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The Role Of Practice In Mathematics Learning

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Abstract

Practice is clearly essential for acquiring cognitive skills of almost any kind. Yet despite this laudable claim 'practice' is a contentious issue, especially in mathematics where some educators associate practice negatively with drill routines. While practice which focuses on rote memorisation without any modicum of understanding is universally decried there is still much debate as to the nature and balance of effective practice in the mathematics classroom. Increased awareness of the purpose and probable learning outcomes of practice activities would be advantageous. In light of recent research that suggests that the distinction between memorising and understanding may not be clear-cut, at least in some countries, this paper examines the nature and relationship of practice to memory and understanding.

Introduction

Anderson, Reder and Simon (1996) assert that practice is clearly essential for acquiring cognitive skills of almost any kind. Yet despite this laudable claim 'practice' is a contentious issue. The following comments by Anderson, Reder and Simon extracted from a recent article in the Investors Business Daily *Does Good Practice Make Perfect?* (Robinson, 1998) illustrates this point:

> *"Nothing flies more in the face of the last 20 years of research than the assertion that practice is bad...All evidence...indicates that real competence only comes with extensive practice. By denying the critical role of practice, one is denying children the very thing they need to achieve competence...The instruction problem is not to kill motivation by demanding drill, but to find tasks that provide practice—while at the same time sustaining interest." Kids, they argue, can learn better through 'deliberate practice'—through hard work and constant feedback to master*

> *knowledge and tasks..."Nobody expects someone to be great without a great deal of practice and time in sports or music but it still seems that in the area of education, there is the notion that all we have to do is give a child a critical insight or inspiration and everything else will fall into place...Intellectual competence has to build up with the same kind of deliberate practice as musical talent of athletic ability."*

In the same article Bornstein, a memory training expert in Los Angeles, laments the current situation in American education:

> *"Learning requires reinforcement—practice and memorization—to master a subject. It's the missing link in American education. Schools tell kids what to learn, but not how to do it...too many schools now assume kids will just pick up things as they go along."*

Practice And Computational Skills

Practice was traditionally favoured as a method of learning computational skills. One view of arithmetic learning that arose early in this century was the 'drill theory'; a product of associative theories of learning. According to Baroody (1985) this theory assumed that:

- children must learn to imitate the skills and knowledge of adults,
- what is learned are associations or bonds between otherwise unrelated stimuli,
- understanding is not necessary for the formation of such bonds, and
- the most efficient way to accomplish bond formation is drill.

Today the acquisition of a sound knowledge and understanding of basic number facts and fluency with basic operations are regarded as central to all major mathematics curriculum statements. Efficient problem solving and the development of new and more complex procedures are, in part, contingent on automatic retrieval of sub-skills from long-term memory:

> *Mathematics, involves multiple levels of processing—the identification of the numerical symbols, the recall or computation of specific sums and differences, and the interpretation of those computations in terms of mathematical principles such as additive*

> *composition, the idea that numbers can be broken down into parts and recombined without changing the quantity.* (Sophian, 1996, p. 30).

However, the view that merely engaging in a sufficient amount of practice, regardless of the structure of that practice, leads to maximal performance has a long and contested history. In the 1970s the role of practice, according to Taylor (1976), was in a state of flux. In the text *Foundations of Maths in the Infant School*, Taylor writes:

> *Times have changed since the bad old days, and sometimes the pendulum has swung so far to the opposite extreme that practice in any overt form has been roundly condemned as arid, unproductive and alien to the philosophy of modern educational methods. Most teachers have pitched their tents somewhere in between these opposing frontiers, but many experience a degree of uncertainty as to how far away they should move from the anti-practice or pro-practice territory.* (p. 160).

Nowadays, learning computational skills and developing conceptual understanding are frequently seen as competing objectives (Hiebert et al., 1997; Pressley & Woloshyn, 1995) and the role of practice in the classroom is less clear.

