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A REVIEW OF THE LITERATURE IN ADULT NUMERACY: RESEARCH AND CONCEPTUAL ISSUES

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1. INTRODUCTION

The increasing need for numeracy skills in all aspects of adult life—family, employment, community—has made numeracy a requisite skill for success in today's society. In the context of Adult Basic Education (ABE), more emphasis is needed on providing quality numeracy instruction to adults to help them achieve the mathematical knowledge and skills that will enable them to adjust to this growing societal demand. The Office of Vocational and Adult Education (OVAE) recognized the need for learners to improve their numeracy skills when it identified mathematics as a core academic area for the development of rigorous content standards. As adult learners are encouraged to move beyond the General Educational Development (GED) and into postsecondary education, the development of numeracy skills will become more critical. However, as educational assessments have shown, 35 percent of all U.S. students are scoring "below basic" on the National Assessment of Educational Progress (NAEP) (NCES, 2002, Math Assessment), with even higher proportions of Hispanic, African American, and low-income students scoring "below basic."

This problem is of significant concern to adult educators because an increasing number of 18- to 25-year-olds are enrolling in adult education programs: the very same students who lack numeracy skills. The concern about the numerous skill deficiencies in today's adult learners is exacerbated by the fact that adult education programs are not adequately prepared to provide numeracy education to a diverse student population that bring different needs, interests, skills, and behavior and attitudes toward numeracy.

Although numeracy instruction plays a significant role in adult education in many countries—notably Australia, the Netherlands, and, more recently, the United Kingdom—the United States has experienced limited attention to numeracy instruction and little research on how local adult education programs teach mathematics or numeracy. There are many reasons for this lack of focus: little agreement on what constitutes numeracy; poor professional development in numeracy; limited understanding of how adults with diverse characteristics, needs, and backgrounds obtain numeracy skills; and the lack of alignment among content standards, curricula and instruction, and assessments. Schmitt (2002) points out that GED preparation has been the driving force in mathematics instruction in most adult education programs. Workbooks focusing on standard computational rules, fractions, whole numbers, decimals, percentages, and prealgebra drive instruction. Exercises tend to emphasize repetitive problems, word problems, and problems with real-life applications.

The Adult Numeracy Initiative is the first major effort of the U.S. Department of Education to improve the research and practice of adult numeracy. This project has several goals:

- Develop a thorough understanding of the current state of the field of adult numeracy.
- Identify the gaps in knowledge about common strategies for teaching adult numeracy and how these strategies differ across different types of learners.
- Identify the type of professional development and teacher certification that should be required for teachers of adult mathematics.

- Identify the type of assessment instruments that might be appropriate for measuring adult quantitative skill acquisition.

The project will achieve these goals through two phases of activity. The first phase, consisting of a literature review, an environmental scan, a technical working group convened to identify critical issues, and commissioned papers to address some of these issues, will distill the limited body of knowledge about current research and practice on adult numeracy instruction, assessment, and professional development. The information from this first phase will inform the second part of the project, which entails the design of curriculum and professional development materials and activities and the design of a research-based intervention or demonstration program that can be tested with a rigorous methodology.

These activities of the Adult Numeracy Initiative seek to answer the following research questions posed by OVAE for the project:

1. How does adult numeracy develop and how does it differ from the development of quantitative literacy in children?

2. What are the social variables that affect quantitative skill acquisition in adults? How should programs address these social variables to enhance skill acquisition?

3. What instructional practices exist in mathematics education for adult learners that are worthy of replication?

4. What outcomes are most important to address in the evaluation of adult education programs in mathematics? What are the best tools or assessments for evaluating these outcomes?

5. What practices exist in professional development and certification requirements for teachers of adult mathematics education that are worthy of replication?

6. What types of programs have been implemented at the state and local levels through federal funding that incorporate or focus on adult mathematics instruction?

7. What types of programs have been implemented at the state and local levels through federal funding that focus on adult mathematics instruction related to adult English language acquisition learners?

This review addresses the first five research questions by summarizing key findings from the literature. The report that will incorporate the findings from the environmental scan will address the final two research questions concerning mathematics instructional programs.

ORGANIZATION OF THE REVIEW

This literature review is the first report of the Adult Numeracy Initiative and lays the foundation for the other substantive activities in the project's first phase. It strives to answer the first five research questions posed by the Statement of Work. The review summarizes the definitions, theories, and research around adult numeracy to organize what is known and to point the way for future research and development. We have organized the literature review into five parts:

- **Issues in Conceptualizing Adult Numeracy** addresses the first and second research questions and presents an overview of the competing approaches to defining adult numeracy. The section then reviews the main theoretical approaches toward teaching and learning mathematics for adults that reflect these definitions. The concepts and theories in this section provide a background and context for the research in instruction and assessment presented in subsequent sections.
- **Adult Numeracy and Mathematics Instructional Approaches and Interventions** reviews the small number of studies done on ABE students, supplemented with an also small number of studies on adults in community college developmental education programs, on the effects of different types of instructional approaches on mathematics learning among adults. In response to the third research question, this section presents the instructional approaches, findings, and methodologies of these studies.
- **Assessment Issues in Adult Numeracy** endeavors to respond to the fourth research question as it summarizes the existing knowledge base regarding assessment in adult numeracy, reviews the uses of assessment, analyzes the nature of assessment and how it can be improved, and summarizes the principles for designing effective assessments for adult numeracy.
- **Professional Development in Adult Numeracy** deals with the fifth research question and discusses the state of professional development in ABE around numeracy. The section notes the low-level background of ABE teachers to teach mathematics, presents professional development approaches, and briefly discusses research on the characteristics of effective professional development.
- **Summary and Implications for Future Research** summarizes the findings of the review and suggests future research and how the field of adult numeracy practice and research might progress. It also briefly suggests how research on children's learning of mathematics may inform research on adults, thus also addressing the first research question.

Writing a literature review is one of the researcher's more difficult tasks. Unless it is to be a life's work, lines must be drawn around the topic to identify what is important, what is to be included, and how it is to be analyzed. This task is even more difficult in the field of adult numeracy, which Diana Coben has aptly called a "moorland," where the lines, where they exist at all, are often indistinct and vaguely drawn. The Adult Numeracy Initiative's research questions identified the general topics we were to cover. Within these topics, two goals guided our approach: (1) to identify the areas of greatest interest to furthering research and practice of adult numeracy instruction and professional development within the U.S. adult education system and (2) to set the stage for the other activities of the project.

The review suggests areas to pursue further in the environmental scan and commissioned papers, including ongoing work on the development of instruction approaches and curricula and professional development. The technical working group and the commissioned papers will also address many of the conceptual and theoretic issues identified in the review.

2. Issues in Conceptualizing Adult Numeracy

> The construct "numeracy" does not have a universally accepted definition, nor agreement about how it differs from "mathematics" (Gal, van Groenestijn, Manly, Schmitt, & Tout, 2005).

This statement, by the authors of a recent international report on adult numeracy, indicates a fundamental problem for anyone reviewing the research literature in this area: there is as yet no consensus about the nature of adult numeracy. Numeracy is a deeply contested concept, beset by terminological confusion, especially when referring to adults. A plethora of similar and loosely related terms compete for attention: *mathematical literacy, techno-mathematical literacy, quantitative literacy, functional mathematics, mathemacy,* and so on. The resultant complexities are discussed in depth in *Adult Numeracy: Review of Research and Related Literature* (Coben, 2003).

The issues of the definition of *numeracy* may seem to be an academic exercise, with little practical value. However, how numeracy is defined has profound implications for all issues of concern to the Adult Numeracy Initiative. Definitions of numeracy have implications for what adults need to know, what should be taught, how students should be assessed, and what professional development teachers need, as a recent international comparative study of adult numeracy frameworks makes clear (Hagedorn et al., 2003). In this section, we summarize the conceptualizations of numeracy and learning theory related to how adults learn mathematics and numeracy.

Definitions of Numeracy

The term *numeracy* originated in the United Kingdom in the *Crowther Report* on the education of children ages 15–18. As "the mirror image of literacy," numeracy was a way of bridging scientific and literary cultures (Ministry of Education, 1959, ¶. 389). The definition entailed "not only the ability to reason quantitatively but also some understanding of scientific method and some acquaintance with the achievement of science." Literacy and numeracy, at a basic rather than an advanced level, have been yoked ever since, with numeracy often subsumed within literacy.

Definitions of numeracy have proliferated. One view equates numeracy with mathematics and computational skills, in much the same way that literacy is viewed as mastery of basic reading and writing. A much broader view focuses on people's capacity and propensity to interact effectively and critically with the quantitative aspects of the adult world (Gal, 2002a). Similarly, in relation to literacy, some argue that numeracy is subsumed in literacy, whereas others argue that debates about numeracy within the context of literacy limit the full operationalization of both concepts. Gal and Schmitt (1994) reported that "some people prefer to use the term 'mathematical literacy,' believing that 'numeracy' is too…limiting in scope. Others feel just the opposite, taking 'numeracy' to be the mirror image of literacy…while viewing 'mathematical literacy' as a sub-area of mathematics" (p. ii). Appendix A presents a sampling of definitions of numeracy.

Maguire and O'Donoghue's (2002) organizing framework (Exhibit 1), developed through discussions with researchers and practitioners in Adults Learning Mathematics – A

Research Forum (ALM), offers a way of bringing some order into the conceptual confusion surrounding adult numeracy. In the framework, concepts of numeracy are arranged along a continuum of increasing levels of sophistication. In the *formative* phase, numeracy is considered to be basic arithmetic skills; in the *mathematical* phase, numeracy is "in context," with explicit recognition of the importance of mathematics in everyday life. The third phase, the *integrative* phase, views numeracy as a multifaceted, sophisticated construct incorporating the mathematics, communication, cultural, social, emotional, and personal aspects of each individual in context.

Exhibit 1.
Adult Numeracy Concept Continuum of Development

PHASE 1	PHASE 2	PHASE 3
Increasing levels of sophistication →		
FORMATIVE (basic arithmetic skills)	**MATHEMATICAL** (mathematics in context of everyday life)	**INTEGRATIVE** (mathematics integrated with the cultural, social, personal, and emotional)

A continuum of development of the concept of numeracy showing increased level of sophistication from left to right (from Maguire & O'Donoghue, 2002)

Formative Phase

Conceptions of numeracy following the *Crowther Report* lost the sophistication of the original definition. For example, "numeracy" first appeared in the UNESCO International Standard Classification of Education in 1997 as "Literacy and numeracy*:* Simple and functional literacy, numeracy." The designations "simple," with respect to content and skills, and "functional," with respect to purpose and application, are telling: numeracy in these definitions refers to basic mathematical, or sometimes specifically numerical or quantitative, skills, which adults are deemed to need to function effectively in society. In this view, numeracy is a basic skill normally acquired in childhood; in some versions of numeracy, what adults are deemed to need is simple arithmetic. Evans (2000) calls this the *limited proficiency* model of numeracy, a hangover from the Victorian period when the "3Rs" of reading, (w)riting, and (a)rithmetic held sway in elementary education. As a corollary, because the content is seen as simple, numeracy may also be thought to be easy to learn, a view roundly rejected by Ma (1999). This view of numeracy is located in Maguire and O'Donoghue's formative phase.

Mathematical Phase

A broader view of numeracy may also be traced back to the United Kingdom, in the 1982 *Cockcroft Report.* This view epitomizes Maguire and O'Donoghue's *mathematical* phase, with its emphasis on the use of mathematics in daily life:

> We would wish "numerate" to imply the possession of two attributes. The first of these is "at-homeness" with numbers and an ability to make use of mathematical skills, which enable an individual to cope with the practical mathematical demands of his everyday life. The second is ability to have some appreciation and understanding of information which is presented in mathematical terms, for instance in graphs, charts or tables or by reference to percentage increase or decrease. (Department of Education and Science/Welsh Office, 1982,¶. 39)

In this phase, numeracy often includes number, money, and percentages; aspects of algebraic, geometric, and statistical thinking; and problem solving based on the mathematical demands of adult life. This view of numeracy has been influential in the Anglophone world, including the United Kingdom's Adult Numeracy Core Curriculum (Basic Skills Agency, 2001). In the United States, this approach appears as part of "functional literacy" approaches, exemplified in the CASAS framework (2004), in several states' mathematics instructional content standards, and in the National Adult Literacy Survey (NALS) (NCES, 1992) and it successor, the National Assessment of Adult Literacy (NAAL) (NCES, 2005). These national surveys measure "quantitative literacy," a concept that clearly falls within this applied mathematics phase.

However, the issue of functionality is not straightforward. Numeracy could be functional with respect to a wide range of contexts and purposes, and the practical mathematical demands of everyday life may require more than basic numeracy. This complexity is acknowledged in Maguire and O'Donoghue's *integrative* phase.

Integrative Phase

All of the most recent, influential approaches to defining adult numeracy fall into Maguire and O'Donoghue's *integrative* phase. In this phase, numeracy is viewed as a complex, multifaceted, and sophisticated construct, incorporating the mathematics, communication, cultural, social, emotional, and personal aspects of each individual in context. FitzSimons and Coben (in press) argue that numeracy in this sense may empower individuals as "knowledge producers" as well as "knowledge consumers"—that is, to become technologically, socially, personally, and/or democratically numerate.

Steen (1990) exemplifies this phase when he outlines five dimensions of numeracy, distinguished in terms of their purposes and associations:

- *Practical*, concerning mathematical and statistical skills that can be put to immediate use in the routine tasks of daily life
- *Civic*, where the focus is on benefits to society
- *Professional*, because many jobs require mathematical skills

- *Recreational*, for the appreciation of games, puzzles, sports, lotteries, and other leisure activities
- *Cultural*, concerned with mathematics as a universal part of human culture

Maguire and O'Donoghue's integrative phase also encompasses critical concepts of numeracy that eschew any automatic association with low-level mathematics. For example, Johnston (1995) proposes that

> To be numerate is more than being able to manipulate numbers, or even being able to succeed in school or university mathematics. Numeracy is a critical awareness, which builds bridges between mathematics and the real world, with all its diversity. [...] in this sense ... there is no particular level of mathematics associated with it: it is as important for an engineer to be numerate as it is for a primary school child, a parent, a car driver or gardener. The different contexts will require different mathematics to be activated and engaged in. (p. 34)

Coben (2000a) also emphasizes the individual's judgments about the use (or not) of mathematics in a given situation:

> To be numerate means to be competent, confident, and comfortable with one's judgments on *whether* to use mathematics in a particular situation and if so, *what* mathematics to use, *how* to do it, what *degree of accuracy* is appropriate, and what the answer means in relation to the context. (p. 10)

Although integrative conceptions of adult numeracy dominate almost all current theorizing and thinking in adult numeracy, this view has only just begun to move beyond a limited core of numeracy researchers and practitioners. Most mainstream practice continues to reflect formative and mathematical approaches to numeracy. However, more integrative approaches to numeracy have become influential over the last few years, as illustrated by projects to define numeracy instructional content standards, the Program for International Student Assessment (PISA), and the Adult Literacy and Lifeskills (ALL) Survey. The numeracy definitions in these projects specify the intended cognitive outcomes of adult numeracy education and/or emphasize the need for the individual to adjust to the increasing technological demands of the knowledge economy.

The introduction of the National Council of Teachers of Mathematics *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989) helped fuel the instructional standards reform movement in mathematics and numeracy (discussed further in the next section). These standards emphasized conceptual understanding and the development of problem-solving and decision-making skills, rather than rule-based learning. This view of mathematics and numeracy has had an impact not only in the teaching of mathematics to children but also in adult education and has helped prompt a movement toward the development of content standards for teaching adult mathematics. The state of Massachusetts (Leonelli & Schwenderman, 1994) and the Adult Numeracy Network's (ANN) mathematics standards framework were among the first attempts at developing an integrative numeracy framework for adult instruction. The following seven themes were proposed to serve as the foundation for the development of numeracy standards (Curry, Schmitt, & Waldron, 1996):

- Relevance/Connections
- Problem-Solving/Reasoning/Decision-Making
- Communication
- Number and Number Sense
- Data
- Geometry: Spatial Sense and Measurement
- Algebra: Patterns and Functions

Several states have moved toward developing mathematics content standards, using basic computational, functional, or integrative approaches, and eight states have already developed mathematics standards. OVAE's Adult Education Content Standards Warehouse project (http://www.adultedcontentstandards.org) has supported states' efforts to develop standards, as has the National Institute for Literacy's (NIFL) Equipped for the Future (EFF) project. EFF's Math Content Standard states that adults should be able to "Use Math to Solve Problems and Communicate" (see Exhibit 2) after participation in adult basic education.

Exhibit 2.
EFF Standard: Use Math to Solve Problems and Communicate

- Understand, interpret, and work with pictures, numbers, and symbolic information.
- Apply knowledge of mathematical concepts and procedures to figure out how to answer a question, solve a problem, make a prediction, or carry out a task that has a mathematical dimension.
- Define and select data to be used in solving the problem.
- Determine the degree of precision required by the situation.
- Solve problems using appropriate quantitative procedures and verify that the results are reasonable.
- Communicate results using a variety of mathematical representations, including graphs, charts, tables, and algebraic models.

From National Institute for Literacy (2000)

The Organization for Economic Co-operation and Development's (OECD) PISA also focuses on using mathematics. It is designed to assess the readiness of 15-year-olds for life beyond school, focusing on the extent to which students are able to use their knowledge and skills to meet real-life challenges. This reflects a change in curricular goals and objectives in many countries, which are increasingly concerned with what students can do with what they learn at school (OECD, 2003).

Mathematical literacy is defined in PISA as

> an individual's capacity to identify and understand the role that mathematics plays in the world, to make well founded judgments and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen. (p. 24)

It encompasses four domains or subscales:

1. Space and shape, which includes recognizing shapes and patterns
2. Change and relationships, which includes data analysis needed to specify relationships or translate between representations
3. Quantity, which focuses on quantitative reasoning and understanding of numerical patterns, counts and measures
4. Uncertainty, which includes statistics and probability

The second PISA survey, which included the United States, covered reading, mathematical and scientific literacy, and problem solving, with a primary focus on mathematical literacy. Conducted in 2003 in 41 countries, it is usually referred to as PISA 2003. The United States ranked 28th out of 40 countries in terms of the percentage of students at each level of proficiency on the mathematics scale in PISA 2003.

In the most recent international survey of adult numeracy (including the United States), the Adult Literacy and Lifeskills (ALL) Survey, also conducted under the auspices of the OECD, the emphasis is on using mathematics in real contexts, including, but not limited to, everyday life. Numeracy is considered in the ALL Survey as **"**the knowledge and skills required to manage and respond effectively to the mathematical demands of diverse situations"; in addition,

> Numerate behavior is observed when people manage a situation or solve a problem in a real context; it involves responding to information about mathematical ideas that may be represented in a range of ways; it requires the activation of a range of enabling knowledge, factors, and processes. (Gal et al., 2005, p. 142)

The issue of level of difficulty experienced by the individual adult when engaging in numerate behavior is tackled in the ALL Survey through an analysis of assessment items in terms of their textual and mathematical complexity. The inclusion of a textual dimension allows for the fact that numeracy is often mediated through text and difficulties in reading may impede numeracy performance. Text may be presented in digital form or on paper, and in the integrative phase, numeracy is often associated with information and communication technologies (ICT). For example, Steen (2001) describes numeracy as a natural tool for the computer age, encompassing the capacity to communicate using digital data.

THEORIES ON LEARNING AND KNOWING MATHEMATICS

Each of the main definitions of numeracy has ties to adult learning theory. In turn, the learning theories have profound implications for the content of mathematics instruction, its pedagogy, and how learning should be assessed (Forman & Steen, 1999). Definition, theory, and instruction are thus tied together: one's view of what numeracy is leads to a theory of learning, and this theory affects preferred approaches to instruction. There remains controversy around the implication of theory to practice because there is little empirical research demonstrating the effects of instructional approaches implied by the theories on how adults know and learn about mathematics.

Behaviorism

Up until the mid-1990s, behaviorist approaches dominated adult mathematics instruction. In the behaviorist approach, learning is defined as a change in behavior observed when a stimulus results in a response. In behaviorist mathematics instruction, the teacher conveys knowledge, such as a number fact embedded in a word problem (the stimulus), to the students who absorb it and produce a solution (the response). Learning is considered to have occurred when the correct solution is given consistently. Learning mathematics in this mode entails immediate recall, retention, and transfer, and understanding is equated with computation and operations, as measured by achievement tests or performance tasks. This approach is associated with an absolutist view of mathematics, that is, the belief in the certainty and truth of mathematics. In the absolutist view, mathematics is a set of absolute truths determined by authority; doing mathematics means following the rules correctly (Coben, 2000a). Behaviorist methods dominated U.S. educational practice until the late 1950s.

Constructivist Theories of Learning

The last 10 years have brought a major shift in ideas about learning mathematics, from a behaviorist perspective to a constructivist perspective (Kieran, 1994) so that constructivism now has a markedly greater influence on contemporary mathematics education. The shift to constructivist theories of learning corresponds to the adoption of integrative definitions of adult numeracy. For example, constructivism underpins the NCTM mathematics standards discussed above. The keystone of constructivism is the notion that all knowledge is constructed by individuals acting upon external stimuli and assimilating new experiences by building a knowledge base or altering existing schemas. Learners actively construct knowledge by integrating new information and experiences into what they have previously come to understand, revising and reinterpreting old knowledge in order to reconcile it with the new (Billett, 1996). Two main strands in constructivism have emerged, following, on the one hand, Piaget (focusing on ways in which individual learners make sense of mathematics) or, on the other hand, Vygotsky (seeing learning as an activity in which shared mathematical meanings are constructed socially). Jaworski (1994) notes that debates between radical and social constructivists parallel debates between these two positions.

Piagetian theories in adult numeracy focus on the importance of an individual's cognitive developmental stage in learning. Piaget proposed four major developmental stages through which a child progresses intellectually from birth to adolescence. Much of the research at the K–8 level has proposed materials and methods that promote student learning at the penultimate stage, the *concrete level,* and progress toward the *formal operations* level, the final stage. The *concrete operational* and *formal operations* levels have been the subjects of a few studies specific to adult populations. These studies include Mayta (1990), who correlated achievement in mathematics to the concrete stage among a group of incarcerated males, and Brockbader (1992), Wolfe (1999), and Martelly (1998), who found the same relationship among community college students enrolled in developmental mathematics courses. Although these studies do not suggest either materials or instructional approaches, they do refute, to varying degrees, Piaget's conviction that the evolution to formal operations is complete by age 15; they also validate the use of concrete materials and manipulatives for adult students.

