme. Massed practice provides the illusion of immediate learning but fails to maintain its effectiveness even after a reasonably brief time. Finding the balance requires extensive classroom testing, and one should probably err on the tradition side of caution, but it is now obvious that the literature raises serious questions about whether the design of traditional textbooks handicaps most students who attempt to learn from them.

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