It may help to resolve this dilemma if we first establish what we mean when we use the word 'practice'. Do we mean only that kind of repetitive activity which has the goal of repeating mathematical processes sufficiently often to memorise them or provide written evidence of accuracy? Or do we include in our definition practice of an experiential nature that provides varied experiences directed towards the development and maintenance of understanding?

Repetitive Practice

While it is doubtful whether anyone would deny the value of experiential or meaningful practice, it is the other kind of practice, often referred to as drill, that is so often called into question. Drill is commonly associated with repetitive practice of a single concept or example type in order to facilitate efficient, accurate or speedy processing. In particular, practice with timed tests, or controlled response times, are often used to develop automaticity of basic number facts considered crucial to more complex problem solving (Wilson & Robinson, 1997). Hasselbring et al. (1988, cited in Carnine, 1989) suggest that basic-fact retrieval times should begin with a time of about 3 seconds and work down to a time of around 1.25 seconds. Likewise, Hatfield et al. (1997) define 'mastery' as the automatic recall of a basic fact combination within a 3-second time period.

Drill routines, very much in vogue in the 1970s, were commonly incorporated in Computer-Assisted Instruction. One highly developed programme was the Stanford CAI programme (reviewed by Resnick & Ford, 1981). The programme contained practice in addition, subtraction, fractions, multiplication, long division, percent and ratio at various levels of difficulty appropriate to individual children. Precisely tailored drills minimised the problem of 'stamping' incorrect bonds by forestalling errors as much as possible. Bonds that were more difficult—as determined by error data for daily performance—received the additional practice they required. The results showed that well-planned drill and practice may increase accuracy in computations. However, children who started out with better accuracy scores improved about as much as did children who started out lower in accuracy—the programme did not have the hoped-for effect of helping the initially less competent children 'catch up'. Furthermore, some concepts were very hard to improve suggesting that drill will not improve all aspects of computational performance.

Those arguing against extensive use of strict drill routines warn that often the result is to habituate children to an unthinking, inflexible mode of response. If children are *only* given retrieval type practice they learn to retrieve answers to specific problems, but because they receive little practice in using the associated procedure they do not readily cope with transfer problems (Cooper & Sweller, 1987). In early number instruction Rathmell (1978) argued that "drill alone will not change the thinking that a child uses; it will only tend to speed up the thinking that is already being used" (p. 17). He argued that the tendency of children to perseverate on counting would preclude the development of automatic responses unless there was intervening instruction in thinking strategies that promoted the transition from counting to retrieval. Several research studies reviewed by Christensen (1991) also found that some children when given drill and practice in basic facts became so proficient at counting that they could, or would, not adopt any other strategies to solve addition questions.

Additionally, tasks that are performed automatically tend to be less under the control of the performer. If we overlearn a skill, we essentially lose sight of the individual components and may then find it hard to make small adjustments (Langer, 1997). This concern is particularly significant when considering the sequencing of practice. According to English and Halford (1995), if students are

asked to practice facts or procedures for which they have little conceptual foundation they are in danger of :

> *losing their grip on any mental models they might have developed in the early years; they have little option but to turn to memorized rules and procedures. It is little wonder that they seldom consider whether their answers are sensible. Because they fail to recognize correspondences between problems, they will not realize that they have produced two different answers for variations of the same problem.* (p.146).

Thus, practice activities which are directed towards an increase in speed and precision must occur late in the instructional sequence in order to avoid the danger of "cramming ready knowledge too early", thus risking that "children will get stuck at an inefficient level of knowledge" (Heege, 1985. p. 377) — students should *know* the information before commencing this form of practice.