Another aspect of Piaget's theory of intellectual development has received less attention in the adult numeracy field, his notion of intellectual growth as involving three fundamental processes: assimilation, accommodation, and equilibration. Assimilation is the process through which new events are incorporated into pre-existing cognitive structures. Accommodation involves changes in these structures to accommodate new information. Through this dual process of assimilation-accommodation, the learner forms *schemata*. Equilibration refers to the balance the learner strikes between his or her schemata and the environment and between assimilation and accommodation. A new experience causes disequilibrium until the learner is able to assimilate and accommodate the new information, thereby attaining equilibrium. Llorente's (1996) study of the problem-solving behavior of adults in Argentina with little formal education in work situations uses Piaget's theory of equilibration to highlight the interactive and constructive nature of everyday knowledge and the social constraints that influence problem solving.

Vygotsky (1978) emphasized the social aspect of learning and the interplay of speech and action in children's learning activities. To Vygotsky, affect, motivation, and will are central to learning. Two of his major contributions to constructivist theory were the ideas of a "zone of proximate development" (ZPD) and "scaffolding," although the latter name was not actually used by Vygotsky (Wilson, Teslow, & Taylor, 1993). Vygotsky defined the ZPD as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers." Scaffolding is the process in which the student masters a skill under the guidance of an expert. There are four basic steps in the process (Wilson, Teslow, & Taylor, 1993):

- The student observes the teacher modeling an activity.
- The student tries the activity under the guidance of the teacher.
- The teacher prompts with cues only when needed.
- The student is free to practice the skill independently.

Vygotsky's work has many applications to the teaching of mathematics and has been referenced by advocates of cooperative learning and problem-solving activities. Like Piaget, Vygotsky studied children, but his theories of ZPD and scaffolding both translate smoothly to the design of instruction for adult mathematics students.

Constructivists maintain that learning is an active process, that collaboration enhances learning, that learning should be situated in realistic settings, and that testing should be integral to the experience, not a separate activity (Merrill, 1991; Wilson, Teslow, & Taylor, 1993). At its most radical sense, constructivist theory holds that each person discovers truth and constructs his or her own unique knowledge base (von Glasersfeld, 1990). Constructivism is associated with fallibilist views of mathematics, in which mathematics is seen as a social construct and therefore value laden, culturally determined, and open to revision. Benn (1977) argues that fallibilist approaches lead to more inclusive, adult-friendly teaching and learning; by contrast, the absolutist view is associated with the product view of mathematics, in which mathematical skills and concepts are seen as external to the learner. In constructivist epistemologies of mathematics education, mathematics education is viewed as a process whereby knowledge of mathematics is gained by doing mathematics.

Socio-Cultural Perspectives on Mathematics

The belief in a socially constructed base of knowledge does not negate the idea of the universal truth of mathematical ideas. But although the concept that 2 + 2 = 4 is true wherever and whoever you are, Bishop (1991) illustrates concepts such as the idea of negative numbers and the angles of a triangle adding to 180 degrees (as opposed to 100 or 150) as evidence of the cultural basis for mathematics. Bishop’s work is an example of ethnomathematics. Ethnomathematicians address the question of whose knowledge counts, challenging the hegemony of the Western model of mathematics from a variety of perspectives (Powell & Frankenstein, 1997). Bishop has identified six pan-cultural mathematical activities: counting, locating, measuring, designing, explaining, and playing; the Western model of mathematics represents one approach to these, but there are others. Against this background, research and practice in ethnomathematics focus on the mathematics of cultural groups and the development of pedagogies that take these different forms of mathematics into account, establishing comparisons between academic mathematics knowledge and local knowledge and analyzing the power relations involved in the use of both kinds of knowledge (Knijnik, 1996).

An interesting example relative to ABE was conducted by Masingila (1992) in a work-place literacy setting. She contrasted the mathematics practices that carpet layers use when estimating and installing their product with the school-based knowledge of general mathematics students. Masingila found that the carpet layers engaged in conceptually deep mathematical thinking as they solved problems encountered during installations. These constraint-filled situations differed substantially from the textbook area problems that the students were required to solve. The straightforward school problems did not prepare the novice carpet layers for the realities of area, ratio and proportion, and measurement experienced on the job.

Feminist studies of mathematics represent another approach from the ethnomathematical, social constructivist view. This work has been influential in the mathematics education of girls and women and in research in gender studies. Becker (1995) sets out two types of knowing developed in feminist research: separate knowing (associated with men and concerned with such things as logic, rigor, abstraction, rationality, and certainty) and connected knowing (associated with women and concerned with intuition, creativity, hypothesizing, conjecture, and experience). She contends that in mathematics and science, separate knowledge is valued over connected knowledge and that this disadvantages girls. She advocates a connected approach to teaching and learning mathematics, through which, she contends, more girls would enjoy mathematics, succeed at it, and choose to study it to advanced levels. Feminists have also taken issue with assumptions about women's allegedly "unmathematical" minds and sought to explain women's and girls' underachievement, where it exists or seems to exist, in cultural rather than biological terms, while seeking to understand and improve the teaching of mathematics to women and girls and their take up of and performance in mathematics (L. Burton, 1995).

A representative study in this vein is Crittenden (2000), who followed eight women, volunteers from an intact class, as they progressed through a preprofessional mathematics review course designed to prepare them for placement in nontraditional jobs in the building trades. Crittenden reports the following:

- The women had difficulty learning mathematics in a classroom setting.
- Although work-related mathematics tasks are often more complex than classroom-based mathematics problems, the women in the study had an easier time learning and using mathematics on the job.
- The women in the study did not perceive any difficulties using mathematics in common budgeting and shopping chores because of the repetitive nature of the tasks.
- The women in the study were unable to use relevant mathematics skills for nonroutine personal finance tasks, such as the evaluation of investment options for retirement planning, because they had either incomplete or unhelpful schemas for the financial services industry.

Ethnomathematics and feminist approaches demonstrate that school mathematics and "street" mathematics differ substantially. Further, the affective environment of the traditional classroom setting can impede student learning despite the best-intentioned efforts of the instructor. Both points should be taken seriously when interventions are designed for the adult numeracy student.

Numeracy and Cognition: Experience and Situations

Despite the importance of understanding cognition—what and how people know what they know—for instruction, such studies in adult numeracy or mathematics education are rare; most studies of cognition and numeracy/mathematics in the education and psychology fields have been developed through research with children. However, there is clear research evidence that mathematical knowledge develops both in and out of school, for adults and children, and is profoundly influenced by experience and cultural practice, as socio-cognitive theorists have shown (Lave, 1988; Saxe, 1991; Schliemann & Acioly, 1989). Such studies emphasize the ability of people to control and regulate their own behavior in relation to their experience in their environment, rather than react automatically to stimuli, as behaviorist psychologists predict.

Adults bring this prior knowledge and life experience to the classroom and apply it to their use of mathematics in a wider range of situations. Effective instruction must be responsive to these experiences, but there is little theory designed toward understanding prior experience and how these experiences affect learning. Duffin and Simpson (1993, 1995) have developed a theory of learning that attempts to classify learners' experiences into three categories: natural, conflicting, and alien (Exhibit 3).

Exhibit 3.
Adult Experiences and Learning Responses

	Experiences	**Responses to Experience**
Natural	Fits the learner's mental structures Is expected and unsurprising	Strengthens the current way of thinking Extends the scope of the internal mental structure
Conflicting	Is inconsistent with the learner's internal mental structures Jars with expectations Highlights limitations or contradictions	Destroys an internal mental structure *or* Limits a way of thinking *or* Merges two mental structures
Alien	Has no connection with the learner's internal mental structures Is meaningless for the learner Cannot be coped with	Ignores the experience *or* Avoids the experience *or* Absorbs the experience as a new mental structure

From Simpson & Duffin (1995)

Duffin and Simpson suggest that the natural-based learner aims to build on existing internal mental structures, developing connections between new and previous experiences. Such learners are likely to develop highly flexible, widely applicable learning because of their highly interconnected mental structures, but they are likely to build up their understanding of complex methods slowly. Meanwhile, for an alien-based learner, new experiences are accepted separately and either are left unconnected or are connected only later in response to any conflicts that may arise. Such learners should be able to master techniques quickly, without the need to build on existing structures, but such skills would be bound by the context in which they were learned and would be difficult to reconstruct if they went unused and became forgotten.

Gal (2000) takes a different approach, beginning from the learner's perspective. He notes that real-life numeracy *situations* are always embedded in the life stream with personal meaning to the individual involved. Adults need numerate skills to enable them to manage diverse types of quantitative situations, and he identifies three types of numeracy situations that adults must manage. *Generative situations* require people to count, quantify, compute, or otherwise manipulate numbers and generate a response. Examples are dealing with simple operations, such as calculating a total price of products while shopping or measuring a shelf; dealing with multistep operations embedded in text, such as completing a tax form; and making reasonable decisions, such as choosing the best home mortgage loan. Resulting responses have clear right or wrong answers.

Interpretive situations require people to make sense of verbal or text-based messages based on quantitative data but do not require them to manipulate numbers. Examples include interpreting a chart in a newspaper article reporting crime statistics or reading a report of a survey with poll results. The response expected in such situations is an opinion or the activation of critical questions that have no clear right or wrong answers.

Decisions situations require people to find and consider multiple pieces of information to determine a course of action. Such situations include identifying ways to use limited resources, such as money or time, and choosing among alternatives (renting the right apartment, purchasing the right car, or deciding on the best insurance, for example). Not only is there no clear correct answer in such situations, but the person may sacrifice precision or accuracy to save time or mental load when deciding on a response and may reach the response in an inefficient or nonstandard way (Gal et al., 2005).

The three numeracy situations are not necessarily distinct categories, and Gal (2000) notes that other types of numeracy situations and hybrid situations are possible. Numerate behavior is also enabled by dispositional elements (prior belief, attitudes, and habits) that motivate and support effective behavior in any situation.

AFFECTIVE FACTORS, ANXIETY, AND LEARNING STYLES

Dispositional elements are central to constructivist theories, which not only posit the importance of experience and situations in learning but also include characteristics of the learner as integral to learning. Research on the role of learners' affect, attitudes, and beliefs in learning mathematics, although widespread for children, has been limited on adults, focusing on attitudes and anxiety about mathematics. Singh (1993) surveyed adults' attitudes toward mathematics and found that abstraction and perceived lack of relevance are common reasons students cited for their dislike for mathematics and that fear of failure induced by instruction and testing in mathematics is a main cause of anxiety.

Sheila Tobias has conducted extensive research on math anxiety in adults. She authored *Overcoming Math Anxiety*, in which she explores the economic impact, both personal and societal, of poor mathematics skills. Using her work with math-phobic individuals, particularly women, Tobias shares her insights into the causes of math anxiety and the myths of math ability (or not), and she suggests ways to help students overcome their anxiety and open the door to disciplines and occupations that require strong mathematical skills. She recommends the following:

- Students need to take charge of their mathematics learning, refusing to be intimidated by their history and the culture of previous mathematics classrooms.
- Teachers must create environments where math anxiety can be discussed openly, help students recognize their mathematics strengths, and provide opportunities for success and difficulty within their zone of proximal development.
- Mathematics books are not an easy read, and part of the desensitization process compels teachers to help students develop appropriate reading skills.
- Teaching styles must be adjusted to include methods that recognize differences invoked by gender and culture.
- Talking and writing about feelings and strategies must permeate the course. (Tobias, 1993)

Several other studies have investigated the existence and effect of anxiety on learning in adult students. Altieri (1987) surveyed developmental studies students (n = 89) at a community college using Kolb's Learning Styles Inventory followed by interviews with 17 of the students and four faculty members. Although the study was not specific to mathematics and anxiety was not the focal question, analysis revealed that anxiety and remembering were the central learning problems of the students. The researcher proposes that the first may be a root cause of the second. Both the students and the faculty named anxiety as the dominant impediment to learning, an impediment that fostered problems with remembering, course pacing, and testing.

Using the Brief Math Anxiety Rating Scale (BMARS) and the Learning Style Inventory-Adapted (LSI-A), Cook (1997) found a connection between anxiety level and perceptual learning style in more than 500 community college students. Cook found that students with audio and tactile/kinesthetic learning styles were more likely to have math anxiety. Female students had a higher math anxiety level, but age was not significantly correlated.

Jost (1997) studied the way that anxiety about mathematics and computer-assisted instruction affected 40 students in an adult education class. He used the Computer Attitude Scale and Mathematics Anxiety Rating Scale along with a demographic questionnaire and conducted analyses to determine the interaction of computer anxiety and demographic variables. He found significant gender differences for computer experience, more negative attitudes, and higher computer anxiety. There was no gender difference for achievement as measured by the final exam in the course.

There are other, correlational studies of math anxiety on adults in developmental mathematics courses. Peskoff (2001) evaluated the relationship between students' level of math anxiety and the strategies they employ to cope with it, using 279 developmental mathematics students. A multivariate statistical analysis related the effects of math anxiety, gender, and course enrollment on 10 coping strategies rated for frequency of use and helpfulness. Peskoff found that students with low math anxiety use and value a wider variety of coping strategies than peers with high math anxiety. High-anxiety students used tutoring services and met with their counselors significantly more than low-anxiety students, and males used the avoidance strategy of exercising or engaging in physical activity significantly more than females. However, students and the faculty considered this strategy one of the least useful strategies. Two strategies considered more helpful by all students and the faculty, completing homework assignments on time and letting the instructor know they do not understand the material, were used significantly more often by females. Students identified two additional strategies that they felt were more helpful: asking questions in class and allowing extra study time before exams.

Parker (1997) interviewed 12 developmental mathematics students who previously had math anxiety to describe the steps they took to overcome their anxiety. Analysis of the data identified six stages in the transition from math anxious to confident. First, each spoke of a personal realization that he or she had to become comfortable with mathematics because some personal goal depended on it. Often that goal was related to job advancement, although that was not the only reason cited. Next, students made a personal commitment to achieving the goal. For some of the subjects, past success mastering difficult tasks spurred belief that they could also be successful at mathematics. They spoke of determination and positive thinking as keys to victory. They then mapped out a strategy to master the subject and took action. Many described the recognition of a significant turning point in both their aptitude and their attitude, which led to positive feelings about themselves and about the value of mathematics, eventually becoming a part of the math support system to help other struggling with mathematics.

Duffin and Simpson (2000) have also explored the tensions between the cognitive and the affective aspects of learning, as has Evans (2000), who goes beyond the focus in some earlier studies on math anxiety to focus on the interrelationship between adults' mathematical thinking and both positive and negative emotions. He argues that thinking and emotion are inseparable, so mathematical activity is always emotional and teachers should encourage adult students to seek to understand what might be emotional blocks to actively seeking out possible applications of their learning.

Learning Styles

Along with affect, recent research has examined the role of individual learning styles in adult education. Two influential examples are David Kolb's (1984) learning style "inventory" that he termed experiential learning and Howard Gardner's (1993) theory of multiple intelligences (MI). Kolb describes learning as an ongoing, circular process based in concrete experiences that the learner reflects upon, abstracts concepts from, and then actively experiments with to enrich the learning base. Learners are classified according to the point in the process where they seem most comfortable. "Divergers" ponder concrete experiences, imagine possibilities, and ask "What if…?" questions, whereas "convergers" start with concepts and seek out a solution. "Assimilators" focus on concepts, reflecting on their abstract qualities with little concern for practical applications. Finally, "accommodators" take concrete experiences and experiment with them to create new experiences and build knowledge.

Gardner's theory combines psychology with neuroscience and identifies eight intelligences: musical, bodily-kinesthetic, logical-mathematical, linguistic, spatial, interpersonal, intrapersonal, and naturalist. These, he contends, are located in different regions of the brain. Someone who is "left brained" is thought to be logical and structured, whereas someone who is "right brained" is more creative and spontaneous. The idea is that by teaching to these "intelligences," teachers can make their lessons more effective.

Learning styles approaches are popular among some adult numeracy educators, and a group of adult literacy teachers in New England has investigated the utility of MI theory to their work. Two of the teachers focused on mathematics instruction, reporting benefits for both teacher and student from the project (Costanzo, 2001).

However, recent research by Frank Coffield and colleagues warns against stereotyping people on the basis of their learning styles (Coffield, Moseley, Hall, & Ecclestone, 2004). Coffield's team surveyed more than 70 instruments designed to identify people's learning styles. They then undertook a rigorous scrutiny of 13 of these instruments, together with a literature review of the main theories on learning styles. They concluded that the idea that various types of "intelligence" are located in diverse parts of the brain is not confirmed by neuroscience. Although certain parts of the brain do seem to control particular activities, the brain is far more flexible and more robust than some theorists had assumed. They also found that some of the most widely used instruments have low reliability, poor validity, and a negligible impact on teaching and learning. Similarly, John White describes learning styles approaches as deterministic and potentially leading people to restrict their own possibilities (White, 1998).

Brain Research: "A New Science of Learning"

The study of cognitive factors and individual differences that affect learning has recently taken a radically different turn, toward brain research. The question of how our understanding of adult numeracy and mathematics teaching and learning might relate to this new research in cognitive neuroscience has been explored since 1999 in the Numeracy Network, which is part of OECD's Brain and Learning project. This project has several aims:

- Develop a "new science of learning" through creative dialogue between cognitive neuroscience, psychology, education, health and policy.
- Discover what insights cognitive neuroscience might offer to education and educational policy and vice versa.
- Identify questions and issues in the understanding of human learning where education needs help from other disciplines. (Organization for Economic Co-operation and Development [OECD] 2004, p. 9)

In the present, second phase (2002–06), the project is focusing on three main issues: literacy, numeracy, and lifelong learning; the findings and policy recommendations will be published in 2006.

The Numeracy Network focuses primarily on brain mechanisms related to fundamental educational skills that enable comprehension of mathematical thought. This includes basic work on numeracy skills and symbolic thinking, with emphasis on the cognitive psychology and neuropsychology of mathematics operations.

An example of work discussed in the project that may have far-reaching implications for understanding mathematics learning at all ages is Dehaene's triple code theory. This theory describes a modular system of brain areas that are active when a child is learning or performing arithmetical operations: addition, subtraction, multiplication, and division. The basic idea is that when manipulating a number, a child does one of three actions, each involving a different region of the brain:

- Performs some visual manipulation (seeing the number as a visual digit, such as "3"),
- Performs some linguistic manipulation (hearing or reading the number as a word, such as "three"), and
- Represents it as a quantity (such as "3 is bigger than 1") (OECD 2004, p. 64).

On the basis of this theory, Dehaene (1992) contends that:

> Adult human numerical cognition can therefore be viewed as a layered modular architecture, the preverbal representation of approximate numerical magnitudes supporting the progressive emergence of language-dependent abilities such as verbal counting, number transcoding, and symbolic calculation. (p. 35)

If Dehaene is right, his theory may explain why some adults have difficulty in one or more of these areas: recognizing, manipulating, or representing numbers. It also tells us that we should not assume that an adult who can do one of these actions will be able to do the others and shows that language is deeply implicated in some, but not all, arithmetical operations. This is just one example; the work of the OECD Numeracy Network shows that there is much debate among cognitive neuroscientists, psychologists, and educationalists. For example, Karmiloff-Smith (2004) argues that modules might pre-exist in the neonate, but that this cannot be assumed from studies of children or adults because domain specificity can emerge over developmental time. Also, it is a long way from producing a theoretical model to proving its explanatory power and then working out the implications for teaching and learning. It is important to recognize the present limitations, as well as the power and potential of brain research with respect to education, and to avoid a determinism that sees brain research as the final arbiter in matters of education. Nevertheless, the development of a "new learning science" is promising, especially if it takes the form of a creative multidisciplinary collaboration.

SUMMARY

This brief review of the competing conceptualizations of adult numeracy and learning has identified a rich and active body of theoretical work. There is substantial debate within the field on how to define and characterize adult numeracy, and we used Maguire and O'Donohue's conceptual framework to organize the competing definitions. Integrative definitions of numeracy have the most influence on recent instructional frameworks and standards developed for adult numeracy. These frameworks also reflect constructivist views of learning that posit that learners actively construct knowledge by integrating new information and experiences into what they have previously come to understand. There is a substantial body of research inspired by constructivist theories, and we reviewed relevant research on the role of learners' prior experience, numeracy situations, math anxiety, and learning styles on adult mathematics learning, along with new, promising brain research.

3. Adult Numeracy and Mathematics Instructional Approaches and Interventions

As just illustrated, there is a rich and lively debate on definitions of adult numeracy and on how adults learn mathematics. Integrative definitions of numeracy and constructivist theories have been particularly influential, and current approaches to numeracy instruction for adults reflect this thinking. In this section we briefly review the predominant instructional frameworks about teaching mathematics to adults. We then present a review of the empirical research evaluating instructional approaches toward teaching mathematics to students in adult education and literacy classes.

Professional Society Instructional Standards

Several professional societies concerned with mathematics instruction have developed standards that influence recent practice in ABE instruction. These standards define instructional content, including the specific facts or subjects to be covered; skills needed, such as problem solving and critical thinking; and process or pedagogy. There tends to be agreement among the frameworks and standards on the need for specific skills such as problem solving, but there is less agreement on specific content and teaching methods (Safford-Ramus, 2006, in press). In particular, there is agreement on the need for critical-thinking and problem-solving skills within mathematics instruction.

National Council of Teachers of Mathematics Standards

Although developed for teaching primary and secondary school mathematics, the framework developed by the National Council of Teachers of Mathematics (NCTM) has been among the most influential in adult mathematics teaching. Three documents present the NCTM approach: *Curriculum and Evaluation Standards for School Mathematics* (1989), *Professional Standards for Teaching Mathematics* (1991), and *Assessment Standards for School Mathematics* (1995). The intent of the *Standards* series was the identification of the best way to teach mathematics the first time. A revised edition of the book, *Principles and Standards for School Mathematics,* was published in 2000.

The NCTM principles provide a valuable model for instructors, balancing content and methodology in light of the needs of the workforce in the twenty-first century and the technology available to workers. Six principles are stipulated for school mathematics:

- ***Equity.*** Excellence in mathematics education requires equity—high expectations and strong support for all students.
- ***Curriculum.*** A curriculum is more than a collection of activities: it must be coherent, focused on important mathematics, and well articulated across the grades.
- ***Teaching.*** Effective mathematics teaching requires understanding what students know and need to learn and then challenging and supporting them to learn it well.
- ***Learning.*** Students must learn mathematics with understanding, actively building new knowledge from experience and prior knowledge.

- ***Assessment.*** Assessment should support the learning of important mathematics and furnish useful information to both teachers and students.
- ***Technology.*** Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances student's learning (National Council of Teachers of Mathematics, 2000).

The six principles undergird the ten standards that are split between content and process. The *content* standards, which focus on what students should learn, include number and operation, algebra, geometry, measurement, and data analysis and probability. The *process* standards define the ways of acquiring and using that content knowledge and include problem solving, reasoning and proof, communications, connections, and representation. Appendix B presents the NCTM standards.