Practice: A Cultural Perspective

Criticism against drill and practice is probably more fairly levelled at 'rote learning', the mechanical memorisation of facts or procedures without attention to meaning. It is commonly accepted that learning mathematics in a rote, unthinking manner, almost always ensures mediocrity. At the very least, it deprives learners of maximising their own potential for more effective performance by its failure to capitalise on the efficiencies of mathematics, such as commutativity. Instruction that emphasises only rote drill of written procedures provides students little chance to construct relations between these procedures and other things they might know (Hiebert & Wearne, 1996). Moreover, continual practice of this sort leads to both the loss of intuitions about mathematics and enjoyment of the activity (Booker, 1998; Foster, 1993).

From a Western perspective rote learning often typifies Asian students' approach to learning, especially at the senior student level (Biggs, 1994). Rote learning is usually closely allied with a surface approach to learning (Biggs, 1993) in which the material is learned in a 'verbatim' manner with the expressed aim of achieving goals extrinsic to the meaning of the material itself. This begs the question: Why do Chinese students, who spend a good deal of time in activities that appear to be aimed at pure memorisation, do so well mathematics in comparison with their Western contemporaries (Stigler & Hiebert, 1997)?

Recent research has suggested that the distinction between memory and understanding may not be clear-cut—at least in some countries (Entwistle, 1998). With rote learning, meaning has no place in the learner's intentions; whereas repetitive learning to ensure accurate recall of already understood information, could rightfully be regarded as part of a deep or an achieving approach: a student who uses repetition to optimise knowledge retrieval may well be making a wise strategic choice. Marton and Booth's (1997) phenomenographic analysis of the conceptions of learning held by students of different countries clearly illustrate such an emphasis on understanding which Asian students describe as 'memorising':

> *In the process of memorising, the text being memorised is repeated several times which may be outwardly suggestive of rote learning. However,...(teachers) explained that, when a text is being memorised, it can be repeated in a way which deepens the understanding...(This) process of repetition contributes to understanding, which is different from the mechanical memorisation which characterises rote learning.* (p. 35).

This distinction between rote learning and meaningful repetition intended to reinforce and extend understanding also contrasts committing to memory what the teacher has presented with understanding for oneself, where the initiative comes from the student (Entwistle, 1998).

Purdie and Hattie (1996) have also looked more closely at the types of rehearsal strategies commonly used by students across cultures. They found that secondary students from Australia and Japan distinguished between two methods for memorising instructional material. The first method involved the use of repetition, either in the form of recitation or in the form of repeated writing. The second method was a more sophisticated form of rehearsal involving an intention to understand as well as committing to memory. Overall, the Japanese students reported a significantly higher preponderance to memorisation. Although the study did not assess the kinds of mental operations that accompanied students' reported use of strategies Purdie and Hattie noted that many of the Japanese students indicated that they used memorisation as a deliberate strategy to increase understanding: "I repeat the information over and over so that I can understand it" (p. 862). Furthermore, the Japanese students maintained the importance of memorisation as a learning behaviour even after experiencing the Australian classroom learning context in which memorisation was not encouraged as a learning strategy. Overall, Australian students reported less use of memorisation than Japanese students; however, high achieving Australian students were more likely than low-achieving students to use memorisation. They were also greater users of the related strategy of doing practice exercises.

Chi (1998) examined Taiwanese secondary school students' perceptions of the New Zealand mathematics teaching compared to their earlier experiences of secondary school mathematics in Taiwan. In Taiwan the students felt that they focused a lot more on the use of drill and practice; in New Zealand, while teachers were more likely to emphasis understanding, they felt that there were fewer opportunities to practice. Students reported that they did more memory work in Taiwan: nine of the 15 interviewees believed that the emphasis on practice supported their mathematics learning, including computational procedures and problem solving, and two specifically discussed benefits to understanding.

Biggs (1994) elaborates several reasons why the use of this strategic rehearsal learning style appears to be more common in Confucian-heritage cultures.