Crossroads

In September 1995, the American Mathematical Association of Two-Year Colleges (AMATYC) released *Crossroads in Mathematics: Standards for Introductory College Mathematics before Calculus*. This document defines the mathematics that students need to be able to pursue collegiate mathematics courses. Such core mathematics may have to be retaught to students who did not meet or master it during their youth. *Crossroads* also suggests methods for implementing instructional improvements. Because virtually all students in U.S. postsecondary studies are adults, *Crossroads* can be looked at as an andragogical document. Also, two-year colleges in the United States are a primary vehicle for adults to reenter further education, so a substantial percentage of that population consists of adults under the most restrictive definition of that term. A revision of *Crossroads,* titled *Crossroads Revisited,* is scheduled for release as this literature review is being written.

AMATYC based its standards development in *Crossroads* on six principles, including that mathematics should be meaningful and relevant and that the use of technology in instruction is essential. *Crossroads* offers three categories of standards: intellectual development, content, and pedagogy. The recommendations for intellectual development emphasize modeling and problem solving, reasoning and communicating mathematically, and the judicious use of technology to accomplish those tasks. The standards for content include number and operation sense, pattern, symbolism and algebra, geometry, functions, discrete mathematics, probability and statistics, and deductive proof. The third focus, pedagogy, examines the place of technology, interactive and collaborative learning, connection to other disciplines and real-world applications, and multiple approaches that embrace all learning styles. Appendix B includes a summary of the recommendations from the 1995 AMATYC document. The revision includes and expands on the earlier lists with substantial attention to math anxiety, learning and teaching styles, assessment, and professionalism.

Other Frameworks

In ABE, state- and practitioner-led projects have developed standards. The Adult Numeracy Network's (ANN) mathematics standards framework (Curry et al., 1996) and the National Institute for Literacy's (2000) Equipped for the Future (EFF) Math Content Standard have been most directly influential. We have already discussed these in Section 2.

Eight states have developed, or are in the process of developing, content standards for mathematics for their ABE programs. The conceptual bases for these efforts vary widely, with some states following an NCTM or EFF model, some employing competency-based approaches, and others defining only basic mathematics content knowledge.

The Mathematical Association of America (MAA) has for many years supported inquiry into the content and teaching methods used in undergraduate mathematics courses. Its Committee on the Undergraduate Program in Mathematics (CUPM) offered recommendations on the mathematics curriculum for all undergraduates in a report published in 2004, *CUPM Curriculum Guide 2004*. The report recommends standards for content selection as well as the conduct of university mathematics courses from the introductory level through the mathematics major. These standards have had influence in adult education, though to a lesser extent that the NCTM and *Crossroads* standards.

RESEARCH EVALUATING INSTRUCTIONAL APPROACHES

Although there has been significant work toward developing instructional frameworks and content standards, there has not been a similarly intense focus on evaluating the effectiveness of these frameworks or the theories underlying them for adult mathematics instruction. Unfortunately, very few research studies have used ABE students to study the effects of adult numeracy instruction, and the research that does exist is neither theory-driven nor guided by any systematic approach. There has been no agenda or systematic model guiding research in adult numeracy (Coben, 2000a). Two previous reviews of this research (Tout & Schmitt, 2002; Coben, 2003) identified fewer than 20 studies on instructional impact on adults; only 9 of the studies identified in these reviews were conducted in the United States. Reviews focusing on identifying methodologically rigorous studies of instructional effects on ABE and ESL students concur. For example, Torgerson, Brooks, and colleagues (2003) identified only one well-conducted randomized control study that used mathematics as an outcome measure, a finding verified by Condelli and Wrigley (2004), who also found that only 9 studies using ABE and ESL students demonstrated a statistically significant impact of instruction.

A central goal of the Adult Numeracy Initiative is to identify instructional practices worthy of replication (Research Question 3). Although the body of field-based, research-practitioner studies on numeracy instruction within ABE classes has been growing, this research uses primarily introspective and qualitative methods. Although the knowledge of experienced practitioners is an important resource in any effort to improve the effectiveness of adult numeracy teaching and professional development, this knowledge must be verified through more-rigorous methodologies. Consequently, our approach is to identify whether rigorous research has found instructional approaches or interventions that have been effective in enhancing the mathematics and numeracy skills of adult learners.

Methodology for Identifying Research

Our review examined all studies conducted between 1985 and 2005 that tested an instructional approach or intervention, used an outcome measure that assessed skills in mathematics or numeracy, and employed some type of comparison group. This review includes only intervention studies with adult students that addressed mathematics skill levels that would be considered basic elementary level through the secondary level. These skills are the basic mathematics skills typically taught to students enrolled in ABE programs and adult students in developmental mathematics programs (typically taught in community college settings).

While we recognize the differences between ABE programs other instructional settings, ABE classes are often taught within community colleges. In addition, developmental mathematics students are in many ways similar to ABE students, and the content of instruction to these students is also similar to what is taught in ABE. We believe that including these studies increases the potential knowledge base and thus can inform ABE instruction and address the goals of the Adult Numeracy Initiative. However, we excluded studies of developmental mathematics interventions that examined instruction of higher level (postsecondary) mathematics skills to adults, such as college algebra, because these skills are beyond what is taught in ABE.[1]

To identify studies, we searched research databases (Proquest, ERIC, EBSCO, MATHS4Life, Dissertation Abstracts International, NALD, and Reference Manager) and generic Web sites (Google.com, Yahoo.com, MSN.com, Askjeeves.com, Webcrawler.com, Altavista.com, Excite.com, and AOL.com), using different permutations of the keywords *adult numeracy basic education* and *adult mathematics basic education.* We also visited numerous national and international mathematics- and numeracy-related Web sites to try to identify additional adult numeracy and mathematics–related sources. Appendix C lists all Web sites and publications included in our search. Reference Manager connected us to catalogs from more than 500 universities, and several features from the software enabled us to categorize all articles by title, author, link to PDF, URL, abstract, link to full text, and keywords, among several other categorization parameters.

This search identified 223 studies, of which only 91 related specifically to adult numeracy. We next deleted studies that

- were not empirical research on instructional interventions,
- did not include adults in ABE classes,
- were conducted prior to 1985,
- did not have outcomes related to learning mathematics,
- did not have a comparison group, and
- included fewer than five students per group.

At the end of this process, our search criteria left only 15 studies for the review, all of which included ABE students.

[1] The U.S. Department of Education (2005) commissioned a separate review of these higher level postsecondary mathematics classes in community college settings, which examined 15 studies of instructional interventions.

To identify additional studies, we included doctoral dissertations, identified through the mathematics dissertation database developed by Safford (2000) and updated to 2002.[2] Safford developed this database by searching *Dissertation Abstracts International (DAI)* using a Boolean search for *Adult AND Mathematics AND Education* in the descriptor field. After we applied our selection criteria, this search resulted in an additional 9 studies, which gave us a total of 24 studies for our review. Appendix D includes a matrix that summarizes all the intervention research studies we have included in this review.

Quality of Research

The Institute for Education Sciences (IES) has established evidence standards for research, embodied in the procedures of the What Works Clearinghouse (WWC; www.whatworks.ed.gov). Applying the evidence standards allows reviewers to rate studies as (1) meeting the standards, (2) meeting the standards with reservations, or (3) failing to meet standards. Studies that meet standards have the strongest evidence of effects. These studies are primarily well-conducted randomized controlled trials and regression discontinuity studies, or quasi-experimental studies of especially strong design.

Although we were not required to follow the WWC procedures or use the evidence standards in this review, we applied them to the adult numeracy studies we identified to evaluate the overall quality.[3] Unfortunately, the methodologies were generally of such low quality that very few could meet the evidence standards. Fewer than 5 studies used random assignment; among these, many had severe differential attrition, which made the resulting groups nonequivalent. Other studies used nonequivalent comparison groups, used very small sample sizes (fewer than 10), used nonstandardized or qualitative outcome measures, did not adequately explain the intervention, or did not adequately explain statistical analyses.[4]

Rather than eliminate all studies that did not meet evidence standards (which would have left us with very little to report), we included all intervention studies that used some type of comparison group and had at least five students per group. In the discussion of all studies, we describe the methodology to allow an assessment of overall study quality.

EFFECTIVE INSTRUCTION FOR ADULT LEARNERS: RESEARCH FINDINGS

Of greatest interest to adult educators is whether the research can identify the characteristics of effective instruction. The instructional frameworks, constructivist theories, and integrative conceptions of numeracy are compelling and beg the question of whether they are effective on adult learners. Unfortunately, our review revealed that very little research examining these approaches met our criteria for rigorous methodology.

[2] Safford's database contains abstracts of 129 dissertations that met her search criteria from 1980 to 2002. The online version of *Dissertation Abstracts International* has abstracts only for the previous year (2003–04), so the two databases together allowed us to retrieve information on all dissertations.
[3] One of the authors of this review (Condelli) received training on the use of the evidence standards as the senior content advisor on adult literacy for the WWC.
[4] Further evidence of the low quality of methodology comes from a review of 17 adult ESL instructional intervention studies (Condelli & Wrigley, 2004) that used WWC procedures. That review included several of the same ABE studies reported here. Only 4 studies met the evidence standards.

The 15 studies of the effects of instruction on mathematics learning for ABE students investigated a remarkably narrow range of topics: 13 compared the effects of technology or computer-assisted instruction (CAI). Of the 2 remaining studies, 1 examined inference training (a contextual learning method for literacy development) and 1 examined participation in family literacy. Among the 9 studies on interventions with developmental mathematics students, 5 studies evaluated cooperative learning methods, which are based on constructivist views of learning, and 4 studies evaluated the use of technology and learning.

USE OF TECHNOLOGY IN INSTRUCTION

Most of the research (13 ABE studies and 4 development mathematics studies) on the effect of instruction of adult mathematics in ABE has examined the effects of the use of instructional technology. The content standards of the three major mathematics education organizations endorse using technology for mathematics instruction. In its *Principles and Standards for School Mathematics*, the NCTM (2000) states:

> Electronic technologies—calculators and computers—are essential tools for teaching, learning, and doing mathematics. They furnish visual images of mathematical idea, they facilitate organizing and analyzing data, and they compute efficiently and accurately. They can support investigations by students in every area of mathematics, including geometry, statistics, algebra, measurement, and number. (pp. 24–25)

In *Beyond Crossroads,* the AMATYC authors (2005) enumerate the technologies used in the community college environment: graphing calculators, mathematics software, spreadsheets, multimedia, computers, and the Internet. They also introduce distance learning, a concept with powerful potential for adult educators. The MAA (2004), although endorsing the use of technology, warns that such use must be judicious:

> The use of technology can help students develop mathematical skills and understanding. However, the use of technology must be focused on students' needs rather than on the capabilities of the technology itself. Instructors must first decide what mathematics is to be learned and how students are to learn it. The answers to these questions will determine whether and how students should use technology. (p. 22)

The research on the use of technology in instruction has not demonstrated that it improves the learning of mathematics by adults over instruction that does not use technology. Among the 13 studies of ABE students and the 4 developmental mathematics studies, only B. S. Burton (1995) and Wilson (1987) found statistically significant increases in achievement for CAI. Lavery, Townsend, & Wilton (1998) reported an impact of CAI, but used a sample of only six students per group. Nurss (1989) and the Indiana Opportunities Industrialization Centers (O.I.C.) of America State Council (1990) also showed a positive effect for CAI, but these studies have severe methodological problems that cloud interpretation. In addition, the instructional approaches represented within the technology and the type of technology studied vary so widely that it is difficult to draw conclusions about instruction from this research.

Although there seems to be no clear advantage or disadvantage to the incorporation of CAI into ABE, GED, or developmental mathematics courses from this research, technology, particularly the Internet, has evolved rapidly and is quite different from what it was when most of the studies were conducted. The studies span 20 years, years that have seen a great change in the quality and sophistication of educational software. The degree of change in technology has been so profound that is questionable whether the early studies have much applicability to the more technologically knowledgeable adults of the 21st century. The adult student cohort in 2005 is more knowledgeable about and dependent on technology than those of 10 years ago. We summarize each study below, beginning with the ABE studies, which include correctional education and GED courses, and concluding with studies of students in developmental mathematics courses.

Computer Use in ABE Instruction

Among the earliest studies in ABE, Barnett (1985) and Reid (1986) reported studies that used Program Logic for Automated Training Operations (PLATO) computer-assisted instruction. The Barnett study had a pretest-posttest design comparing students in two juvenile correctional facilities. There was no indication of the number of participants or the instruments used to measure the variables. Achievement and attitude of students in the PLATO group were not significantly different from those of students who received only traditional instruction.

Reid (1986) compared three teaching methods: CAI using PLATO, tutoring using Laubach materials, and traditional teaching. Subjects (n = 30) were members of existing ABE/GED classes. The TABE M and D levels served as pre- and posttest instruments. There was no significant difference in mathematical achievement among the three groups, although the CAI group gained 1.9 grade levels while the traditional group gained 1.1. Robichaud (1985) also compared students in traditional settings with those whose regular instruction was supplemented by CAI. No details concerning instrument or evaluation were supplied, but she reported that statistical analysis revealed no significant difference in skills gained. However, there was a significantly positive change in attitudes toward computers and the instructional use of CAI by the CAI users. In a later study, B. S. Burton (1995) revisited the same question of traditional versus CAI instruction with more definitive results. He compared CAI and traditional instruction with 200 adults at a vocational technical adult education center, using the TABE M and D as its assessment measure with a nonequivalent control group design. Students using CAI were found to do significantly better in mathematics than those in the control group. Age and gender had no effect, but student ethnicity and extent of prior formal education did affect results.

Nurss (1989) assessed the effectiveness of the Principle of Alphabet Literacy Systems (PALS) CAI program on the literacy skills of adult nonreaders, compared with traditional adult basic education. This trial showed a significant, positive effect for the traditional adult basic education classes (i.e., the control group). Attrition, however, was extremely high in both groups. Of the 74 students assigned to the control group, 15 percent (n = 11) remained at the posttest; 32 percent of the 135 students in the experimental group (n = 43) completed the program. One could conjecture that the “cream” of the control remained and therefore performed well on the test. In addition there was differential attrition, with more of the control group staying to completion, which clouded the results. However, it might be argued that the greater retention of the experimental group indicated higher student satisfaction with the instruction.

The Indiana O. I. C. of America State Council (1990) reported the results of a study that examined the effectiveness of traditional classroom instruction versus computer-assisted instruction in raising the competency levels of adults one grade level for every 80 hours of instruction. Of the 149 individuals who were pretested, only 50 attended more than 30 hours and remained at the time of posttesting. Evaluation was done using a randomized methodology with the ABLE test as the pre- and posttest instrument. No information was supplied concerning the statistical analysis used to evaluate the results. However, the report indicates that the overall average grade change for CAI students was 2.6 grades compared with an average of 1.84 grades for non-CAI students. The high attrition again makes these findings difficult to interpret.

The objective of a study by Nicol and Anderson (2000) was to evaluate an experiment that compared CAI and teacher-implemented instruction in numeracy. It is unclear whether the same two teachers taught the two intervention groups. The researchers randomized the adult students into three groups of eight students. The method of random allocation was not described, but stratification by gender was implied. The researchers reported no difference in improvement between the teacher-led intervention and the CAI, but given the very small numbers in each group, there is a high possibility of a Type II error in this study.

Lavery, Townsend and Wilton (1998) conducted a randomized control trial of 12 students in New Zealand to compare the learning outcomes associated with basic literacy education programs conducted through traditional instruction with computer-assisted instruction. The students and instructional approaches in these programs are similar to those in U.S. adult education courses. The study measured the gains in reading and numeracy skills in two "training opportunities" classes. Six students received traditional teaching, and another six used Readers' Workshop, Math Concepts and Skills, and Computer Curriculum Corporation's Computer Assisted Learning (CAL) software packages. Participants' reading and numeracy skills were measured by the Burt Word Reading Test, the Neale Analysis of Reading Ability, and the KeyMath Revised Test. The results show that significantly greater achievements were made in reading (word recognition, word accuracy, and comprehension) and numeracy (mathematical concepts, operations, and applications) under CAI than under traditional instruction. The students who used the CAL made a 3-year gain on the Burt, over 1 year on the Neale, and 16 months on the mathematics test in less than 2 months of instruction. During the same time, the students who received traditional teaching made no gains in reading skills and showed a slight decline in mathematics performance.

Computer Use in Correctional Education

In addition to Barnett (1985), three studies focused specifically on incarcerated populations. Winters, Teslow and Taylor (1993) studied the effect of a CAI-supplemented program on ABE/pre-GED and GED students in an adult correctional facility. Five students were assigned to either the experimental or the control group (n = 10), and the researchers pre- and posttested with the TABE. The statistical methods used to analyze the data were unclear, but the results favored the CAI intervention: 86 percent of the students in the pilot study advanced in level in mathematics in contrast to a 50 percent gain in the control group.

A comparison of students advancing one year or more showed 43 percent for the pilot study versus 14.5 percent for the control group. Once again, the small sample size limits the utility of this study.

Batchelder and Rachel (2000) studied the effect of skill-and-drill tutorial software to enhance mathematics and language skills. They randomly assigned 71 male inmates in the prison's GED program to receive either the regular classroom instruction offered or classroom instruction supplemented by CAI using the tutorial software. The classroom instruction consisted of four hours per day in English, mathematics, history, and science. Students in the experimental group received three hours of instruction per day but spent the fourth hour using the CAI software for mathematics and reading. Inmates were posttested with the CASAS reading and mathematics tests after receiving 80 hours (four weeks) of instruction. There was no significant difference between the groups on these tests.

Burnham (1985) examined the effect of a televised curriculum on an incarcerated ASE population. Subjects in a nonequivalent control group research design ($n = 40$) were pretested using the General Educational Performance Index (Form AA) and posttested using Form BB of the same test. The experimental group used an instructional televisions series, Adult Math, as a reinforcement resource, viewing the "telelessons" under supervision and then completing workbook exercises tied to the program. The control group completed self-paced workbooks and used other instructional materials but did not view the television series. The researcher found no difference in achievement between the groups, although he cautions that Adult Math is more effective when the subjects have grade-level scores of at least 5.8 in arithmetic and reading and that the literacy levels of incarcerated populations are noticeably lower than those of the general population.

Computer Use in GED Instruction

Two other studies evaluating computer-based instruction (CBI) were GED specific. Wilder (1994) compared the effects of a CBI simulation-test treatment, a CBI drill-and-practice program, and a traditional workbook drill-and-practice class on retention, completion time, and elevation of test scores on the mathematics section of the GED. The research design was a three-group, posttest-only design with unequal sample sizes, where a total of 564 students self-selected into the classes. Wilder followed the students for five years, with 308 students retained long enough to get a GED diploma. In addition, 94 percent of the simulation group was retained compared with 65 percent in the CBI drill group and 36 percent in the workbook-only group. Completion time was also considerably less in both CBI groups. Scores on the test were not significantly different.

Wardlaw (1997) studied the effect of CAI on achievement and attitude for a group of pre-GED and GED adults. The study was conducted in established classes with 60 students each in the treatment and control groups. Pre- and posttesting was done using the TABE and the Semantic Differential Attitudinal Questionnaire. Wardlaw found no significant difference on either achievement or attitude. He does offer an important caveat for developers planning to incorporate CAI into a program. Wardlaw surveyed ABE facilities and found that although some were well equipped, many others had few or outdated workstations. One facility had banned student use of the equipment because the director believed that the students were using it to arrange dates rather than study. Wardlaw suggests that these environmental issues may have contributed to the failure of CAI to effect positive attitudinal change.

Computer Use in Developmental Mathematics Instruction

Four studies examined the use of CAI with developmental mathematics students in tertiary institutions. In an early study, Wilson (1987) described a diagnostic and tutorial program that was conducted at a vocational school in Kentucky. The researchers designed a diagnostic test for pre- and posttesting, which they normed against the TABE at the 8.75 grade equivalent. The results of the experiment showed a significant effect in favor of the experimental group. Toet (1991) studied a randomly selected sample of students who had been placed into remedial reading, English, or mathematics at a community college. Using the TABE, she compared achievement between students who completed assignments based on textbook use and students who worked in a CAI laboratory. The group taking basic mathematics showed a statistically significant cognitive gain. Those studying beginning algebra were retained longer at a statistically significant level of .05. There was no significant retention difference for the basic mathematics group.

Hsieh (1992) examined the effect of two specific features of CAI, animation and manipulation, on 54 students participating in two computer-based laboratory (CBL) sections of a developmental mathematics course. The students were randomly assigned to receive instruction with or without animation and with or without manipulation. The outcome measures were overall achievement, retention of content, and motivation, measured through a questionnaire. The researcher listed five findings:

- Animation enhanced retention when the tasks required high-level cognitive processes such as analysis or synthesis.
- Animation did not help learning or retention when the tasks were comprehension of mathematical concepts.
- Animation increased continuing motivation.
- Manipulation helped the transference of mathematical concepts learned through a computer to paper-and-pencil tests.
- Manipulation did not promote intrinsic motivation.

In the most recent and most thoroughly defined study, Costner (2002) examined the effectiveness of a computer algebra system (CAS) on achievement and attitudes of students in a college remedial algebra course. Students in the treatment group (n = 26) used the CAS to discover algorithms, explore algebraic manipulation, and identify misconceptions, while students in the control group (n = 25) did not have access to the CAS. Several instruments were used in the study: a researcher-designed pretest and periodic section tests; a departmental final exam; the Fennema-Sherman Attitude Toward Success in Mathematics Scale, the Confidence in Learning Mathematics Scale, and the Mathematics Usefulness Scale; a researcher-designed questionnaire and semistructured interview (n = 5); and periodic writing assignments. There was no statistically significant effect on achievement or surveyed attitudes. However, the qualitative data gathered through the questionnaire revealed significant differences in attitudes and in classroom culture issues. Students in the treatment group cited the helpfulness of group work and classroom discussions more often than students in the control group. With respect to the use of CAS, the treatment group welcomed the ability to check their work and get immediate feedback. They felt that the CAS helped them see mathematics differently, yet they attributed little of their new mathematical understanding to technology. One criticism was the unavailability of the computer in testing situations. The researcher suggests that assessment needs to be altered if CAS is an integral part of the course.

RESEARCH EVALUATING INSTRUCTION BASED ON CONSTRUCTIVIST THEORIES

As discussed in Section 2, constructivist theories of instruction and learning—the hypothesis that all knowledge is constructed by individuals acting upon external stimuli—has had a great influence on recent work in adult mathematics and numeracy instruction. Although no studies have directly examined the effect of constructivist approaches of mathematics learning on ABE students, researchers have studied two constructivist models, cooperative learning and discovery learning, on students enrolled in developmental mathematics courses.

We identified three studies on cooperative learning and two studies on discovery learning. Only one of the studies on cooperative learning found a positive effect, but none indicated that cooperative learning has a detrimental effect on achievement for adult students. Findings also suggested that cooperative learning may contribute positively to student attitude while decreasing math anxiety. The studies on discovery learning were more positive, with all showing positive effects on either affective measures or measures of mathematics achievement or understanding.

Cooperative Learning

Cooperative learning embraces a number of classroom organization styles, all of which group students in learning teams for some or all of the instructional time. Several models, according to Neil Davidson, share the following characteristics (Davidson in Slavin, 1985):

- The class is divided into small groups composed of two to six members.
- Each group has its own working space, which may include a section of the blackboard.
- The group is involved in discussing mathematical concepts and principles, practicing mathematical techniques, and solving problems.
- The teacher moves from group to group, checks the students' work, and provides assistance in varying degrees.
- The groups sometimes gather outside of class to work on projects.
- Within in each group, certain leadership and management functions must be performed.

Students in Costner's study (2002) cited above found the use of group work and classroom discussion helpful. Two other studies have reported findings from research investigating the use of cooperative learning with adult populations.

Peer tutoring is cooperative learning between two individuals where each learns from and with the other. Berry (1996) studied the effect of peer tutoring in dyads on adult students in a remedial algebra class. Two studies were conducted: a 6-week program and a 12-week semester. Students self-selected the classes but had no knowledge of the planned intervention. Instructors were randomly assigned and trained in the intervention after assignment. In each case, three peer-tutoring sections were contrasted with three traditional lecture sections. Pre-and posttests were given using the Suinn Mathematics Anxiety Rating Scale, the Fennema-Sherman Mathematics Attitude Scales, a profile questionnaire, and an abbreviated version of the institutional Freshman Skills Assessment Program test. An open-ended survey was also used. Sections had an average of 35 students (n = approximately 210). Of the variables measured, only attitude increased significantly during the 6-week study. For students in the 12-week semester, the intervention group showed significant improvement in mathematics achievement and attitude as well as reduced anxiety.

In a study by Ellis (1992), each of seven instructors at a community college taught one developmental algebra section that incorporated the use of in-class study groups and one section that did not use groups. She compared the achievement and completion rates and found no significant difference between the experimental and control groups for the group neither as a whole nor on the basis of age or gender.

Discovery Learning

One method of using cooperative learning in the adult mathematics classroom is termed small-group discovery (Safford, 1998; Davidson, 1985). The NCTM standards include the use of discovery learning for mathematics. Davidson (1985) described the method in the following way:

> The instructor introduced new material with brief lectures at the beginning of class, during which he posed problems and questions for investigation. For most of the class time, the students worked together cooperatively at the blackboard in four-member groups. The students discussed mathematical concepts, proved theorems, made conjectures, constructed examples and counter-examples, and developed techniques for problem solving. The instructor provided guidance and support for the small groups.

Although discovery learning has not been studied in ABE research, three studies using developmental mathematics students have examined approaches that allowed students to use discovery learning to construct their own knowledge.

Bartlett (1993) used a guided discovery approach to teaching mathematics in one section of a developmental mathematics course at a university. She defined the methodology in the following way: “Under the guidance of the teacher, students find and use their own rules and generalizations to solve other problems.” The experimental group (n = 27) was a class taught with this approach and was compared with the same class taught in a previous quarter (n = 52) without the approach. Outcome measures were mathematics performance measured by a researcher-developed test and mathematics anxiety measured by the Math Anxiety Rating Scale (MARS). Students in the experimental class performed better on the outcomes, and Bartlett reported that the experimental method was effective in improving the mathematics performance of adult students.

Ramus (1997) reported similar findings from a course with 13 developmental mathematics students that used discovery learning methods. She supplemented quantitative measures (course tests) with qualitative interviews of 8 students. Students reported a sense of ownership of the rules of algebra because they had discovered them from classroom exercises and also self-reported a positive change in attitude toward mathematics and increased confidence that transferred to other activities outside the classroom. Quantitative measures, derived from the course examination, were less conclusive. Examination results were scored using two rubrics, one to measure correctness and one to measure the use of problem-solving strategies. An ANOVA showed that the experimental section performed as well as the evening section but less well than the daytime class. The author suggested that the different demographic composition of the evening and experimental classes may have affected the outcome as much as the intervention.

Pace (1989) explored the applicability of constructivist methods to the teaching of geometry concepts in a remedial mathematics class at an urban community college. Students ($n = 67$) were pretested using the Applied Geometry Test, the Van Hiele Geometry Test, and the New Jersey College Basic Skill Placement Test. They were randomly assigned to four sections of the course, two experimental and two control, all taught by the same instructor. The treatment class instruction consisted of five 80-minute sessions during which students explored concepts of area and perimeter using activities embedded in applied problem-solving settings. Students were posttested and delayed posttested. The data were assessed using single and multivariate linear regression models. Those in the treatment program performed significantly better than their counterparts.

ABE Instructional Interventions

Our review identified only two additional studies of instructional interventions on the ABE student population that included a measure of mathematics as an outcome measure. In neither of these studies was numeracy or mathematics instruction the main focus of the intervention. One study examined inference training, a meaning-making strategy used for reading development. This study may be relevant to adult mathematics instruction to the extent that numeracy may be considered an integrative skill that includes literacy abilities. The second study examined the general impact of family literacy instruction compared with general ABE instruction and therefore provides an indication of the overall effect of the programmatic model, although not mathematics instruction specifically.

Farr (1987) investigated the effects of inference training in learning vocabulary on verbal abilities and mathematics problem solving among 40 ABE students. Half the students had inference training, a predictive reading strategy where they were taught vocabulary skills and reasoning training, and the other students received traditional ABE instruction without the training. Although the main focus of the study was literacy development, mathematics problem solving was included as a dependent variable to ascertain whether training in inferencing in language acquisition would be reflected in other areas. The results showed a correlation between mathematics performance and reading performance. The results also showed that verbal ability correlated with the ability to solve analogies and neologisms.

Irby et al. (1992) conducted a randomized control trial of approximately 25 predominantly black and Hispanic students in an ABE setting; 15 students were in a family literacy project (intervention group), and 10 were enrolled in GED classes only (control). The objective of the study was to evaluate the effectiveness of a family literacy project on the numeracy and literacy levels of adults. The intervention was conducted in a family literacy project comprising several components, and ABE classes were offered twice a week for 12 weeks. Instructors developed individualized educational plans for each student to work at his or her own pace. The results indicated that students in the family literacy project showed a higher average gain in reading and mathematics compared with the GED class.

SUMMARY

In a recent review of the research on the effects of instruction of ABE and ESL students, Condelli and Wrigley (2004) concluded that the research:

> …reflect[s] a haphazard and unorganized approach toward studying adult literacy and [is] not guided by any theory, approach or school of thought about good pedagogy. They do not provide a comprehensive body of knowledge on the impacts or literacy interventions in ABE. (p. 22)

The same can be said of the research studying the effects of instruction in mathematics and numeracy on ABE students. With only 15 studies examining mathematics interventions, almost all of them dealing with the use of technology in instruction, we cannot consider this research a meaningful guide toward directing future efforts in practice or research. The additional 9 research studies on developmental mathematics students suggest promising directions, particularly in studying constructivist approaches toward teaching and learning. However, this research is also limited and indicates a very early state of inquiry.

Besides the need for theory- and standards-driven research, our review has identified a lack of research on instruction for adults that addresses individual learning differences. There are descriptive and theoretical studies on how adults learn, including cognitive influences, learning disabilities, gender differences and motivation, but we found no studies of how learning and instruction interact with these differences to influence the development of numeracy. In addition, we found no research of any type examining instruction to adult ESL learners. There exists no research base at all on how numeracy is taught in ESL classes, let alone studies that examine instructional approaches and their impact on these learners.

4. Assessment Issues in Adult Numeracy

As we have just demonstrated, the research on the impact of instruction on adult mathematics learning has not kept pace with the strides in theory development or conceptualizations in numeracy. The same situation exists in regard to the assessment of adults' mathematics and numeracy skills. There exist very few assessments of mathematics skills for ABE students, and those that do exist do not address critical-thinking and problem-solving skills or other aspects of numeracy. Assessment in adult literacy programs is driven more by the GED tests and the need to meet reporting needs of the National Reporting System (NRS), the adult education program's accountability system.

In this section, we not only review the scant research base and practice on adult numeracy assessment but also reflect on key issues related to the development of effective assessments in adult numeracy education. We bring to the surface issues and dilemmas that can inform the goals of the Adult Numeracy Initiative and a future research and development agenda in this area. We begin with an overview of the purposes of assessments in adult numeracy and the limited related research and take a closer look at the most widely used instruments. We then analyze the nature of an assessment and what can be improved about it and summarize principles and ideas to inform the conceptualization of "good" assessments in numeracy education.

The Purposes of Assessments in Adult Numeracy Education and Related Research

A discussion of the assessment of numeracy in adult education is a complex and at times daunting matter. The very heterogeneous array of adult education programs encompasses varying sizes and formats; the programs operate in different contexts with different degrees of independence; and many of their operations are undocumented. Numeracy education is often subsumed as part of "basic education," "literacy education," "workplace education," "prison education," and other titles, unlike "mathematics education," which normally occupies a prominent and separate space in K–12 school contexts. Hence, numeracy is often *not* discussed as a stand-alone topic.

Purposes of Assessment

Assessments related to the learning of numeracy (and literacy) are undertaken for many purposes associated with needs that learners, teachers, and program administrators face in various stages of activity (Sticht, 1990; Ananda, 2000), as follows:

- *Entrance stage.* Assessments are conducted as part of an initial diagnosis of incoming students' skills, capacities, and work habits. Assessments inform decisions about placement, help set learning goals, and influence the choice of curricula and teaching/learning methods. In the context of numeracy learning, entrance-stage assessments may also have to detect whether learners have informal mathematical knowledge, math anxiety, or other characteristics that may contribute to or affect further learning. Additional assessments may be needed for new students who show evidence of having special learning needs; the results of these assessments may have an impact on decisions about special accommodations or adaptations so that these learners can demonstrate their full range of capacities (Sacks & Cebula, 2000).

- *Teaching / learning stage.* After a period of learning, assessments may be used for formative evaluation or feedback, that is, to monitor learners' progress, examine areas of strength and weakness, and help with designing a further course of study or deciding on needed interventions. When learning is undertaken with the goal of eventually passing a formal, external test (e.g., GED, workplace certification), selected exams or practice tests may be used intermittently to determine whether learners are ready to engage in the real test. At the entrance stage and at this stage, assessments may involve a mix of teacher-developed or locally designed methods, both written and oral, as well as formal instruments from external sources (e.g., commercial standardized assessments, GED practice tests). The assessments should enable *both* the teacher and the learners to understand the interpretation of the results of the assessment and the logic underlying decisions.
- *End/exit stage.* When learners end their prescribed program of studies, or when programs need to measure learners' progress because of accountability reporting demands by sponsors (e.g., the NRS) or as part of accreditation schemes, assessments may be used to document overall learning gains and thus serve a summative function or help with program evaluation. At times, the end stage may be a stepping stone into a new cycle of learning numeracy or mathematics at a higher level; hence, summative assessments may also serve a diagnostic function.
- *Other assessments.* Although partially overlapping with the uses of assessment above, sometimes assessments are conducted as part of research projects by academic researchers or by state and federal agencies. They may be part of program evaluation initiatives that emerge from the needs of stakeholders other than the learners, teachers, or administrators linked with a specific program. These external demands may affect the time allotted to assessments or the level of motivation of those being assessed.

Related Research

Our review of the literature shows that it is difficult to locate publications relating to adult numeracy assessment because this topic is usually intertwined with assessments pertaining to literacy and other skill areas. Hence, the knowledge base we uncovered is quite limited and patchy. Below are examples illustrating the dearth of attention to assessment related directly to numeracy learning.

- Of a total of 88 presentations, workshops, and discussion groups in the proceedings of the last three conferences of ALM (Adult Learning Mathematics, an international forum of researchers and practitioners) held in 2002, 2003, and 2004, only 4 discussed assessment; only 2 of these presented empirical data (both on the same single study).
- In the 2002, 2003, and 2004 issues of *Adventures in Assessment*, a widely read online magazine published once a year by SABES/World Education in

Massachusetts for adult education practitioners nationwide, only 1 of a total of 20 articles examined mathematics assessment.

- In the *Research Companion to Principles and Standards for School Mathematics,* published by NCTM in 2003 (Kilpatrick, Martin, & Schifter, 2003), out of 23 core chapters, only 1 directly examined assessment issues.

Few authors in the sources above directly addressed numeracy assessment, yet quite a few touched on more general issues with *relevance* to numeracy assessment, such as problem-solving processes, task authenticity, the role of context demands on performance, the impact of dispositions such as beliefs or attitudes, the nature of mathematical practices in workplace versus school contexts, and many more. This finding should not be too surprising because assessment serves many useful functions in any learning and teaching context and affects what learners, teachers, and programs do, yet it is a *support* activity in the service of larger goals.

Indeed, in the literature search we conducted for this review, numerous articles presented opinions and models for assessment or reported on studies that used assessments of numeracy skills (e.g., to evaluate learning gains). Few sources, however, focused on the characteristics of adult numeracy assessments or on their improvement as an object of scholarly inquiry and empirical research. Most of those that did were *not* related to adult education per se, but to the development of policy-driven research projects and large-scale assessments (Kirsch, Jungeblut, Jenkins, & Kolstad, 1993; Gillespie, 2004; Gal et al., 2005; Ginsburg, Cooke, Leinwand, Noell, & Pollock, 2005; Brooks, Heath, & Pollard, 2005). On a broad systemic level, assessments of adults have been examined in connection with the development of the NRS and the search for performance measures that can satisfy accountability requirements or in the context of planning for the National Assessment of Adult Literacy (Stites, 2000). These efforts looked across a range of skills, with literacy (i.e., language-related skills) at the forefront and numeracy in the background, sometime in a restricted sense, such the notion of “Quantitative literacy” as defined in the NALS (Kirsch et al., 1993) and subsequently in the NAAL.

Over the last 10 to 15 years, several monographs have examined aspects of assessments in adult education programs. Some looked at assessment issues in general (Rose & Leahy, 1998) or reviewed a broad range of assessment tools (Sticht, 1990), whereas others focused on methods that can be used for assessment in specific contexts, such as teaching workplace literacy (Taylor, 1997; Sticht, 1999) or English language learners (Van Duzer & Berdan, 1999). Some projects focused less on instruments and more on ways the assessments can be incorporated to support teachers’ ongoing work (Ananda, 2000) or on considerations affecting the decisions of administrators or teachers to adopt one assessment scheme over another (Nagel, 1999).

Only two reports were found on issues in numeracy assessment in the context of adult education programs, yet they are of partial use in the present context. Cumming, Gal, and Ginsburg (1998), as part of the Numeracy Project at the National Center on Adult Literacy (NCAL) and with the goal of informing practitioners and program personnel more than policymakers, examined principles for good assessment and limitations of methods in field use, especially of the TABE test. Although informative, this review referred to TABE versions 5-6, which have since been replaced by versions 7-8 and, starting in 2003, by TABE 9-10 whose content has changed somewhat.

As part of a project of the National Literacy Secretariat in Canada, Hagedorn and colleagues (2003) examined several numeracy frameworks and provided a detailed description of the features of the "math" component of three tests in widest use (GED, TABE, and CASAS). They also examined the EFF mathematics standards, already introduced in Section 2, and the numeracy aspects of the NRS. Both the EFF and the NRS descriptors are not tests; rather, they outline the content areas or skills that adults are expected to develop during instruction and thus have to be eventually assessed. Although useful as a summary of existing frameworks with implications for assessment, the Hagedorn report was meant to be descriptive and does not provide a critical analysis of tests or frameworks.

OVERVIEW OF WIDELY USED INSTRUMENTS FOR ABE NUMERACY ASSESSMENT

With the implementation of the NRS, all states must now use for reporting purposes a standardized test to measure educational gain in ABE and ESL students. *NRS Implementation Guidelines* require that tests must be reliable and valid; allowable tests include the Tests of Adult Basic Education (TABE), the Comprehensive Adult Student Assessment System (CASAS), the Basic English Skills test (BEST), and the Adult Basic Learning Examination (ABLE)(OVAE, 2005). Although these requirements do not preclude the use of other types of assessments (e.g., nonstandardized) for other needs of teachers and programs as long as they are reliable and valid, most programs have adopted the mathematics sections of the TABE and CASAS (Gal & Schuh, 1994) to measure the mathematics abilities of ABE learners.

We now take a look at these two assessment instruments and critically evaluate them in light of the numeracy definitions and instructional frameworks presented earlier. In addition, we also note the GED test, which for many adult education programs serves as an important target or milestone as they prepare ABE learners.

TABE

The TABE is a family of widely used standardized tests published by CTB/McGraw-Hill. The most recent revision of the tests, version 9-10, was put into use in 2003 (TABE 2003a, 2003b, 2003c). In addition to various subtests related to literacy, two of the TABE subtests assess "mathematics computation" and "applied mathematics," each with 40 to 50 multiple-choice questions presented with four response options. The test is norm-referenced (i.e., scores are computed in reference to a norming group of adults), and results are usually reported as grade-level equivalents divided into five levels, from preliteracy (level L – equal to grades 0–1.9) to Advanced (level A – equal to grades 8.6–12.9). The TABE system includes a Locator test and a short Survey form that according to the publisher can be used to help place students at different levels. At each level, two equivalent forms exist, presently 9 and 10, which according to the publisher can be used to measure growth and educational gains as pre- and posttest measures. It is important to note that the TABE is a skill-based test; that is, most items measure specific skills (e.g., whole number operations, conversion of fractions), often with relatively little contextual information. The publisher claims that the revised forms 9-10 offer better coverage of key areas of mathematics. The training materials for teachers, also from the publisher, indicate that the higher skill levels use not only items in arithmetic but also some that touch on measurement, geometry, statistics, and algebra. That said, no systematic analysis has been published of the actual content by which we could evaluate these claims, and presently it appears that teachers and programs are expected to use the test on the assumption that it is "better" but without having access to much detailed information regarding its alignment with instructional goals.

CASAS

The CASAS is widely used for assessing adult basic reading, mathematics, listening, writing, and speaking skills. The CASAS (2004) manual claims to measure some 300 separate *competencies* by using items couched in realistic *functional* contexts. CASAS was designed from the outset to offer an integrated system for assessment, training, and evaluation. It offers more than 100 separate tests, which measure groups of competencies at different levels of ability by using items that examine proficiency in performing specific tasks involving solving life-skill problems or applying general reading and mathematics skills. Like the TABE, the CASAS uses only multiple-choice items, although the emphasis is on dealing with such real-world situations as workplace, community, or family tasks, all of which may involve the activation of multiple skills. The CASAS manual does not explain exactly how the tests are scored, but it appears that test scores are based on the difficulty estimates for each item, which were derived through IRT (Rasch) scaling. Scores are usually reported on a numerical scale ranging between 150 and 250, commonly divided into five levels from A (beginning literacy) to E (advanced adult secondary).

Both the TABE and the CASAS claim that using the tests enables programs to establish measurable goals, conduct diagnostic assessments, document learning outcomes, and report program gains to students, staff, and external stakeholders. Practitioners who want to use the tests in educational contexts are offered various suggestions for *accommodations* in test administration for students with special learning needs. The test publishers claim that these accommodations do not change what the tests intend to measure. Further, numerous tables of "correlations" are available from the publishers, which link specific test items or scale scores to various chapters or units in a diverse range of instructional materials, thus enabling teachers to assign learning resources to students who fail specific test items. In particular, the CASAS (2004) technical manual provides numerous tables showing linkages or mapping between CASAS levels and levels or score ranges for other systems or measures, such as NRS, EFF, GED, and NALS.

The developers of both assessment systems claim that their instruments undergo rigorous test development and validation procedures and meet common psychometric standards. The CASAS technical manual lists various studies that have provided information about the tests' validity, such as content validation through various procedures involving different stakeholders, positive association between CASAS scores and learning gains, or positive correlations in linking studies between CASAS scores and GED mathematics scores. The TABE Web site presents more modest information (undated report) on the same topics, such as positive gains in programs that used CTB/McGraw-Hill instructional materials and measured performance by TABE forms and positive correlations between TABE scores and grade levels in school.

It is important to emphasize that the recent GED 2002 versions have been developed on the basis of the NAEP Mathematics Framework, and item types and their proportions in the GED are designed to reflect NAEP content guidelines. Both the TABE and the CASAS are *not* expressly designed to reflect NAEP, yet both show as part of their validation data that scores on the TABE or the CASAS are highly predictive of scores on the GED. Given that the CASAS is competency-based and the TABE is skill-based, further analysis is warranted to understand what cognitive and other processes are at work when learners work on all these different instruments yet achieve highly correlated results.

A Critical Look

The TABE and the CASAS are widely employed, yet they have differences in logic, construction, and use. Nevertheless, they both appear to be reliable and valid as far as standard techniques and published sources allow us to evaluate. Various concerns and questions can be raised that touch on validity, construct coverage, permissible interpretations of the meaning of test scores, and alignment between assessments and instruction. These concerns are presented below regarding the TABE and the CASAS, but they are just as relevant when evaluating the quality of other assessments:

- Both tests claim to have good content validity, in part ascertained by interviewing diverse educators and learners, yet little information is published regarding their underlying construct. Both, and especially the TABE, purport to cover key mathematical subdomains such as number, measurement, algebra, and statistics (in the higher skill levels). These appear to be linked to well-known frameworks of mathematical knowledge, such as the one from NCTM. However, little published information exists (from test publishers or other sources) about the extent to which the tests cover broader facets of numeracy and acknowledge the nature of the everyday mathematical tasks and problems that adults have to solve. We are *not* claiming here that they do not do so—only that there is no published materials on the underlying construct and its coverage. For example, test manuals do not report the percentage of items representing the key subdomains or having high versus low literacy demands. The Massachusetts Department of Education (2005) compared the content of TABE, AMES, CASAS and ABLE to the state curriculum frameworks. The analysis found that the TABE is best aligned to the state's ELA and Math standards, but the TABE items aligned with only 50% of the framework and the test has limited ability to provide information deemed essential for teachers and students.
- How is it possible to reconcile the fact that one test (TABE) is skill based and one is competency based (CASAS)? On the one hand, a test that emphasizes assessing skills in a decontextualized context may not provide much information on learners' capacities and competencies in a functional context. This is a serious issue from the point of view of skill transfer because there is no valid evidence that skill transfer can happen. Indeed, research on everyday mathematics, noted above, suggests that the transfer of school or decontextualized learning is difficult. On the other hand, the demonstration of competencies in a functional context may be domain-specific (Strasser, 2003) and learners may not have more generalizable skills. A related research question asks to what extent are the

practitioners who are using the tests aware of the tests' different logic and the implications for the interpretations about skills that can be drawn from each test?