> *One reason has to do with the nature of common learning tasks; for example, learning the thousands of characters in common use obviously requires a good deal of repetitive learning, rather more than learning an alphabet system. However, this is not intended as mindless rote learning. Characters are traditionally learned by the Two Principles. The First Principle involves much intertwined activity using the Five Organs: the eyes to see the shape, the ears to hear the sound, the hand to write the shape, the mouth to speak the sound, the mind to think about the meaning. The Second Principle is to contextualise; each character as it is learned is formed with another into a word, and each word is formed into a sentence. Repetitive certainly, rigid maybe, but embedded in meaning always ...with much use of learner activity in widely different modes. ...*
>
> *The limited number of characters means that new meanings are created according to which characters are juxtaposed with each other. Text thus becomes multi-layered, with shifts and shades of meaning being revealed on repeated readings. Repetition thus has an important role at the text level, as well as at the work and sentence levels. However, this does not mean that memorisation is actually a means of acquiring understanding, but simply that mastering certain complex tasks requires much repetitive preliminary work...understanding grows with repetition.* (p. 27)

Thus, the source of the Asian learner paradox can be explained as a failure of Western educationists to recognise important cultural differences in the ways students learn 'Confucian heritage cultures' (Biggs, 1994). It is apparent that the Asian conception of learning assumes that memorisation and a deep approach are not mutually exclusive (Sadler-Smith & Tsang, 1998). The Asian learner who is taking a deep approach to learning is indeed making an effort to memorise, and is at the same time intending to gain understanding. Learning through repetition may not simply result in more learning or simple rote learning; it may well result in a different kind of learning.

Purdie and Hattie (1996) conclude that the strong emphasis on memorisation strategies by the Japanese students in their study highlights the need for educators to re-evaluate the place of memorisation and related practices in student learning. "By labelling such behaviours as rote learning and dismissing them as inferior tools in the process of learning, teachers may well be doing their students a disservice" (p. 865). Sadler-Smith and Tsang (1998) also propose that further research is needed to clarify the extent to which the two approaches (memorisation-with-understanding and mechanical memorisation) conflict with or complement each other.

When we apply the concept of memorisation-with-understanding to mathematics education it would appear that if practice is to lead to a strengthening of relationships constructed by individuals then *thinking* must accompany repetition. In this way the double payoff of constructing a knowledge base and remembering a math fact can be realised.

Practice And The Use Of Thinking Strategies

Influenced by constructivist theories, recent research in early number has seen a change of emphasis from children's performance to their thinking and understanding (Mulligan & Mitchelmore, 1996). Research investigating children's strategies for developing number knowledge suggest that instructional activities which emphasise efficient strategies for deriving unknown facts should have a prominent place in early school mathematics and claim that teaching children 'thinking strategies' is more effective than drill, in facilitating learning, retention, and transfer of basic facts (e.g., Carpenter et al., 1997; English & Halford, 1995; Mulligan & Mitchelmore, 1996; Steinberg, 1985; Thornton, 1978).

However, the following response to the National Council of Teachers of Mathematics *Standards* document by the American Mathematics Society Resource Group (1998) argues for a more moderate view:

> *We find plausible the idea that devising personal ways to deal with arithmetic problems can promote number sense. On the other hand, we suspect it is impractical to ask all children personally to devise an accurate, efficient, and general method for dealing with addition of any numbers—even more so with other operations. Therefore, we hope that experimental periods during which private algorithms may be developed would be brought to closure with the presentation of and practice with standard algorithms...We believe that neither pure rote mastery of algorithms nor purely privately invented algorithms can optimise learning of arithmetic. Finding a good balance between the two is a delicate business and a matter for much practice and study.* (p. 274).

In a study by Christensen (1991) a comparison was made between the effectiveness of instruction in cognitive strategies and systematic drill and practice in facilitating the transition between counting and retrieval of single-digit addition facts, and the subsequent development of proficiency in single-digit addition. Two classes of children were compared: one group received training in strategy development and other received drill and practice on addition facts using a variety of techniques which were expected to enhance students' competence in addition but did not involve any instruction in the use of thinking strategies. The results indicated that the practice group performed as well as, or better than the strategy group.

Christensen (1991) offered the following explanation for this challenge to the contention that strategy instruction is necessary and that practice is insufficient for efficient retrieval of basic facts:

> *It appears that for many children in the study the thinking strategies which were taught did not fit comfortably into their existing cognitive organisation. Therefore, the strategies were ignored. This contrasts with the practice group, where children spontaneously developed and used the strategies, although they were not explicitly taught. This suggests the hypothesis that practice facilitates cognitive change, so that strategies become and integral part of the student's mathematical knowledge rather than an irrelevant appendage to the understandings.* (p. 66).

Furthermore, she noted that those children who invented their own strategies as a consequence of practice used these strategies more effectively than those who acquired strategies through instruction and were less likely to use inappropriate strategies. It appears that the strategies developed through practice (e.g., make up as many question involving the addend, oral drill with flashcards, bingo, worksheets, games and independent exploration of number facts), may have resulted in enhanced metacognition and consequently led to a more effective use of strategies. Accordingly, she suggests that the call to engage in extensive instruction of thinking strategies, to the detriment of 'practice' needs to be approached with caution. "It appears that the processes involved in children's construction of knowledge are quite complex and are influenced by classroom practices in ways quite unintended by the teacher" (p. 67).

Christensen's (1991) findings support educators with a constructivist orientation who contend that strategic knowledge in particular, is applied more generally if discovered or constructed by learners, rather than being explicitly taught to them (Kamii & Dominick, 1988; Muthukrishna & Borkowski, 1995). Carpenter et al.'s (1999) Cognitively Guided Instruction research programme provides compelling support that young children can invent strategies to solve a variety of computation problems by modelling the action or relations described in the problems. Proponents of teaching situations which focus on providing opportunities to reconstruct notions of number argue that children must first have opportunities to build their own mental structures for organising the facts and developing thinking strategies in order to provide support for the memorisation of basic skills. The value of developing such understandings is that it obviates wasteful practice, makes the acquisition process more efficient, and makes the knowledge acquired more durable and adaptable (Carpenter et al., 1997).

However, with regard to mastery of basic facts English and Halford (1995), while clear on the benefits of understanding, point out that it is equally clear the mastery requires practice:

> *There is no cognitive "magic" that produces appropriate performance automatically. Good mental models can make learning both more enjoyable and more efficient, greatly reduce learning effort, facilitate seeing relations between concepts, and promote abstract reason, but our performance also has an associative component, which brings efficiency through practice.* (p. 80).

A Balancing Act

In a recent New Zealand study, Anthony and Knight (1999) worked with a group of six middle-school teachers who critiqued within their own classrooms a range of activities focusing on basic skills. While all the teachers in the project were well aware of the need to develop some understanding of basic number computation before implementing practice designed to achieve automatic recall of basic facts, they were initially divided as to the relative importance of memory and understanding in the learning and retention process. For some, there was a reluctance to spend much time on memory work because of the negative connotations associated with 'rote learning'; for others, there was a tendency to first teach understanding and then, assuming that the children now 'understood', to focus on the consolidation of facts and procedures.

Within the study the teachers assessed the purpose and learning outcomes of activities associated with basic facts in terms of memory and understanding. The critical evaluation of each activity increased the realisation that understanding is an ongoing process, deepening as conceptions expand and the number and solidity of connections among them develop. As such, practice activities need to be planned which continually encourage children to reassess their understanding and provide opportunities to revisit even the most fundamental of mathematics concepts. The teachers in the study found the Think Board (Figure 1) (Gervasoni, 1999; Herrington, Wong, & Kershaw, 1994) particularly effective—both in assisting children to make connections in basic facts concepts and providing a 'window' into children's developing understanding of number.