- There is a long-standing awareness of the limitations of forced-choice items, used by both the TABE and the CASAS, to reflect reasoning, problem-solving, or communication skills (Sticht, 1990). A further limitation of the TABE results from its extensive reliance on problems that involve little or no text, ignoring the inherent links between numeracy and literacy skills in everyday functional contexts. The CASAS involves more stimuli with text in them, but test-takers do not have to produce any text. Thus, the tests do not address the expectation that learners of mathematics are also able to "communicate mathematically" (NCTM, 2000; U.S. Department of Labor, SCANS, 1991).
- Both tests expect accurate results that can be clearly classified as right or wrong. However, many real-life situations call for approximate answers, estimates, or opinions or judgments rather than for accurate results. Further, both tests score performance in terms of correct/incorrect responses. They ignore the possibility of a partially correct response. Yet, recent large-scale assessments of mathematical skills employ scoring systems that give credit to partial responses (such as TIMSS and PISA; Ginsburg et al., 2005) or accommodate various levels of accuracy in responses (such as ALL; Gal et al., 2005). The upshot is that because of their forced-choice format, both the TABE and the CASAS lose information about the skills of the adults being tested—it is technically feasible to accommodate more levels of performance in ways that better reflect the nature of adults' numeracy.
- There are claims that a hierarchy of skill levels cannot be ascertained in all areas of mathematics (Kilpatrick, 2001; Gal et al., 2005). It is unclear how the developers of the two tests have coped with this issue in their suggestions for interpretation of test results. This is especially true of the TABE, where raw scores are converted into grade-level equivalents, given known limitations of grade-level equivalents (Spruck Wrigley, 1998; Sireci & Zenisky, 2003).

Overall, the TABE and the CASAS assessments reflect definitions of adult numeracy within the *formative* and *mathematical* phases in the Maguire and O'Donohue framework discussed in Section 2. Neither assessment is adequate for conceptions of numeracy in the *integrative* phase, such as those embodied in many of the standards and frameworks influencing the field. The NRS descriptors for numeracy also reflect the formative and mathematics phases of numeracy, with most skills related to arithmetic or "number." Additional numeracy-related skills are listed under "functional and workplace skills" and mainly call for the ability to read graphs and charts, deal with forms, and "solve multi-step problems." This last statement implies an integration of skills, giving the NRS descriptors a "split personality" when it comes to numeracy issues.

Tests that assess skills such as problem solving and critical thinking are difficult to develop. They are also hard to implement in the ABE system because they are time-consuming to administer and difficult to score. However, assessments reflecting the integrative approach to numeracy are used in the Netherlands as part of its national Realistic Mathematics Education (RME) curriculum for adult students and in Australia for its Certificates in General Education for Adults (CGEA) framework (Tout & Schmitt, 2002).

The implication is that it is possible to create assessments that align with overall instructional models. Assessment should focus educators on broader instructional goals and be designed in a way that will not encourage teachers to "teach to the test." Many programs already use the GED test as a de facto definition of what students need to know. This situation may become more ingrained with the increased use of both the TABE and the CASAS, which are sanctioned for use by many states and programs to meet NRS demands.

DEFINING THE MEANING OF ASSESSMENT AND HOW IT CAN BE IMPROVED

The absence of recent studies and critical analyses related to assessment in adult numeracy programs justifies the current review of assessment issues in the Adult Numeracy Initiative. As a starting point, we briefly reflect in this subsection on the nature of assessments and how they can be improved before discussing in the next subsection the criteria for "good" assessments in the area of adult numeracy education.

Definitions of assessments may vary, yet in one way or another, they all discuss a systematic process for collecting and evaluating information about people (Anastasi, 1997). In the context of learning mathematical topics, Wilson and Kenney (2003), using the NCTM *Assessment Standards* (1995), explain that the information collected pertains to "a student's knowledge of, ability to use, and disposition towards, mathematics." As Wiggins (1992) has aptly warned, however, all too often there is a tendency to equate assessment with testing and to assume that testing is a simple, complication-free process that yields clear-cut results. Instead, it should be acknowledged at the outset that assessment is far from being a simple or unitary construct and that the complex nature of an assessment has implications for how it can be improved.

An analysis of various claims and ideas raised in the testing and assessment literature over several decades (e.g., Cronbach & Gleser, 1965; Messick, 2000), coupled with an analysis of the multiplicity of purposes of assessments in adult numeracy education and of the diverse ways in which they can be used by learners, teachers, and programs, shows that an "assessment" as used in adult education has at least four key components.

First, all assessments use an *information collection* component, a process or sequences of steps and activities for gathering data in diverse ways (Anastasi, 1997). The collection may involve a tool, a person, or both (e.g., a written GED test, a teacher using a scoring rubric to grade a learner's written solution to a word problem or the contents of a cumulative portfolio of a learner's class work over a period of time, an observation form for rating an employee's performance on a work sample used for workplace licensing, a computer-based questionnaire). The tools themselves may have different degrees of formality or complexity. Artifacts or technical aids, such as a hand-held calculator, a ruler, or computer software, may be involved and used by the learner.

Second, an assessment usually activates a *judgment/evaluation component* in which information from different sources (e.g., subtest scores, performance on functional tasks, teacher observations) may first be integrated or combined and then evaluated. In this component, *meaning* is given to collected data, and *interpretations* are reached on the basis of expectations, performance standards, norms, and the like, whether implicit (e.g., a teacher's informal evaluation) or explicit (e.g., number of correct responses compared with national norms, IRT scaling of responses of groups of test-takers). When the data collection involves a simple test (e.g., a single TABE booklet), the evaluation of a person's performance may appear simple and free of human judgment, as in the calculation of a total raw score on a test and its conversion to a grade level equivalent. However, when we examine the overall range of occasions when information about a specific learner is collected and evaluated, we clearly see that many judgments and interpretations are involved. As the psychological testing literature has repeatedly emphasized (e.g., Goldberg, 1986), people's judgments and interpretations in such situations may be affected by multiple factors and may have different degrees of accuracy or validity. Consider the challenge of evaluating whether a learner "knows" or "does not know" a certain mathematical construct or procedure when the learner is not a native speaker of English or is anxious. In these and similar circumstances, the teacher/assessor has to decide what (if any) allowance to make for language or learning style differences, and the judgment process may be affected by a host of seemingly external but at times very relevant factors.

Third, the assessment will often involve a *decision component* that may be interwoven with the first two components (Cronbach & Gleser, 1965). For example, a student may be routed to different test forms on the TABE on the basis of the TABE Locator test or may receive different items as part of a computerized adaptive test system that is based on preliminary item parameters chosen by researchers. Another example occurs when a teacher has to decide whether to introduce an accommodation (e.g., add testing time, rephrase a question) because of personal characteristics of a specific learner, and if so, how far to go in this regard.

Fourth, assessments in educational contexts always involve a *human component* because people may be the object of the assessment, conduct the assessment, or examine its results and reach some conclusions. Teachers or administrators involved in the assessment pathway have beliefs, attitudes, emotions, and both personal and organizational motivations. The performance of learners undergoing assessment may be influenced by dispositional factors discussed in earlier sections (e.g., math anxiety or test anxiety, beliefs about testing) or by motivational factors (the perceived importance of the learning of mathematical topics, or of the assessment event itself, in the context of the learner's life course and goals). The learner-related factors and teacher-related factors may operate separately or interact with each other, and they may have an impact on the behavior, attention level, or degree of effort invested by those being assessed or doing the assessment.

Finally, *value judgments* affect all the other assessment components in explicit or implicit ways. Test planners, administrators, teachers, and learners may operate in different social or organizational ecologies and may have different perspectives on issues such as what is *important* to measure or what is a *fair* assessment. Adult education staff who administer the assessments, often lack sufficient training on the purpose, administration and scoring of tests and impose their own judgment and values on assessment. This lack of training and understanding may lead to improper administration, invalid scores and incorrect interpretation of outcome measures. Experts interested in psychological and educational testing have time and again argued and demonstrated that values affect choice of data collection methods, interpretations, judgments, and behaviors of stakeholders involved in an assessment (Messick, 2000). The recognition of the centrality of values and the influence of the human component on all aspects of the assessment pathway (e.g., test planning, selection of a data collection method, interpretations of performance, decisions) has led to a strong emphasis on the need for thorough training for those involved in assessing human capabilities

(Alfonso & Pratt, 1997). This recognition has also led various professional associations to establish professional standards in this area.

It follows that assessment is a complex, dynamic system. It can combine technical elements and supporting artifacts. It involves human interaction as well as internal and external actions and choices of individuals. It unfolds over time and is conducted in a social context that presents diverse demands on those being assessed. Both the inner workings (setup, artifacts used or not, evaluation of performance, time limits imposed) *and* the outcomes of an assessment (scores, written evaluation, pass/fail decisions) are influenced by criteria or values imposed by the assessment designer, by the beliefs and training of the humans conducting the assessment, by the motivation and reactions of those being assessed, and by organizational stakeholders.

These considerations lead us to two important realizations:

- **Judgments** regarding the "goodness" or "quality" of an assessment can refer to *any* of its components—not only to the collection methods (e.g., content and format of test items or tasks used) but also to the stages involving integration and interpretation, or decisions. Further, given that assessments always involve humans and are embedded in a certain context, the quality of an assessment may also be related to such associated factors as the demand characteristics of the testing context, time limits, artifacts used, training of the people involved, and the values or criteria applied when interpreting performance.
- **Improvements** in an assessment can relate to any of its components or associated factors described above, either alone or in combination. Further, assessments in adult numeracy education usually occur in an organizational context (e.g., ABE program, community college, workplace); hence, broader institutional or systemic issues can also be examined and improved, such as how assessment processes are scheduled or budgeted, the criteria that program directors use for choosing one assessment method over another, or the professional qualifications and preparation of those administering assessments or interpreting their results.

Considerations for Developing Improved Assessments for Adult Numeracy

If we have concerns about current assessments, we should first consider what criteria to use to make value judgments about them and then reflect on whether these criteria are the right ones. Discussions of what counts as a good assessment often begin with a description of a set of general principles or criteria. The literature on psychological and educational assessment invariably states that assessments should be examined in terms of their *reliability* and *validity* and specifies multiple types or forms of each of these two key psychometric properties (Anastasi, 1997). The testing literature has also referred, using somewhat different terminology, to various other important aspects of assessments, such as *degree of standardization* of an instrument (seen as reflecting its degree of subjectivity or objectivity); *cost* of testing; *ease of scoring and usage*; *fairness* or *discrimination*; and *utility*, a concept related to the contribution of a test to an organization making acceptance/rejection or placement decisions (Cronbach & Gleser, 1965). These attributes of assessment are typically required of all high-stakes educational assessments. Indeed, the NRS *Guidelines* require all adult education programs to use standardized, reliable, and valid assessments.

However, in discussing the assessment of *numeracy*, we must note additional principles or ideas, especially by those involved in teaching the relevant subject matter. The U.S. mathematics education community has articulated several principles for assessment as part of the reform movement, which started two decades ago. The Mathematical Sciences Education Board (1994) enumerated three principles of good assessment in mathematics: the *Content Principle* (assessment should reflect the mathematics that is most important for students to learn), the *Learning Principle* (assessment should enhance mathematics learning and support good instructional practices), and the *Equity Principle* (assessment should support every student's opportunity to learn important mathematics). NCTM's (1995) *Assessment Standards* raised additional points, later reiterated in its *Principles and Standards for School Mathematics* (2000), regarding *openness*, *valid inferences*, and *coherence* of an assessment with the curriculum and instruction.

The mathematics-oriented assessment principles echo several key ideas found in the general testing literature, especially regarding validity, fairness, and utility. Yet, these principles go above and beyond technical demands for validity and reliability and bring new elements into the discourse about good assessments of numeracy skills. They also encompass the nature of mathematical knowledge, the intended goals of the learning process, and the varied uses of an assessment or its influence regarding the learner, the teacher, and the program. Messick (1989) has argued that validity should be viewed broadly as the extent to which empirical findings and theoretical rationales support the *appropriateness of inferences* and *actions* based on test scores or performance on the assessment instrument. However, the actions taken by a teacher and a learner *after* they know an assessment's results are seldom based on the assessment itself. Rather, such actions are influenced by the broader ecology or context within which the assessment takes place and within which the teacher and the learner operate. In particular, an assessment becomes meaningful when there is a linkage among the assessment, the curriculum, and the learner's own goals (which are especially important for adult learners; Donovan, 2002), as well as when both teachers and learners believe that an assessment measures valued skills or capacities. It thus becomes paramount to examine what content areas related to mathematics and numeracy are important for adults to know.

What Should Be Assessed in Adult Numeracy Instruction?

The answer to this question will affect our judgment of the quality of different assessments in numeracy education. However, the answer is complex because it depends on the breadth of the analysis being attempted and on the extent to which we go beyond traditional ideas that equate mathematical knowledge with mastery of basic arithmetic concepts and accurate execution of computational procedures.

Section 2 has already reviewed several perspectives on the concept of numeracy, clustered into three groups or phases: formative, mathematical, and integrative. Below we summarize these and also consider additional key influences that help us sketch the nature of the skills, knowledge, and dispositions that are part of the constructs that could be the focus of teaching/learning, and hence also of assessments, in the field of adult numeracy education:

- Curriculum frameworks and statements regarding the goals of mathematics learning for adults and young adults (e.g., Australian Committee for Training Curriculum, 1994; Curry et al., 1996; NCTM, 2000; Stein, 2000) present a broad set of areas for learning: knowledge and understanding of numbers and operations that involve computation, as well as number sense and estimation; algebra and modeling; geometry and shape; measurement; and data and chance. In addition, knowing mathematics involves problem solving, reasoning, and communicative capacities as well as an understanding of connections and representations of various mathematical ideas.
- Conceptions of workplace skills (e.g., U.S. Department of Labor, SCANS, 1991; Mayer, 1992; Packer, 1997; Forman & Steen, 1999) further show that effective functioning on the job involves not only a diverse set of mathematical and arithmetical skills but also broader knowledge and skills related, for example, to the ability to allocate resources, handle scheduling, understand the role of quantitative information in the operation of systems, and use technological tools to quantify or display quantitative information.
- Teachers and the professional literature have mostly addressed the acquisition, teaching, and learning of language skills and mathematical skills as two separate areas of inquiry and practice with little crossover (Gal, 2000). However, many real-world functional tasks require adults to integrate numeracy and literacy skills. Examples are interpretive tasks that do not require the manipulation of numbers but do require the expression of opinions (e.g., statistical literacy tasks, decision tasks involving notions of chance) and other tasks that involve numbers or quantitative statements embedded in text (e.g., forms, schedules, manuals, technical and financial documents, statistics in the media). Kirsch and Mosenthal (1993) integrate numeracy and literacy in their literacy model, which comprises prose, document, and quantitative components. The integration of these skill areas underlies the design of various large-scale surveys of numeracy and mathematical skills, such as the NALS, the International Adult Literacy Survey (IALS), NAAL, and the recent ALL survey (Gal et al., 2005), and the design of some quantitative literacy tasks in the Trends in International Mathematics and Science Study (TIMSS).
- The research on ethnomathematics, briefly discussed in Section 2, has focused on the nature of everyday mathematics. One of the conclusions in this literature is that differential performance can occur when assessments are divorced from, as opposed to contextualized in, realistic settings (Lave, Murtagh, & de la Rocha, 1984). Problem solving in contextualized real-life and work activities may be complex and different from solving school-like problems (Resnick, 1987; Greeno, 2003). Many researchers (e.g., Strasser, 2003; Wedege, 2003) discuss the hidden aspects of workplace mathematics and point to the fact that workers often have trouble identifying the "math" in what they do or encounter. These and other observations suggest that good assessments need to enable learners, teachers, and programs to identify the ability to transfer and apply learned numeracy skills in real, functional contexts, but not only those where the mathematics is explicit and obvious. At the same time, the ability to handle functional numeracy tasks will not necessarily imply that a learner has acquired generalizable skills or the ability

to handle abstract or more formal mathematical concepts and ideas. Thus, a mix of both functional and more abstract tasks may be needed.

- Finally, many studies and curricular frameworks emphasize the critical role that positive *attitudes, beliefs, and habits of mind* (collectively called here *dispositions*) can play in supporting effective and confident numerate behavior and in enhancing adults' ability to manage the mathematical demands of different situations (MacLeod, 1996; Gal, 2002b). Indeed, items measuring selected dispositions associated with mathematical activities and feelings about mathematics are part of major large-scale assessments in the mathematical areas (e.g., NAEP, PISA), and more elaborate scales have been included in the ALL survey and shown (Gal et al., 2005) to correlate positively with performance.

Overall, the picture emerging from this review is that it is presently unclear how well statements about target skills or curricular standards (as reflected, for example, in the EFF and ANN standards, or in the NRS skill specification) are linked to the structure and content of key assessment schemes and how all these are aligned with instructional practices. Too little is known about the types and uses of assessments developed locally by teachers or programs, and no systematic analyses have been conducted of the mathematics or numeracy components of the most recent versions of the TABE, the CASAS, and other assessment systems. Clearly there is room for states and programs to develop or experiment with assessment systems that offer better or at least more explicit alignment with curricular goals and teaching methods, and some states (such as Massachusetts or Ohio) have recently begun to take steps in this direction.

CONCLUSIONS

Multiple factors converge to challenge anyone trying to summarize the "state of the field" in numeracy assessment or to offer any quick fixes. The scope of the objects to be assessed (e.g., skills, capacities, dispositions) and the deficiencies of current assessment methods depend to some extent on the eye of the beholder. Definitions of numeracy vary, from relatively narrow notions that focus on computational or procedural skills to broader, integrative views that go well beyond computations and encompass a broad set of mathematical skills, communicative and interpretive abilities, supporting dispositions, and skill transfer. The teaching/learning contexts in which adults engage with numeracy-related topics vary greatly given the diversity of backgrounds, ages, or purposes for learning that adults bring. Conceptions regarding the goals of adult numeracy education and of the competencies to be developed evolve over time and are affected by multiple stakeholders (Curry et al., 1996; Forman & Steen, 1999; Kilpatrick, 2001).

Policymakers' pressures for accountability have an impact on what skills are deemed important and assessed (or not) by programs and teachers (Stites, 2000). Funding and program accountability requirements, and especially the NRS, place different emphases on preferred forms of assessment, although they allow the concurrent use of tests that provide different types of information of varying qualities. This approach may provide information that learners have made some progress, but what exactly that progress is and whether the progress is toward valued goals cannot be fully ascertained from the reported information provided by current instruments. The reliance on only standardized tests for reporting, tests that presently rely on multiple-choice format, runs the danger of pushing more teachers to "teach for the test" and stay away from using assessment approaches that rely more on performance in diverse forms, such as oral presentations, portfolios, or various locally developed assessments (which are quite popular with adult educators in countries such as United Kingdom and Australia).

Given NRS demands, there is likely to be a tendency to use only one or two styles of information gathering for multiple purposes (Nagel, 1999; Messemer & Valentine, 2004). The use of only one or two instruments may in fact have some advantages; for example, it can enable learners, teachers, and funders to use a consistent system of concepts and interpretations when reporting and discussing assessment results. Yet, the use of only one or two instruments may be problematic, given on the one hand the different needs of learners, teachers, and programs and on the other hand the breadth of the numeracy construct (at least according to the integrative views presented in Section 2) that is at present only partially addressed by existing large-scale assessments. The multiplicity of purposes or contexts of the uses of assessment outlined earlier implies a need for different forms and types of information gathering and interpretation at different points during a learner's progress in a program. The reports covered in our review do not contain much information on the extent to which the assessment methods in use in programs are sufficiently differentiated in terms of these multiple purposes—they may be, but this issue requires further investigation, given that in each assessment only a limited number of items are used.

As Cumming & Gal (2000) have argued, teachers have a key role in changing assessment practices. Teachers need to reflect on their goals and curricula in light of extant perspectives on the goals of mathematics learning for adults and how well assessment practices are aligned with such goals to better cover the full range of skills and dispositions expected of numerate adults. Eventually, however, most instruction is delivered at the individual teacher level. The teacher is thus the main player and a strategic partner whose knowledge, values, decisions, practices, and training need to be considered when thinking of improving assessments in ways that can better address instructional, validity, and accountability needs.

5. Professional Development in Adult Numeracy

One of the major thrusts of the Adult Numeracy Initiative and of the states is to improve the quality of instruction in adult education. Several states have moved in this direction by developing content standards, many of which model the ANN and the NCTM standards, and by implementing numeracy initiatives and policy changes to foster better adult numeracy teaching. The vehicle by which states can implement these changes into practice, however, is professional development that improves an instructor's knowledge and skills to teach the mathematical content and processes reflected in the standards (Gal & Schmitt, 1995). Professional development is regarded as a key mechanism for strengthening the instructor's content knowledge and teaching and learning processes.

This section explores issues in numeracy professional development, examines the gaps in professional development in adult numeracy, and sheds light on how numeracy-based professional development is positioned in literacy-driven programs. It also offers a brief review of research on professional development in general with attention drawn more specifically to research related to numeracy professional development, including professional development quality.

Very little research in this area has been conducted on adult education teachers. We supplement this sparse research with studies from the K–12 research literature, although we recognize the vast differences between the characteristics of teachers, the teaching environment, and professional development opportunities in K–12 and those in ABE.

Issues in Professional Development

Professional development is considered a principal vehicle for advancing educational improvement on both a national and a local level. As long as there is a need to restructure education, professional development will remain an imperative device for steering educators to effective practice and for improving their instructional capacity. Through professional development, teachers gain opportunities to collaborate with others in their field, initiate practitioner research, model instructional techniques, and even apply theories and concepts to real classroom activities.

Primary issues related to professional development in adult numeracy are vast and varied, which has implications for defining quality professional development practices for adult numeracy. The scant research on professional development in the context of adult numeracy and basic education reveals little about well-tested, professional development–driven directions for improving ABE numeracy practice in general and highlights gaps and needs in professional development in ABE numeracy in relation to teacher capacity. The close relationship between literacy and numeracy shrouds a clear picture of the quality and quantity of numeracy professional development that is offered. Furthermore, the lack of a standard definition of numeracy thwarts opportunities for a proper conceptualization of ABE numeracy professional development, which presents a challenge in examining literature to identify quality, common practices, and the potential for replicable interventions.

Need For Professional Development in Numeracy

Adult education teachers appear to be especially unprepared to teach mathematics, which makes professional development in the area of numeracy essential. Many adult numeracy teachers come from the K–12 arena where there is already a shortage of qualified teachers (Darling-Hammond, 2000). For example, the California Commission on Teacher Credentialing (CCTC, 2004) reported that in the 2002–2003 school year, more than 20,000 teachers in California were teaching with emergency permits and credential waivers. To complicate matters, a huge percentage of ABE instructors teach on a part-time basis, which gives them very little opportunity to receive adequate professional development and training. Gal's (2002a) review found little evidence of mathematics training among adult education teachers, with fewer than 10 percent of teachers reporting that they were certified in mathematics. Gal also observed that there are no university-based graduate programs on teaching mathematics to adults, although in Australia, some efforts have been made to provide adult numeracy teachers with opportunities for professional development (Tout & Johnston, 1995; Marr & Helme, 1991; DEET, 1993).

Lack of preparation is compounded by low teacher retention (National Commission on Teaching and America's Future [NCTAF], 2003), especially in low-income urban areas likely to have high numbers of adult numeracy students. Many teachers in these areas are responsible for teaching multiple subjects for which they are not trained to teach. This seems to be an international trend. The U.K.'s Advisory Committee on Mathematics Education (ACME, 2002) points out that with a shortage of professional development opportunities in the K–12 setting in general, finding quality professional development could be a hard test for those who teach adult numeracy. For K–12 teachers who also teach ABE part-time, hardly any content-based professional development opportunities are available. The same situation can be said to exist in the United States.

The lack of adequately trained teachers has consequences for student achievement and for educational reform. Although no research has measured the relationship between teacher preparation and the achievement of adult numeracy students, research done with children (Rice, 2003) shows that teacher preparation had the strongest correlation to student achievement in reading and mathematics. Coben (2003) notes that:

> Adult numeracy teacher education is currently undergoing major transformation. Some teachers' inadequate subject knowledge is a continuing concern. Studies with children suggest that: initial and ongoing teacher education increases subject knowledge, facilitates career development and encourages future research and development; effective teaching correlates with engagement in continuing professional development. (p. 7)

Inadequately trained teachers will be unable to help students achieve in numeracy if they do not know mathematical content, if they are not trained in pedagogical principles specific to or appropriate for the adult learners represented in most adult education programs, or if they have been inadequately prepared to meet state standards (ACE, 1999). Research shows that a substantial number of teachers learned to teach by using a model of instruction that focuses on memorizing facts (Darling-Hammond & McLaughlin, 1995; Porter & Brophy, 1988) without integrating procedural and conceptual instruction (Desimone, Smit, Baker, & Ueno, in press). They may not have been taught to integrate procedural and conceptual instruction and thus focus on rote memorization (Leonelli & Schwendeman, 1994) and decontextualized situations (Lionelli, 2005), strategies deemed futile for adult numeracy students (Coben, 2003; Skemp, 1986). Owing, in part, to the inadequacy of adult numeracy training, teachers tend to pivot back on traditional pedagogical techniques (Little, 1993; Loucks-Horsely, Love, Stiles, Mundry, & Hewson, 1998; Sparks & Loucks-Horsely, 1989). Some teachers are not trained adequately in the mathematics principles (Massachusetts ABE Math Team, 1994) and concepts needed to teach numeracy; they often teach numeracy the way it was taught to them in school and incorporate methods they learned in college (Leonelli, 1999). Adults need "good numeracy provision" (Newmarch, 2005) to be able to make tangible use of abstract numeracy concepts. Because adults construct information differently than children do (Rogers, 2003), teachers will need much more than K–12 knowledge and experience to help adults achieve in numeracy class.

The ACME made the case that professional development should help teachers "unpack" mathematics by motivating teachers and helping them increase their knowledge of innovative ways to promote mathematics to a diverse body of students. Organizations in the United States make comparable statements, focusing on practitioner development that will "encourage the learning and teaching of mathematics in a manner which is interesting and appropriate to adults" (Massachusetts ABE Math Team, 1994) so that "educators can refocus the adult numeracy curriculum in a meaningful way" (Curry et al., 1996) in an effort "to change the way math is actually taught and learned in an adult literacy community" (Brover, Deagan, & Farina, 2005). Teachers also need to know adult learning theories (Hansman & Wilson, 1998; Brookfield, 1986; Knowles, Holton, & Swanson, 1998; Lawler, 1991; Merriam & Caffarella, 1999; Mezirow, 1991). Moreover, they need to know about adult numeracy learning. Teacher attitude also plays a key role in adult numeracy practice. Instructors need to consider their own attitudes about numeracy (Stoudt, 1994), especially because their outlook and viewpoints about numeracy are likely to influence how they teach it to adults.

The National Research Council's Mathematics Learning Study Committee (2001) identified the kinds of knowledge that K–8 mathematics teachers need in order to teach mathematics proficiently. Teachers, quite obviously, need to be aware of the individual needs of their students, need to know how to manage their classrooms, and should have an "elaborated, integrated knowledge of mathematics" so they can anticipate and understand students' different interpretations of concepts (p. 381). According to the committee's analysis of K–8 research, proficient teaching of mathematics consists of the following components:

- Teachers must possess a deep understanding of core mathematical concepts and of the ways their students' understanding matures. Teachers must be able to see and make connections between their knowledge and their classroom practices.
- Teachers must possess a repertoire of instructional and classroom management routines that they can implement fluently.
- Teachers must possess a strategic competence of mathematics in order to respond, on the fly, to students' questions or statements. Professional development programs can give teachers practice in analyzing and dealing with instructional problems.

- Teachers must exercise adaptive reasoning. They must reflect frequently on topics such as the difficulties their students are encountering.
- Teachers must bear a disposition that is productive: they must view their own knowledge, practice, and learning as valuable, and they must feel confident in their own ability to learn from their students' thinking.

These principles can easily be applied to adults. ABE mathematics students represent diverse characteristics, and ABE numeracy teachers need to be able to design lessons, manage ABE numeracy classrooms, create an environment that fosters quality numeracy teaching, and teach mathematics to adults who will need to integrate and transfer such knowledge to multiple aspects of their lives. This could be a daunting task, especially for inexperienced ABE mathematics teachers, so the need for quality professional development grounded in principles and research that correlate not only to mathematics achievement in general but to ABE mathematics achievement in particular is urgent. The burgeoning ABE population, as well as the increasing workforce demand for numerate employees, underscores the urgency for quality professional development in the area of ABE mathematics.

Overlapping Relationship Between Literacy and Numeracy

Professional development and teacher training in adult numeracy are often included under the umbrella of "literacy," thereby resulting in both the appearance of a nonessential need for effective teacher training in numeracy and underdeveloped numeracy professional development programs. A consequence of this indirect numeracy professional development is literacy-centered numeracy classroom practice through which teachers teach numeracy merely as a tangential element of adult literacy.

Because of the intricate relationship between numeracy and literacy, it is quite easy for practitioners to deemphasize the need for professional development for teachers who teach numeracy to adult learners (Maguire & O'Donoghue, 2002). Numeracy teachers who have knowledge of literacy might be able to integrate numeracy with literacy instruction (Kallenbach, 1994; Lucas, Dondertman, & Ciancone, 1991) and teach in a way that is "relevant, contextualized, and essentially linked to overall literacy" (Stout, 1994, p. 11), but the call for numeracy-specific teacher professional development (Gal & Schmitt, 1995) may not be answered.

Certainly, there is some value for teachers to have pedagogical knowledge of literacy in an adult numeracy class. In their examination of the pedagogical relationship between language and literacy, researchers found numeracy to be embedded in, and intricately overlapping with, literacy (Lee, Chapman, & Roe, 1994). Mathematical knowledge is ingrained in language, and teaching numeracy requires the use of literacy skills. The literacy activities that occur in numeracy classes, such as reading word problems and decoding word meanings, could be strengthened through professional development that shows teachers how to use reading to help students maximize their ability to use mathematics in their everyday life, as well as how to incorporate numeracy and literacy activities that build on student experience. Because numeracy and literacy are often taught within the same academic context, it will be helpful for teachers to understand the correlations between numeracy and literacy and design appropriate curricula and assessment for adults (Buchanan & Helman, 1997). Of benefit also will be their ability "to find different ways to assess literacy students' progress in mathematics" (Buchanan & Helman, 1997, p. 19). Numeracy professional development in this regard needs to be deliberate and direct with guided intent to help teachers complement their knowledge in literacy with strong pedagogical techniques in numeracy.

Definitional issues of numeracy, as discussed in Section 2, and numeracy's relationship to mathematics and literacy become issues here. Without clarity about what numeracy means, it is difficult to formulate consistent approaches to professional development in a way that fully measures teacher instructional capacity and instructional change.

RESEARCH IN PROFESSIONAL DEVELOPMENT AND ADULT NUMERACY

As the review in Section 3 shows, adult numeracy instruction is an underresearched area of inquiry. This lack of research extends to professional development in adult numeracy. Indeed, identifying components of quality professional development and measuring the impact on instructor knowledge and skills are areas that we have only begun to explore in the last decade. Recent research has examined the impact of participation in professional development on instructors' knowledge, skill levels, and instructional practices. Much of this research has occurred at the K–12 level and focuses on teacher learning and teacher change (Corcoran, 1995; Hargreaves & Fullan, 1992; Lieberman, 1996; Little, 1993; Loucks-Horsely, Love, Stiles, Mundry, & Hewson, 1998; Sparks & Loucks-Horsely, 1989; Stiles, Loucks-Horsley, & Hewson, 1996), with only limited research in the adult education arena. The research literature is a mix of large- and small-scale studies (Dias, 1997; Falk & Kilpatrick, 1998; Gray, 2003; Porter, Birman, Garet, Desimone, & Yoon, 2004), teacher surveys of preservice and in-service experiences (Joseph, 1997; Maguire & O'Donoghue, 2002), and evaluations of professional development programs (Brown, 2002; Earl, Fullan, Leithwood, & Watson, 2000; Earl, Levin, Leithwood, Fullan, & Watson, 2001; Earl, Watson, Levin, Leithwood, Fullan, & Torrance, 2003) designed to improve teaching and learning.

Although different approaches have been tried in teaching numeracy to adults (Tout & Johnston, 1995; Marr & Helme, 1991; DEET, 1993), the state of numeracy professional development is such that priorities vary. With little research available to identify quality professional development practices, teachers are left with a very small repertoire of proven pedagogical techniques to use and inspire changes in the adult numeracy classroom.

Nonetheless, to provide guidance for numeracy professional development, we can draw from two empirical studies conducted in the United States that identify characteristics of quality professional development: an evaluation of the Eisenhower Professional Development Program, actually a coordinated set of studies designed to evaluate the effectiveness of the federal government's professional development program for elementary and secondary school teachers (Porter et al., 2004, p. 4), and How Teachers Change: Study of Professional Development in Adult Education, conducted by the National Center for the Study of Adult Learning and Literacy (NCSALL).

The Eisenhower study is the first large-scale empirical comparison of the effects of different characteristics of professional development on teachers' learning. The evaluation of the program includes three quantitative studies: (a) telephone interviews with a national probability sample of Eisenhower coordinators in 363 school districts; (b) a mail survey to collect a national probability sample of 1,027 teachers who participated in 657 Eisenhower-assisted activities; and (c) a third study in which 287 mathematics and science teachers participated. Researchers augmented these studies with a set of case studies in five states with districts representing regional, ethnic, and economic diversity. Their evaluation of available literature about best professional development practices revealed five key features of quality professional development:

1. **Duration** — is sustained over time (including the total number of contact hours and the span over which the activity takes place)
2. **Content Knowledge** — focuses both on content in the subject area and on how students learn that content
3. **Active Learning —** promotes active learning, gives teachers opportunities for hands-on work, and includes opportunities for teachers to observe expert teachers, to link ideas learned in professional development to the teaching context, to examine and review student work, and to make presentations, lead, and write
4. **Collective Participation** — emphasizes collective participation of groups of teachers from the same school, department, or grade level
5. **Coherence** — forms part of a coherent program for teacher learning and development (e.g., consistent with teachers' goals and aligned with state and district standards and assessments) (Porter et al., 2004)

A major finding in the Eisenhower study is that to improve professional development, it is more important to focus on duration, collective participation, content, active learning, and coherence than on the type of development (e.g., mentoring, teacher networks, individual research project, traditional workshop or conference). The type of delivery has an effect on teacher outcomes only insofar as the activities reflect the key features (Garet, Porter, Desimone, Birman, & Yoon, 2001).

Professional development does not occur in a vacuum; contextual factors play a role in the delivery of high-quality professional development and have an impact on change (Desimone, Porter, Garet, Yoon, & Birman, 2002; Porter, Garet, Desimone, & Birman, 2003). In general, the Eisenhower studies showed that effective professional development involves the proper alignment of various program components, including management, funding sources, standards and assessments, and collective participation. At the K–12 level, school district practices regarding the alignment of professional development, standards and assessments, and teacher involvement in planning affect the quality of the professional development. In adult education, the most important system factors affecting teacher change are access to preparation time, access to benefits as part of their adult education jobs, and a voice in decision making (Smith, Hofer, Gillespie, Solomon, & Rowe, 2003).

The How Teachers Change Study (Smith et al., 2003, p. 11) was designed to help professional development decision makers understand the impact of professional development (including system, program, and individual factors) on teacher change. The study examined how adult education teachers changed after participating in three models of professional development: (a) a *multisession workshop* (experiential, active learning activities), (b) a *mentor teacher group* (study circles, peer coaching, and observation), and (c) a *practitioner research group* (teachers investigate their classroom practice and collect and analyze data). The study also investigated the most important individual, professional development, program, and system factors that influenced the type and amount of teacher change.

Of a sample of 106 adult education teachers from three New England states (Maine, Massachusetts, and Connecticut), 100 teachers took part in 18 hours of one of the three models of professional development and provided researchers data through questionnaires and interviews before, after, and one year after participating in the study. Six teachers served as a comparison group. Also, six teachers were randomly selected from each group to serve as a subsample. Participants who completed 12 out of 18 hours were considered completers; 16 participants dropped out of the study. The research team designed all three professional development models, using the best methods and accepted principles of adult learning and effective professional development, and recruited and trained experienced teachers or professional development leaders in each state to facilitate the professional development.

An analysis of data showed implications for the *amount* of teacher change, the *roles* in which teachers changed, the *ways* in which they changed, and also the *factors* that influenced teacher change. Regarding the amount of teacher change, the study suggested that most teachers, including those who dropped out, changed at least minimally through knowledge and action gains, with relatively few experiencing no change. The majority of teachers changed in their role as classroom teachers as opposed to other academic roles they may have played. In looking at the *ways* the teachers changed, the findings showed that the majority (72 percent) of the 83 completers demonstrated change, most of which was nonintegrated (thinking or acting) change.

Other factors that demonstrated teacher change were motivation to attend professional development, years of experience in the field of adult education, venue of first teaching experience, and level of formal education. Factors that led to teacher change were hours of professional development attended, quality of professional development, and collaborative participation. As in the Eisenhower study, the model of professional development was not a factor. Contextual factors that affected change were teacher access to benefits and prep time, the program's history in addressing learner persistence, and teacher access to decision making.

The K–12 literature has introduced several ways to develop teachers' abilities to teach with mathematical proficiency. The National Research Council's Mathematics Learning Study Committee (2001) identified four models of professional development that allow teachers' "knowledge, conceptions and practice […] to grow and evolve" (p. 385). The committee sorted professional development programs into those that focused on mathematics, those that focused on student thinking, those that focused on cases, and those that focused on "lesson study," a practice that originated in Japan.

- **Focus on mathematics**: Instructors seek to develop teachers' proficiency with core content from elementary school mathematics. Teachers are asked to unpack familiar content and make explicit the underlying procedures they use. The instructors, in the meantime, expose teachers to concepts that belie familiar procedures.

- **Focus on student thinking**: Teachers read the written work and problem-solving strategies of real students, consider how students' thinking can inform their lessons, and discuss how they interact with their own students. This model is based on Cognitively Guided Instruction (CGI), a professional development program that helps teachers develop instructional materials after they watch and listen to their students solve problems.
- **Focus on cases**: Teachers study a mathematics topic and the contexts surrounding it (e.g., the assignment, the students' work, the teacher's materials). Studying cases "serves as a basis for discussion and inquiry rather than as [a] [model] of instruction for the teachers to emulate" (p. 395).
- **Focus on lesson study**: Teachers create a lesson plan together, and then one teaches it to the group. The group revises it together, and the next person teaches the lesson. The teachers conduct very detailed analyses of effective mathematics instruction and revise their own teaching practices in the process.

The foregoing models should inform adult educators as they think about designing professional development programs for adult numeracy instructors. Regardless of which models are delivered, however, the content of professional development is likely to be driven by content standards. The NCTM standards for mathematics reform and EFF, for example, have led to a call for teachers to develop strong capacity in mathematical content. This interest resulted in heavy emphasis not only on the inclusion of numeracy in adult basic education (Tout & Schmitt, 2002) but also on how to provide quality professional development to adult numeracy teachers (Gal & Schuh, 1994), including the use of adult numeracy curricula content as a vehicle for professional development (Massachusetts ABE Math Team, 1994).

Several organizations, such as the Arkansas Adult Numeracy Campaign (ANC), the Math Education Group (MEG) in New York City, and the Massachusetts Adult Basic Education Math Standards project, have modified and extended the K–12 *Principles and Standards for School Mathematics* to address content in adult numeracy professional development. Although these efforts provide guidance, more long-term research is needed to draw safe conclusions about which professional development initiatives work specifically in the context of adult numeracy and which do not.

International Efforts

While issues about the nature of quality and content of adult numeracy professional development are debated in the United States, other countries seem to have taken a lead. In the United Kingdom, Australia, and the Netherlands, numeracy has been well established as a separate area of inquiry, and numeracy teachers are given more structured opportunities for professional development than in the United States. For example, urgent calls in Australia for reformed numeracy teacher training (Marr & Helme, 1991) resulted in the development of Adult Numeracy Teaching: Making Meaning in Mathematics (Tout & Johnston, 1995*),* also called the ANT, which is an 84-hour professional development program designed to support teachers of adult numeracy in the context of ABE. The program comprises a coherent system of strategies and readings to enable teachers to learn how to use manipulatives and design their teaching to meet the everyday needs of students. However, the efficacy of the program is still not clear because there has been no intervention to verify such information.

Also produced in Australia, *Breaking the Math Barrier: A Kit for Building Staff Development Skills in Adult Numeracy* (Marr & Helme, 1991) is a book designed for a two- to three-day numeracy teacher training course. The book is also useful for teacher self-study as well as for mathematics teachers who are interested in learning more about teaching adult numeracy, literacy teachers who are interested in teaching numeracy, and numeracy teachers who want to develop specific numeracy teaching skills and strategies. The book supports a participatory model of staff development and provides teachers with background theory, including activities and materials that they could use with students. Like the ANT, it does not appear that any interventions have tested the effectiveness of the strategies prescribed in this book.

What is clear is that the field of adult numeracy is facing major transformation, and so is the area of adult numeracy professional development. The call for curriculum developers to produce more professional development materials for numeracy teachers is being slowly answered, although the call for researchers to respond with more efficacy research to verify the effectiveness of the techniques and strategies prescribed in the books and curriculum available remains unanswered.

SUMMARY

The search for research on effective professional development in adult numeracy produced scant examples of best practices grounded in rigorous research and no examples addressing the effect of adult numeracy profession development. Advances in this area first require agreed-on principles to inform adult numeracy teaching and instruction and then research-based standards of professional development directly related to these principles. The move toward developing content standards for adult numeracy instruction holds promise in filling this need. However, what adult numeracy professional developers need to know to facilitate the development of adult numeracy teachers has not been articulated clearly, nor has it emerged in any research. Professional developers must also conceptualize the anticipated end result of training and engage teachers in activities that will enable them to help students meet their goals.

According to an evaluation of the available research, Web sites related to adult numeracy, and practitioner issues discussed in articles, the state of numeracy professional development is such that teachers who are not adequately prepared to teach adult numeracy may have some difficult identifying good practice because of the relatively limited repertoire of information currently available. Adult numeracy teachers have relatively little time, limited compensation, and few resources to learn on their own. Many resources put limited emphasis on teacher training and development, and of the information provided, much of it is grounded in opinion and limited experience, rather than in research.

The future does hold promise. Several ABE-focused professional development initiatives in adult numeracy are currently under way. These projects include the Adult Numeracy Campaign (AANC) in Arkansas; the Adult Literacy Resource Center (ALRC) and the Adult Volunteer Literacy Tutoring Project in Illinois; the Center for Adult Learning and Literacy (CALL) and Math Instructional Ideas for College Transitions Teachers (MIICTT) project in Maine; the ABE Math Standards Project in Massachusetts; the Math Education Group (MEG); the Ocean Sciences and Math Collaborative Project in Oregon; Making Math Real Institute and Clinic (MMR) in California; TERC in Massachusetts, and South Carolina's

Workplace Resource Center (WRC). The next activity of the Adult Numeracy Initiative project will gather more information from these projects and address other key issues identified in this review to further adult numeracy instruction and research within the ABE program.

6. Summary and Implications for Future Research

This review of the literature on the research and conceptual issues of adult numeracy has examined definitions and theories of numeracy, reviewed the research on instruction and assessment, analyzed commonly used assessments, provided a framework for evaluating and improving assessment, and reviewed what we know about professional development for teaching mathematics to ABE adults. The review addresses five of the research questions presented in Section 1 that OVAE posed for the Adult Numeracy Initiative and builds a foundation for the project by describing the current state of the field. In this section, we summarize the findings of the review and present implications for future research to promote progress in research and practice.

Definitions and Theories of Adult Numeracy

The construct of numeracy has no single, universally accepted definition, and there remains considerable debate on how best to define it, especially when referring to adults. We briefly traced the definitions from the origin of the concept in the United Kingdom in 1959 along a continuum of phases of development. These definitions include views of numeracy as basic arithmetic and computations skills; functional definitions, where numeracy is mathematics in "context" to cope with the demands of everyday life; and views of numeracy as an integrative skill, incorporating mathematics, communication, cultural, social, emotional, and personal aspects of individuals in context. This view of numeracy as a multidimensional, integrated skill is dominant in all current theorizing and thinking on adult numeracy.

As in other areas of learning, theories on how adults learn mathematics have gone through a shift from behaviorist theories, where the teacher is the conveyor of objective knowledge to students who absorb it to create a response, to constructivist theories, which now predominate. The adoption of constructivism as the guiding theory to approaches to mathematics instruction corresponds to the adoption of integrative definitions of numeracy. Constructivist theories argue that all knowledge is constructed by individuals acting on external stimuli and assimilating new experiences by building a knowledge base or altering existing schemas. Learners actively construct knowledge by integrating new information and experiences into what they have previously come to understand, revising and reinterpreting old knowledge in order to reconcile it with the new. Research inspired by constructivist theories has examined the role of social and cultural perspectives, personal experience and situations, affective factors and individual learning styles on how adults construct meaning about and learn mathematics.

Instructional Approaches and Interventions for Adult Numeracy

Since the 1990s, several professional societies and other organizations developed frameworks and standards for teaching mathematics. All of these frameworks reflect integrative definitions of numeracy and principles of constructivist theories toward learning. The most influential for instructing adults have been the frameworks developed by the National Council of Teachers of Mathematics (NCTM), the American Mathematical Association of Two-Year College's (AMATYC) *Crossroads in Mathematics,* the Adult

Numeracy Network's (ANN) mathematics standards framework, and the National Institute for Literacy's Equipped for the Future (EFF) Math Content Standard. Each of these frameworks or standards projects defines instructional content, including specific facts or subjects to be covered; skills needed, such as problem solving and critical thinking; and instructional processes or pedagogy. There tends to be agreement among the frameworks and standards on the need for specific skills such as critical thinking and problem solving, but there is less agreement on specific content and teaching methods.