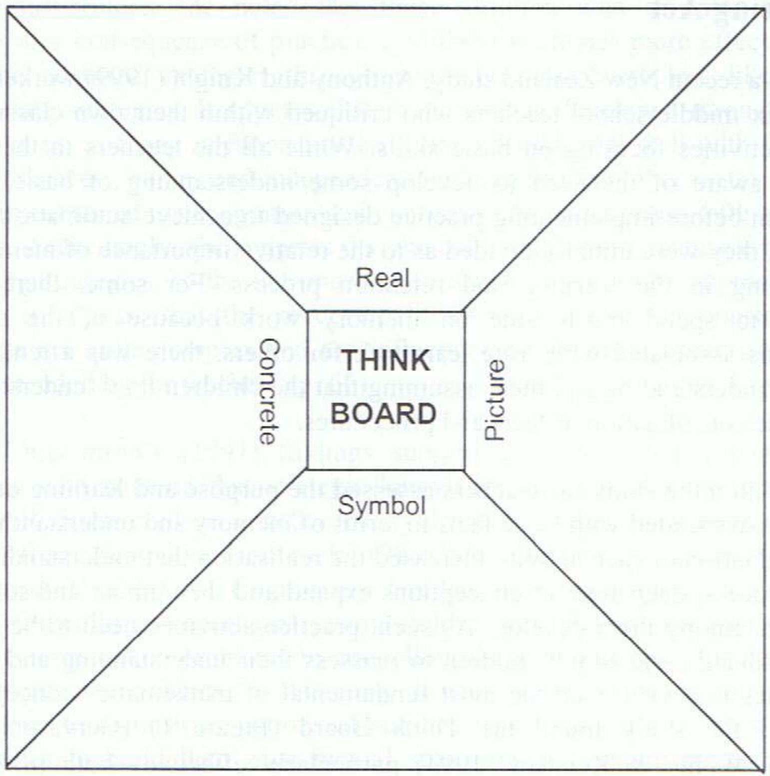

Figure 1: Think Board

Additionally, as students and teachers became clearer as to the specific purpose to the trial activities they increased their awareness of more effective learning strategies. Learning strategies associated with activities which focused on the development of automaticity of basic facts included concentration on specific difficult facts, use of visual/tactile aids, self assessment of progress and review of previously memorised facts. Homework activities which included additional information about the process of learning and the purpose of the activity were found to be especially effective. Children responded well to the challenge to learn their tables and teachers reported improved student attitudes, increased students confidence, and increased risk-taking in problem solving situations as a result of students' improved basic fact knowledge.

Within the scope of basic fact learning we suggest that initially children need to develop an understanding of the meaning of the operation under consideration and its relationship to previously introduced operations. However, this is not something which can be done once and then be assumed to be there. We cannot assume that a student who can distinguish between an addition word problem and a multiplication one this week will be able to do so next week, any more than we can assume that the same student will be able to remember what 8×7 is over the same period. It is more appropriate to think of children's understanding as emerging rather presuming that the child either does or does not understand a given topic or area (Carpenter & Lehrer, 1999).

To assist with problem solving and the development of new procedures and concepts students need to be able to recall their current understanding of the multiplication operation just as much as they need recall of the multiplication facts.

> *The idea of 'understanding' seems to refer partly to knowledge which has been confidently stored, and partly to a memory of how that knowledge has been successfully organised in the past...But it is the combination of knowledge and well established thinking pathways which allows explanations to be constructed to suit a specific question, a particular audience, and a perceived context.* (Entwistle, 1998, p. 97).

As such, practice is important to assist both the development of understanding and the recall of related knowledge.

Within the context of curriculum reforms that increasingly promote teaching and learning mathematics with understanding we need to be more aware of the role and purpose of practice activities. In classrooms where learning is viewed a problem solving, where tasks are treated as problems to be solved rather than exercises to be completed using pre-specified procedures, practice should be viewed as a critical component of the development and maintenance of procedural knowledge and the understanding of mathematics.

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