The recent blooming of work advancing numeracy concepts, theory, and instructional frameworks, however, has not guided empirical research examining instructional practice. Very few studies have used ABE students to conduct research on the effects of adult numeracy instruction. In our review of all research from 1985 to 2005 on the effects of instructional interventions on mathematics teaching for ABE students, we found only 24 studies. Most of these studies evaluated the impact of computer-assisted instruction and did not provide a definitive answer on the effects of this technology on adults' mathematics learning. The research is neither theory-driven nor guided by any systematic approach. Only five studies examined approaches based on constructivist theory, and findings were inconclusive, though suggestive that cooperative and discovery learning might be effective. With so few studies, there clearly has been no agenda or systematic model guiding research in adult numeracy instruction.

Assessment and Professional Development in Adult Numeracy

Assessment used by ABE programs for measuring knowledge of mathematics is also undeveloped and not researched. We found the research base limited and patchy with only a few studies over the last five years even addressing ABE mathematics assessment. Current assessments are not aligned with the predominant instructional frameworks. Accountability demands, such as NRS requirements, drive most assessment in ABE programs. The NRS framework does not address problem-solving or critical-thinking skills, and neither do two widely used assessments that measure mathematics: the TABE and the CASAS. These assessments measure basic mathematics content knowledge and functional skills but are not adequate for measuring integrative conceptions of numeracy. Assessments geared toward passing the GED tests are also inadequate for measuring critical-thinking skills.

Professional development is the main mechanism for advancing effective instruction, but we found almost no research on the characteristics of effective professional development approaches for ABE teachers of mathematics. Yet research does show that ABE teachers are especially in need of training in mathematics instruction, having little prior training or experience. This lack of preparation is compounded by the relatively low retention of teachers within ABE.

Research in effective professional development for K–12 teachers suggests that several factors must be aligned for professional development to have significant impact: duration, collective participation, content, active learning, and coherence. Changes in K–12 mathematics education materials and methods have begun to percolate into the adult education system, but without professional development that provides both explanations for and examples of the new content, there is danger that teachers will continue to teach what and as they were taught.

IMPLICATIONS FOR FURTHER RESEARCH

It is perhaps not surprising that there is little rigorous research studying the effects of numeracy instruction, assessment, or professional development on adults. The field has not received attention from policymakers, nor has there been funding for research or a research agenda, especially in the United States. Further, there has been little meaningful instruction in adult numeracy that researchers could study. The ABE system is difficult to study, with mostly part-time teachers with little background or training in mathematics and widely varying program arrangements and approaches toward instruction among the states. ABE students are also difficult to study, entering as they do with varying goals and initial skills and attending for relatively short times. These conditions make the implementation and evaluation of instructional approaches and professional development difficult and also inhibit advancements in assessment. Work on developing and aligning assessment to instruction can make little progress in the absence of generally accepted instructional models.

However, the recent proliferation of instructional frameworks and content standards holds promise for improving this situation. These standards and frameworks not only suggest directions for research but also can provide a guide for developing meaningful instruction that will help adult learners cope with the demands of modern life. Varied and meaningful instruction creates a classroom environment that researchers can evaluate. We present a brief discussion of the implications for further research that our review suggests for theory and instruction, assessment and professional development.

Further Research on Instruction

Our review of theories on how adults learn mathematics found a dominant influence of constructivist theories that could inform a research agenda. These theories propose that students take ownership of concepts that they construct under expert guidance. How adults perform this construction depends not only on the content and skills taught but also on their cultural background, past experience, the learning situation, and their attitudes and affect. Educational experiences are affected by students’ mathematics histories, which can have a profound effect on students’ ability to learn mathematics as adults.

The little research to date has not addressed these issues in any organized way. The limited research identified—15 studies of ABE students and 9 studies in developmental mathematics—seems like guerrilla warfare far more than an organized victory campaign toward improving adult numeracy instruction. To move the field forward, we suggest the following five areas for further research.

1. **Evaluate instructional frameworks and theories of adult mathematics learning.** The NCTM and other influential instructional frameworks suggest content knowledge, skills, and strategies that learners need and suggest ways of delivering this content through instruction. They all to some extent include constructivist principles of learning. However, very limited research exists evaluating these instructional approaches with ABE students. A few of the studies of technology and discovery and cooperative learning that we identified touched on concepts embodied in the frameworks, but more systematic and organized research evaluating the instructional components of these frameworks is needed.

Research is also needed evaluating other theoretical and instructional approaches to mathematics learning.

2. **Identify and evaluate specific instructional practices.** The instructional framework and standards are often prescriptive about how instruction should be provided, but the suggested approaches are often phrased generally. Teachers need more specific guidance on how to implement instructional practices, and these practices require evaluation. Without this guidance, teachers must continually invent practice from scratch, using only general advice. For example, directing that students "discuss the solutions to a problem" provides little specificity. Research needs to identify and validate what a "discussion" entails (National Research Council, 2001).
3. **Study how adults learn mathematics in class.** There is little research on classroom dynamics that would facilitate classroom learning. We assume implicitly that instruction acts on students and that opportunities to learn are actually moments of learning, but if and how this occurs has not been studied. Research that describes what students have to know and do and what teachers can do to help students learn is needed. Constructivist theories that suggest ways adults construct meaning can guide this research, but empirical research needs to verify these approaches in the ABE mathematics classrooms.
4. **Explore the role of learner attitudes, affect, and experience.** There is currently no research on ABE students' attitudes toward mathematics, affective factors such as math anxiety, or the role of students' prior knowledge and how these elements affect learning. However, there is evidence from research on how child learn mathematics and general learning research that understanding such personal and instructional interactions is essential for understanding how adults learn mathematics.
5. **Examine ESL learners and students with learning disabilities.** Two completely neglected areas of research in adult mathematics have been instruction for adult ESL learners and instruction for students with learning disabilities. We found no research on how to provide instruction to these learners, on how they learn, or on how to address the challenges these learners face in learning mathematics. Research needs to pay particular attention to instruction for adult ESL learners, who make up over 40 percent of students in the adult literacy programs.

Research on Mathematics Instruction for Children

Because there is virtually no systematic research in ABE identifying effective mathematics instruction, the field could benefit from examining some of the research on mathematics instruction for children. The principles of instruction and learning in K–8 mathematics are rooted in the same theories of constructivism as instruction and learning in the field of adult mathematics.

The National Research Council's Mathematic Learning Study Committee (2001) synthesized the research on teaching and learning mathematics in the K–8 classroom. The committee's findings, presented in *Adding it Up: Helping Children Learn Mathematics*, bolster and inform the small body of research in adult mathematics education. The committee divided the research into three areas: how teachers interact with mathematical content, how teachers interact with their students, and how students interact with mathematical content. Although there are clear and profound differences between the K–12 instructional setting and ABE, as well as differences between children and ABE learners, a brief review of some of the key findings suggest practices that may be worthy of research for adult mathematics.

- Students learn best when they are given academically challenging work that focuses on making sense of problems, solving problems, and building skills. Teachers should support their students' cognitive activities without reducing the difficulty of the task.
- Teachers will keep students interested if they engage students' background knowledge, scaffold appropriately, emphasize multiple solution strategies, and privilege explanation and meaning-making by asking students to explain their thought processes.
- Teachers will keep students motivated if they set high expectations for their students, assign tasks that their students can succeed at with reasonable effort, and tap into students' intrinsic motivation by helping them view the content as fun, relevant, and worth their time.
- Instruction should allow students to make connections and organize knowledge; should build on what students already know and take advantage of their informal, everyday knowledge of mathematics; should not involve "overly abstract instruction that proceeds too quickly"; and should not rely on rote memorization.
- Teachers should show students the value of using multiple ways to solve problems and give students the freedom to explore different problem-solving methods.
- Cooperative groups can be an effective way to facilitate learning, develop students' social skills, and keep more students intellectually engaged.
- The use of manipulatives can be valuable if students are shown how to make connections between the object, the mathematical symbol, and the idea that each represents.

The practices discussed above—presenting cognitively demanding content, setting high expectations, keeping students motivated, and creating a safe and supportive learning community—suggest a wide variety of practices that can be tried with adults and evaluated through a rigorous research agenda.

Development of Improved Assessment

The adult numeracy field clearly needs to design better assessments for large-scale use that not only examine procedural skills and focus primarily on arithmetic but also are broader and call for more diverse forms of learner reactions and performances. Currently available assessments do not align with the standards or frameworks recently developed and do not reflect integrative conceptions of numeracy. The field needs a new approach toward numeracy assessment where assessments examine connected knowledge, communication skills, and interpretative abilities; they could examine learners' capacity to cope with nonroutine problems, text-rich tasks, and realistic, ill-structured problems. Having information about such capacities could provide much needed information about learning gains that would be more directly linked to adults' needs.

The essence of a good assessment is that it is appropriate for the context, purpose, and interpretation made or needed. Assessment has to be fully linked with the learning and teaching goals of a program and must reflect, for teachers, students, and policymakers, what is valued in a student's performance and learning in numeracy. Overall, the ideas expressed in this review point to the existence of a set of high expectations regarding both the desired breadth of the curriculum and the richness of the teaching and learning process in adult numeracy education. We list suggested characteristics to guide development of assessments for adult numeracy that are better aligned with instructional standards and frameworks.

1. Offer a balanced coverage of key domains deemed part of a broad view of adult numeracy, including numbers and operations, algebra and modeling, geometry and shape, measurement (time, money, length/volume, etc.), and statistics and probability.
2. Not only examine knowledge and skills in the key domains listed above but also more broadly provide information about learners' problem-solving, reasoning, and communicative capacities, as well as learners' understanding of connections between different mathematical and statistical ideas and their ability to explain and justify their reasoning.
3. Include types of items and stimuli that provide information about ability to
    a. interpret, critically react to, explain, and communicate about quantitative and statistical information embedded in print or media messages with varying types of documents and displays;
    b. cope with a mix of well-structured and ill-structured problems that require different forms of response and interaction (e.g., by mixing multiple-choice and constructed-response items, written and oral reports, group activities) and use tasks for which the reactions and responses required are choices and decisions and do not necessarily have clear answers; and
    c. use different tools or technologies relevant for learners' life circumstances or work goals.
4. Provide information about learners' ability to demonstrate confident numerate behavior in life and work contexts of value to learners and programs. This point relates to skill transfer and points to the need to examine the realism and authenticity of tasks.
5. Document beliefs, attitudes, or habits of mind that may affect both learning in class and numerate behavior outside the classroom.
6. Enable teachers and programs to identify the mathematical experiences and strategies that adults bring and that may contribute to, or otherwise hamper, their learning of more formal types of mathematics.
7. Ensure they are appropriate for adults with special learning needs, for low-literacy students, or for students from other cultures and languages.

We need to grapple with the development of broader and more sophisticated assessments in the Adult Numeracy Initiative project and in the field in the coming years. It is not at all clear that states, programs, teachers, or even learners will be open to such ideas, owing to beliefs, conceptions of mathematics or numeracy, or practicalities of adult education programs and limited time and energies. Nonetheless, the criteria and influences discussed here, along with the analysis of the four components of assessment, can serve as a basis for examining the quality of assessments beyond a focus on technical aspects of reliability and validity.

RESEARCH TO IMPROVE PROFESSIONAL DEVELOPMENT

Research on professional development in ABE has been neglected in general and is almost nonexistent where adult numeracy is concerned. The professional development approaches and principles we did identify as effective come from research on K–12 teachers. Yet the limited research does identify a clear need for better trained teachers in ABE and more systematic, ongoing training on principles and approaches to mathematics instruction. The dedication of the numeracy instructors cannot offset the weak mathematical backgrounds that the majority of them possess. Part-time employment, low wages, and uncompensated leave compound the problem of attracting to professional development the very teachers who most likely need content enrichment.

We offer three suggestions for further research that may advance professional development for ABE educators.

1. **Study the relationship between teachers' knowledge of mathematics and instructional effectiveness.** We reviewed research that showed that few ABE teachers have training in mathematic instructions. Given ABE program realities, this state of affair is unlikely to change in the next several years. Research that explores how much mathematics knowledge teachers really need to be effective instructors will help us understand training needs the field can address. This research needs to be coupled with research on how teachers use their knowledge of mathematics and knowledge of adult learners in planning instruction.
2. **Study the effectiveness of professional development delivery systems**. Because ABE programs are likely to continue to have limited resources to provide professional development, research could help improve the field by evaluating the effectiveness of different approaches toward training and ongoing professional development. This research could focus both on *how* to provide effective training and on the effectiveness of *different mechanisms* for professional development. For example, given the limited programmatic resources and time available to ABE teachers, the use of technology and distance learning as a professional development mechanism may be a promising area to research.
3. **Study the impact of numeracy professional development on teacher knowledge, behaviors and learner outcomes**. Given the adult education delivery system and parttime nature of both teachers and learners, what is the best way to design a research study that can focus on providing scientifically based evidence that specific professional development strategies actually change

> behavior and outcomes. These types of studies would provide definitive evidence of what works in professional development.

Changes in materials and methods in K–12 mathematics education have begun to percolate into the adult education system. But without professional development that provides both explanations and examples of the new content, there is the danger that teachers will continue to teach what and as they were taught. As the agents of instruction, ABE teachers cannot change or improve their numeracy instruction without sound, systematic, and ongoing professional development.

CONCLUSION: MOVING FORWARD

This literature review provides a portrait of the current state of theory, instruction, assessment, and professional development of numeracy education for ABE students. The project team identified the relevant research in adult mathematics education and grouped the studies within the framework of the Adult Numeracy Initiative research questions. The driving philosophy was for this report to serve as a research baseline. To determine a direction for moving the field forward, it was critical to develop an understanding of how far adult mathematics education has come and where it is now.

A technical working group of experts in mathematics and numeracy research and practice will build on the information and recommendations of the review to identify the key critical issues on which to focus further efforts and will commission papers to study some of the issues identified here in greater depth. The review will also guide another project activity, an environmental scan of current professional development and instructional projects focusing on adult numeracy. We offer the review as the first piece of the puzzle that will present a clearer picture and direction of the field by the end of the project.

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APPENDIX A – DEFINITIONS OF NUMERACY

Sources	**Definitions**
AAMT, 1997	Numeracy "involves using some mathematics to achieve some purpose in a particular context."
Brown, 2002	Numeracy is the "competence and inclination to use number concepts and skills to solve problems in everyday life and employment."
Coben, 2000b, p. 35	To be numerate means to be competent, confident, and comfortable with one's judgments on whether to use mathematics in a particular situation and if so, what mathematics to use, how to do it, what degree of accuracy is appropriate, and what the answer means in relation to the context.
Evans, 2000, p. 236	The "limited proficiency" vision of numeracy prevails. Against this vision, he offers a "provisional working definition for a reconstituted idea of numeracy" as meaningful social practice: the ability to process, interpret, and communicate numerical, quantitative, spatial, statistical, even mathematical, information, in ways that are appropriate for a variety of contexts, and that will enable typical members of the culture to participate effectively in activities that they value.
Gal, 2000	He characterizes numeracy as a semiautonomous area at the intersection between literacy and mathematics (p. 23). He describes three different types of "numeracy situations": "generative," "interpretive," and "decision." Generative situations require people to count, quantify, compute, and otherwise calculate. Interpretive situations demand that people make sense of verbal or text-based messages that may be based on quantitative data but require no manipulation of numbers. Decision situations "demand that people find and consider multiple pieces of information in order to determine a course of action, typically in the presence of conflicting goals, constraints or uncertainty" (p. 15).
Johnston & Tout, 1995; Yasukawa, Johnston, & Yates, 1995	We believe that numeracy is about making meaning in mathematics and being critical about maths. This view of numeracy is very different from numeracy just being about numbers, and it is a big step from numeracy or everyday maths that meant doing some functional maths. It is about using mathematics in all its guises – space and shape, measurement, data and statistics, algebra, and of course, number – to make sense of the real world, and using maths critically and being critical of maths itself. It acknowledges that numeracy is a social activity.
Johnston & Yasukawa, 2001	Numeracy is "the ability to situate, interpret, critique and perhaps even create mathematics in context, taking into account all the mathematical as well as social and human complexities which come with that process."
O'Donoghue, 2003, p. 8	Numeracy and mathematics are not interchangeable terms; numeracy is seen as encompassing some elements of mathematics, rather than vice versa: Mathematics and numeracy are not congruent. Nor is numeracy an accidental or automatic by-product of mathematics education at any level. When the goal is numeracy, some mathematics will be involved, but mathematical skills alone do not constitute numeracy.
McDevitt, 2001	Numeracy has been defined as the kinds of math skills needed to function in everyday life — not one fixed set of skills but rather a continuum of skills that an adult draws from to meet different needs. And it's numeracy that we want for our learners, not just math.

APPENDIX B – PROFESSIONAL SOCIETY STANDARDS

NCTM's Content Standards

Number and Operations

- **Students should be able to:**
  - **Understand numbers, ways of representing numbers, relationships among numbers, and numbers systems;**
  - **Understand meanings of operations and how they relate to one another;**
  - **Compute fluently and make reasonable estimates.**

Algebra

- **Students should be able to:**
  - **Understand patterns, relations, and functions;**
  - **Represent and analyze mathematical situations and structures using algebraic symbols;**
  - **Use mathematical models to represent and understand quantitative relationships;**
  - **Analyze change in various contexts.**

Geometry

- **Students should be able to:**
  - **Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships;**
  - **Specify locations and describe spatial relationships using coordinate geometry and other representational systems;**
  - **Apply transformations and use symmetry to analyze mathematical situations;**
  - **Use visualization, spatial reasoning, and geometric modeling to solve problems.**

Measurement

- **Students should be able to:**
  - **Understand measurable attributes of objects and the units, systems, and processes of measurement;**
  - **Apply appropriate techniques, tools, and formulas to determine measurements.**

NCTM's Content Standards

Data Analysis and Probability

- **Students should be able to:**
  - **Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them;**
  - **Select and use appropriate statistical methods to analyze data;**
  - **Develop and evaluate inferences and predictions that are based on data;**
  - **Understand and apply basic concepts of probability.**

Problem Solving

- **Students should be able to:**
  - **Build new mathematical knowledge through problem solving;**
  - **Solve problems that arise in mathematics and in other contexts;**
  - **Apply and adapt a variety of appropriate strategies to solve problems;**
  - **Monitor and reflect on the process of mathematical problem solving.**

Reasoning and Proof

- **Students should be able to:**
  - **Recognize reasoning and proof as fundamental aspects of mathematics;**
  - **Make and investigate mathematical conjectures;**
  - **Develop and evaluate mathematical arguments and proofs;**
  - **Select and use various types of reasoning and methods of proof.**

Communication

- **Students should be able to:**
  - **Organize and consolidate their mathematical thinking through communication;**
  - **Communicate their mathematical thinking coherently and clearly to peers, teachers, and others;**
  - **Analyze and evaluate the mathematical thinking and strategies of others;**
  - **Use the language of mathematics to express mathematical ideas precisely.**

NCTM's Content Standards

Connections

- **Students should be able to:**
  - **Recognize and use connections among mathematical ideas;**
  - **Understand how mathematical ideas interconnect and build on one another to produce a coherent whole;**
  - **Recognize and apply mathematics in contexts outside of mathematics.**

Representation

- **Students should be able to:**
  - **Create and use representations to organize, record, and communicate mathematical ideas;**
  - **Select, apply, and translate among mathematical representations to solve problems;**
  - **Use representations to model and interpret physical, social, and mathematical phenomena.**

AMATYC *Crossroads in Mathematics*

Standards for Content

1. **Students will perform arithmetic operations, as well as reason and draw conclusions from numerical information.**
2. **Students will translate problem situations into their symbolic representations and use those representations to solve problems.**
3. **Students will develop a spatial and measurement sense.**
4. **Students will demonstrate understanding of the concept of function by several means (verbally, numerically, graphically, and symbolically) and incorporate it as a central theme into their use of mathematics.**
5. **Students will use discrete mathematical algorithms and develop combinatorial abilities in order to solve problems of finite character and enumerate sets without direct counting.**
6. **Students will analyze data and use probability and statistical models to make inferences about real-world situations.**
7. **Students will appreciate the deductive nature of mathematics as an identifying characteristic of the discipline, recognize the roles of definitions, axioms, and theorems, and identify and construct valid deductive arguments (Cohen, 1995).**

Standards for Pedagogy

1. **Mathematics faculty will model the use of appropriate technology in the teaching of mathematics so that students can benefit from the opportunities it presents as a medium of instruction.**

2. **Mathematics faculty will foster interactive learning through student writing, reading, speaking, and collaborative activities so that students can learn to work effectively in groups and communicate about mathematics both orally and in writing.**

3. **Mathematics faculty will actively involve students in meaningful mathematics problems that build upon their experiences, focus on broad mathematical themes, and build connections within branches of mathematics and between mathematics and other disciplines so that students will view mathematics as a connected whole relevant to their lives.**

4. **Mathematics faculty will model the use of multiple approaches--numerical, graphical, symbolic, and verbal--to help students learn a variety of techniques for solving problems.**

5. **Mathematics faculty will provide learning activities, including projects and apprenticeships that promote independent thinking and require sustained effort and time so that students will have the confidence to access and use needed mathematics and other technical information independently, to form conjectures from an array of specific examples, and to draw conclusions from general principles (Cohen, 1995).**

Appendix C – List of Web Sites and Journals Searched

Web Sites

1. ABC Canada
2. Adult Community and Further Education (ACFE)
3. Adult Learning Math (ALM)
4. Adult Literacy and Numeracy Australian Research Consortium (ALNARC), The
5. Adult Numeracy Down Under
6. Adult Numeracy Network
7. American Association for the Advancement of Science (AAAS)
8. American Mathematical Association of Two-year Colleges (AMATYC)
9. American Mathematical Society (AMS)
10. American Statistical Association (AMS)
11. Association for Women in Mathematics (AWM)
12. Association of Mathematics Teacher Educators (AMTE), Canadian Mathematical Society (CMS)
13. Australian Council for Adult Literacy (ACAL)
14. Australian Council of TESOL Associations (ACTA)
15. Australian Literacy Educators' Association (ALEA)
16. Australian Literacy Federation (ALF)
17. Basic Skills Agency (BSA)
18. Canadian Mathematical Society

Journals (Online and Print)

1. Academic Leadership
2. Academic press electronic journal library
3. Adult Basic Education: An Interdisciplinary Journal for Adult Literacy Educators
4. Adult Education Quarterly
5. American Journal of Mathematics
6. American Mathematical Monthly
7. American Mathematical Society Journals
8. Annals of Mathematics
9. Arizona State University - Bilingual Research Journal
10. Australian Mathematical Society Gazette
11. Bulletin of the London Mathematical Society
12. Canadian Applied Mathematics Quarterly
13. Canadian Journal of Mathematics
14. Canadian Mathematical Bulletin
15. Canadian Mathematical Society Notes
16. Central European Journal of Mathematics
17. Chreods
18. Comparative Education Review
19. Current Issues in Education

Web Sites	Journals (Online and Print)
19. **Catalog of Mathematics Resources on the WWW and the Internet**	20. **Education Next**
20. **Center for Applied Linguistics (CAL)**	21. **Educational Studies in Mathematics**
21. **Center for Educational Change in Mathematics and Science**	22. **Effective Teaching**
22. **Center for Research in Mathematics and Science Education (CRMSE)**	23. **Electronic Library of the European Mathematical Society**
23. **Center for Research on Education, Diversity & Excellence (CREDE)**	24. **Electronic Research Announcements of the AMS**
24. **Center for Research on Evaluation, Standards, and Student Testing (CRESST)**	25. **Euromath Bulletin**
25. **Center for Research on the Education of Students Placed at Risk (CRESPAR)**	26. **Harvard Education Publishing Group**
26. **Center for Science, Mathematics and Engineering Education (CSMEE)**	27. **Harvard Educational Review**
27. **Center for the Enhancement of Science and Mathematics Education (CESAME)**	28. **Indiana University Mathematics Journal**
28. **Center for the Study of Teaching and Policy (CTP)**	29. **International Education Journal (IEJ)**
29. **Center on English Learning & Achievement (CELA)**	30. **Journal for Research in Mathematics Education**
30. **Centre for the Study of Mathematics Education (CSME)**	31. **Journal of Industrial Teacher Education**
31. **Clearinghouse on Adult, Career, and Vocational Education (ACVE)**	32. **Journal of Science Education**
32. **Commission on Adult Basic Education (COABE)**	33. **Journal of the London Mathematical Society**
33. **Conference Board of the Mathematical Sciences (CBMS)**	34. **Journal of Vocational and Technical Education**
34. **Consortium for Mathematics and Its Applications (COMAP)**	35. **Mathematica Journal**
35. **Consortium for Policy Research in Education (CPRE)**	36. **MathUser**
36. **Department for Education and Skills Standards Site (DfES**	37. **National Forum Journals**
37. **European Mathematical Society (EMS)**	38. **New York Journal of Mathematics**
	39. **Northeastern Mathematical Journal**
	40. **Phi Delta Kappan, The**

Web Sites	Journals (Online and Print)
38. **Extend Resources for Mathematics Education**	41. **Reading Online**
39. **International Commission on Mathematical Instruction (ICMI)**	42. **State University of West Georgia — Online Journal of Distance Learning Administration**
40. **International Literacy Institute (ILI)**	43. **Teacher Education Quarterly**
41. **Literacy Online**	44. **Teachers College Record**
42. **LiteracyNet**	
43. **Massachusetts ABE Standards**	
44. **Maths4life**	
45. **Math Forum**	
46. **Mathematical Association of America (MAA)**	
47. **Mathematical Sciences Education Board (MSEB)**	
48. **Mathematical Sciences Research Institute (MSRI)**	
49. **Mathematics Hotlist**	
50. **National Adult Literacy Database (NALD)**	
51. **National Center for Early Development and Learning (NCEDL)**	
52. **National Center for Improving Student Learning and Achievement in Mathematics and Science (NCISLA)**	
53. **National Center for the Study of Adult Learning and Literacy , The (NCSALL)**	
54. **National Centers, The**	
55. **National Council of Teachers of Mathematics (NCTM)**	
56. **National Institute for Literacy (NIFL)**	
57. **National Literacy Trust**	

Web Sites	Journals (Online and Print)
58. **National Numeracy Network**	
59. **National Research and Development Center (NRDC)**	
60. **National Science Teachers Association**	
61. **NSW Board of Adult and Community Education (BACE)**	
62. **Research and Practice in Adult Literacy (RaPAL)**	
63. **Shell Centre for Mathematical Education Society for Industrial and Applied Mathematics (SIAM)**	
64. **Supporting Adult Applied Learning and Teaching (SAALT)**	
65. **Teachers College Record**	
66. **TERC**	
67. **Victorian Adult Literacy and Basic Education Council (VALBEC)**	

APPENDIX D – SUMMARY OF MATHEMATICS AND NUMERACY INTERVENTION STUDIES REVIEWED

Studies Discussed in Section 3, Adult Numeracy Instructional Approaches and Interventions

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
		ADULT BASIC EDUCATION		
1.	Barnett, T. L. (1985). A comparative analysis of the PLATO computer-assisted instructional delivery system and the traditional individualized instructional program in two juvenile correctional facilities owned by the Commonwealth of Pennsylvania. *Dissertation Abstracts International, 46* (09), 2668A. (UMI No. 8525658)	The study used Program Logic for Automated Training Operations (PLATO) computer-assisted instruction. The study had a pretest-posttest design with random assignment of subjects in two juvenile correctional facilities. There was no indication of the number of participants or of the instruments used to measure the variables.	Achievement and attitude of students in the experimental group were not significantly different from those in the control group.	
2.	Batchelder, J. S., & Rachal, J. R. (2000). Effects of a computer-assisted-instruction program in a prison setting: An experimental study. *Journal of Correctional Education, 51,* 324–332.	Batchelder and Rachal studied the effect of skill and drill tutorial software to enhance mathematics and language skills. They randomly assigned 71 male inmates in the prison's GED program to receive either the regular classroom instruction offered or classroom instruction supplemented by CAI using the tutorial software. The classroom instruction consisted of four hours per day in English, mathematics, history, and science. Students in the experimental group received three hours of instruction per day but spent the fourth hour using the CAI software for mathematics and reading.	Inmates were posttested with the CASAS reading and mathematics tests after receiving 80 hours (four weeks) of instruction. There was no significant difference between the groups on these tests.	

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
3.	Burnham, P. T. (1985). A field test of a structured television curriculum on the mathematics achievement of incarcerated high school equivalency learners. *Dissertation Abstracts International, 46* (05), 1175A. (UMI No. 8514722)	The study examined the effect of a televised curriculum on an incarcerated ASE population. Subjects in a nonequivalent control group research design (n = 40) were pretested using the General Educational Performance Index (Form AA) and posttested using Form BB of the same test. The experimental group used an instructional televisions series, Adult Math, as a reinforcement resource, viewing the "telelessons" under supervision and then completing workbook exercises tied to the program. The control group completed self-paced workbooks and used other instructional materials but did not view the television series.	The researcher found no difference of achievement between the groups, although he cautions that Adult Math is more effective when the subjects have at least 5.8 entry grade-level scores in arithmetic and reading and that the literacy levels of incarcerated populations are noticeably lower than those of the general population.	Computer-Assisted Instruction
4.	Burton, B. S. (1995). The effects of a computer-assisted instruction and other selected variables on the academic performance of adult students in mathematics and reading. *Dissertation Abstracts International, 57* (07), 2798A. (UMI No. 9639904)	This study revisited the same question of traditional versus CAI instruction with more definitive results. Two hundred adults at a vocational technical adult education center participated in the study.	The study used the TABE M and D as its instrument and a combination of a nonequivalent control group design and a causal comparative design. Students using CAI were found to do significantly better in mathematics than those in the control group. Age and gender had no effect. Ethnicity and extent of formal education did affect the results.	
5.	Farr, C. W. (1987). Effects of inferencing training on verbal abilities and mathematics problem-solving among adult basic education students. *Dissertation Abstracts International*, *48* (08), 2021A. (UMI No. 8725351)	Farr investigated the effects of inferencing training in learning vocabulary on verbal abilities and mathematics problem solving among 40 ABE students. Half the students had inference training, a method where they were taught vocabulary skills and reasoning training. The other students received traditional ABE instruction without the training. Although the main focus of the study was literacy development, mathematics problem solving was included as a dependent variable to ascertain whether training in inferencing in language acquisition would be reflected in other areas. The results showed that there was a correlation between mathematics performance and reading performance. The results also showed that verbal ability correlated with ability to solve analogies and neologisms.		

	Study Name	**Description of Intervention and Population Measured**	**Outcome Measure and Effects Found**	**Further Conclusions/ Implications**
6.	Indiana O.I.C. of America State Council. (1990). *A comparative study of adult education Indianapolis/Richmond. Third-party evaluation final report.* Indianapolis, IN: Author.	Study examined the effectiveness of traditional classroom instruction versus computer-assisted instruction (CAI) in raising the competency levels of adults one grade level for each 80 hours of instruction. Of the 149 individuals who were pretested, only 50 attended more than 30 hours and remained at the time of posttesting. Evaluation was done using a randomized methodology with the ABLE test as pre- and posttest instrument. Population: Economically disadvantaged adults, predominantly female, ages 17–67 (mean age = 32.3 years) who tested below 12th grade/GED competency levels on the ABLE. Un- or underemployed.	No information was supplied concerning the statistical analysis used to evaluate the results. However, the report indicates that the overall average grade change for CAI students was 2.6 grades compared with an average of 1.84 grades for non-CAI students. The high attrition again makes these findings difficult to interpret.	
7.	Irby, T. R., et al. (1992). *The Joliet Junior College Center for Adult Basic Education and Literacy's ''Families about success'': Intergenerational programming that works.* Joliet, IL: Joliet Junior College.	Irby conducted a randomized control trial of approximately 25 predominantly black and Hispanic students in a ABE setting; 15 students were in a family literacy project (intervention group), and 10 were enrolled in GED classes only (control). The objective of the study was to evaluate the effectiveness of a family literacy project on the numeracy and literacy levels of adults. The intervention was conducted in a family literacy project comprising several components and ABE classes were offered two times per week for 12 weeks. Instructors developed individualized lesson plans for each student to work at his/her own pace.	The results indicated that students in the family literacy project showed a higher average gain in reading and mathematics compared to the control	
8.	Lavery, L., Townsend, M., & K. Wilton (1998). Computer-assisted instruction in teaching literacy skills to adults not in paid employment. *New Zealand Journal of Educational Studies, 33*(2), 181–192.	Lavery and colleagues conducted a randomized control trial of 12 students in New Zealand to compare the learning outcomes associated with basis literacy education programs conducted via traditional instruction with computer-assisted instruction (CAI). The study measured the gains in reading and numeracy skills in two "training opportunities" classes. Six students received traditional teaching and another six used Readers' Workshop, Math Concepts and Skills, and Computer Curriculum Corporation CAL software packages. Participants' reading and numeracy skills were measured by the Burt Word Reading Test, the Neale Analysis of Reading Ability, and the KeyMath Revised Test.	The results show that significantly greater achievements were made in reading (word recognition, word accuracy, and comprehension) and numeracy (mathematical concepts, operations, and applications) under CAI than under traditional instruction. The students who used the CAL made three years' gain on the Burt, over one year on the Neale, and 16 months on the mathematics test in less than two months of instruction. During the same time, the students who received traditional teaching made no gains in reading skills and showed a slight decline in mathematics performance.	

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
9.	Nicol, M. M., & Anderson, A. (2000). Computer-assisted vs. teacher-directed teaching of numeracy in adults. *Journal of Computer Assisted Learning, 16,* 184–192.	Objective of study was to evaluate an experiment that compared computer-assisted and teacher-implemented instruction in numeracy. It is unclear whether the same two teachers taught the two intervention groups. The researchers randomized the adult students into three groups of eight. The method of random allocation was not described, but stratification by gender is implied.	The researchers reported no difference in improvement between the teacher-led intervention and the CAI, but given the very small numbers in each group, there is high possibility of a Type II error in this study.	
10.	Nurss, J. R. (1989). *PALS evaluation project.* Atlanta, GA: Georgia State University, Center for the Study of Adult Literacy. (ERIC Document Reproduction Service No. ED313573)	This study assessed the effectiveness of the PALS CAI program on the literacy skills of adult nonreaders compared with traditional adult basic education.	This trial showed a significant, positive effect for the traditional adult basic education classes (i.e., the control group). Attrition, however, was extremely high in both groups. Of the 74 students assigned to the control group, 15% (n = 11) remained at the posttest; 32% of the 135 students in the experimental group (n = 43) completed the program. One could conjecture that the “cream” of the control remained and therefore performed well on the test. In addition there was differential attrition, with more of the control group staying to completion, clouding the results.	
11.	Reid, M. N. B. (1986). A comparative study of three teaching methods used in Adult Basic Education and General Educational Development mathematics programs. *Dissertation Abstracts International, 47* (08), 2853A. (UMI No. 8626463)	Study compared three teaching methods: CAI using PLATO, tutoring using Laubach materials, and traditional teaching. Subjects (n = 30) were members of existing ABE/GED classes.	The TABE M and D levels served as pre- and posttest instruments. There was no significant difference in mathematical achievement among the three groups, although the CAI group gained 1.9 grade levels while the traditional group gained 1.1.	

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
12.	Robichaud, K. K. (1986). The use of computer assisted instruction with Adult Basic Education students: A comparative study. *Dissertation Abstracts International, 47* (06), 1985A. (UMI No. 8621681)	Study compared students in traditional settings with those whose regular instruction was supplemented by CAI. The variables chosen for comparison of two such groups were skills gains in mathematics and reading and change in attitudes toward computers. The attitudes of CAI users toward CAI also were assessed.	No details concerning instrument or evaluation were supplied. Robichaud reports that statistical analysis revealed no significant difference in skills gained. There was a significantly positive change in attitudes toward computers and the instructional use of CAI by the CAI users.	
13.	Wardlaw, R. (1997). Effects of computer assisted instruction on achievement outcomes of adults in developmental education programs: A comparative study. *Dissertation Abstracts International, 58* (10), 3804A. (UMI No. 9811694)	Wardlaw studied the effect of CAI on achievement and attitude for a group of pre-GED and GED adults. The study was conducted in established classes with 60 students each in the experimental and control groups. Pre- and posttesting was done using the TABE and Semantic Differential Attitudinal Questionnaire.	Wardlaw found no significant difference on either achievement or attitude.	He does offer an important caveat for programs planning to incorporate CAI into a program. Wardlaw surveyed ABE facilities and found that although some were well equipped, many others had few or outdated workstations. One facility had banned student use of the equipment because the director believed that the students were using it to arrange dates rather than study. He suggests that these environmental issues may have contributed to the failure of CAI to affect positive attitudinal change.

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
14.	Wilder, M. (1994). The effects of a simulation test model of the General Education Development (GED) program as compared to the effects of a drill and practice, both computer-based and workbook-based on GED mathematics scores, retention, and time. *Dissertation Abstracts International, 57* (07), 2808A. (UMI No. 9639896)	Wilder compared the effects of a computer-based instructional (CBI) simulation-test treatment, a CBI drill and practice program, and a traditional workbook drill and practice class on retention, completion time, and elevation of test scores on the mathematics section of the GED.	The research design was a three-group, posttest only design with unequal sample sizes, where a total of 564 students self-selected into the classes. Wilder followed the students for five years, with 308 students retained long enough to get a GED diploma; 94% of the simulation group was retained compared with 65% in the CBI drill group and 36% in the workbook only group. Completion time was also considerably less in both CBI groups. Scores on the test were not significantly different.	
15.	Winters C. A., Matthew, M., Booker, F., & Fleeger, F. (1993). The role of a computer-managed instructional system's prescriptive curriculum in the basic skill areas of math and reading scores for correctional pre-trial detainees. *Journal of Correctional Education, 44*(1), 10–17.	Winters and colleagues studied the effect of CAI-supplemented program on ABE/pre-GED and GED students in an adult correctional facility. Five students were assigned to either the experimental or control group (n = 10).	Pre- and posttesting was conducted using the TABE. The statistical methods used to analyze the data were unclear, but the results favored the CAI intervention: 86% of the students in the pilot study advanced in level in mathematics as opposed to a 50% gain in the control group. A comparison of students advancing one year or more showed 43% for the pilot study versus 14.5% for the control group. Once again, the small sample size limits the utility of this study.	

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
		DEVELOPMENTAL MATHEMATICS		
16.	Bartlett, L. E. (1993). The evaluation, improvement, and dissemination of a guided discovery method for teaching developmental mathematics. *Dissertation Abstracts International, 54* (12A). (UMI No. 9411836)	Bartlett used a guided discovery approach to teaching mathematics in one section of a developmental mathematics course at a university. The experimental group (*n* = 27) was a class taught with this approach and was compared with the same class taught in a previous quarter (*n* = 52) without the approach.	Students in the experimental class performed better on the outcomes. Bartlett reports that the experimental method was "very effective in improving the mathematics performance of adult students." Outcome measures were mathematics performance measured by a researcher-developed test and mathematics anxiety measured by the Math Anxiety Rating Scale (MARS).	
17.	Berry, A. J. (1996). The effects of peer tutoring on adult students in remedial algebra at an urban community college. *Dissertation Abstracts International*, *57* (08), 3433A. (UMI No. 9701475)	Berry studied the effect of peer tutoring in dyads on adult students in a remedial algebra class. Two studies were conducted: a 6-week program and a 12-week semester. Students self-selected the classes but had no knowledge of the planned intervention. Instructors were randomly assigned and trained in the intervention after assignment. In each case, three peer tutoring sections were contrasted with three traditional lecture sections.	Pre-and posttests were given using the Suinn Mathematics Anxiety Rating Scale, the Fennema-Sherman Mathematics Attitude Scales, a profile questionnaire, and an abbreviated version of the institutional Freshman Skills Assessment Program test. An open-ended survey was also used. Sections had an average of 35 students (*n* = approximately 210). Of the variables measured, only attitude increased significantly during the 6-week study. For students in the 12-week semester, the intervention group showed significant improvement in mathematics achievement and attitude as well as reduced anxiety.	

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
18.	Costner, B. G. (2002). The effects on student achievement and attitudes of incorporating a computer algebra system into a remedial college mathematics course. *Dissertation Abstracts International*, *63* (07), 2483A. (UMI No. 3059227)	Costner examined the effectiveness of a computer algebra system (CAS) on achievement and attitudes of students in a college remedial algebra course. Students in the treatment group (*n* = 26) used the CAS to discover algorithms, explore algebraic manipulation, and identify misconceptions, while students in the control group (*n* = 25) did not have access to the CAS.	Several instruments were used in the study: researcher-designed pretest and periodic section tests, a departmental final exam, the Fennema-Sherman Attitude Toward Success in Mathematics Scale, Confidence in Learning Mathematics Scale, and Mathematics Usefulness Scale, a researcher designed questionnaire and semistructured interview (*n* = 5), and periodic writing assignments. There was no statistically significant effect on achievement or surveyed attitudes. However, the qualitative data gathered via questionnaire revealed significant differences in attitudes and in classroom culture issues. Students in the treatment group cited the helpfulness of group work and classroom discussions more often than students in the control group. With respect to the use of CAS, the treatment group welcomed the ability to check their work and get immediate feedback, they felt that the CAS helped them to see mathematics differently yet attributed little of their new mathematical understanding to technology.	One criticism was the unavailability of the computer in testing situations. The researcher suggested that assessment needs to be altered if CAS is an integral part of the course.

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
19.	Ellis, N. F. (1992). The effect of in-class study groups on achievement and course completion rates in developmental algebra classes. *Dissertation Abstracts International, 53* (07), 2283A. (UMI No. 9237220)	In the study, each of seven instructors at a community college taught one developmental algebra section incorporating the use of in-class study groups and one section where groups were not used.	Ellis compared the achievement and completion rates and found no significant difference between the experimental and control groups for the group, neither as a whole nor on the basis of age or gender.	Older adult students had a significantly greater residual gain than traditional students regardless of the method employed. Women had a significantly greater residual gain than men in the entire study and in the control group. In the experimental group, the differences between men and women were not statistically significant. The group as a whole, traditional students, older adult students, and men had slightly higher completion rates in the experimental classes. In none of these cases, however, was the difference in completion rates statistically significant. Women had virtually identical completion rates in the two types of classes

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
20.	Hsieh, F. J. (1992). Effects of animation and manipulation on adult learning of mathematical concepts. *Dissertation Abstracts International, 53* (09), 3094A. (UMI No. 9301313)	Hsieh (1992) examined the affect of specific features of CAI, animation and manipulation, on 54 college students participating in two computer based laboratory (CBL) sections of a mathematics course. The students were randomly assigned to receive instruction with/without animation and with/without manipulation. It is not clear from the design whether this was a four-group design or a two-group.	The outcome measures were overall achievement, retention of content and motivated, measured through a questionnaire. The researcher list five findings: Animation enhanced retention when the tasks required high level cognitive processes such as analysis or synthesis, Animation did not help learning or retention when the tasks were comprehension of mathematical concepts, Animation increased continuing motivation, Manipulation helped the transference of mathematical concepts learned through a computer to paper-and-pencil tests, and Manipulation did not promote intrinsic motivation.	

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
21.	Pace, J. P. (1989). A model for teaching area and perimeter concepts from a constructivist perspective to adult community college students through applied problem-solving and activity-based instruction. *Dissertation Abstracts International, 51* (02), 0442A. (UMI No. 9008820)	This study explored the applicability of constructivist methods to the teaching of geometry concepts in a remedial mathematics class at an urban community college. Students (n = 67) were pretested using the Applied Geometry Test, the Van Hiele Geometry Test, and the New Jersey College Basic Skill Placement Test. They were randomly assigned to four sections of the course, two experimental and two control, all taught by the same instructor. The experimental treatment consisted of five 80-minute sessions during which students explored concepts of area and perimeter using activities embedded in applied problem-solving settings.	Students were posttested and delayed posttested. The data were assessed using single and multivariate linear regression models. Those in the experimental program performed significantly better than their counterparts.	By the measure of geometry achievement used in this research, the experimental program of teaching significantly increased students' short- and long-term performance. Every linear regression model supported the conclusion of a significant, unconfounded increase in student performance. Videotaped interview data provided additional insight into what apparent changes had occurred in students' geometrical conceptions. This study provides a well-defined model for the teaching and learning of area and perimeter through applied problem solving. In addition, it has at its core a conceptual model that is adaptable for use in the teaching and learning of other mathematical concepts.

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
22.	Ramus, K. S. (1997). How the mathematics education reforms pertain to undergraduate curriculum: An introductory study of an experimental developmental algebra course for adults. *Dissertation Abstracts International, 57* (12), 5090A. (UMI No. 9717243)	In this hybrid study (*n* = 13), students were interviewed by a third party using an open-ended interview protocol.	Students reported a sense of ownership of the rules of algebra because they had discovered them from classroom exercises and also self-reported a positive change in attitude toward mathematics and increased confidence that transferred to other activities outside the classroom. Quantitative measures, derived from the course examination, were less conclusive. Examination results were scored using two rubrics, one to measure correctness and one to measure the use of problem-solving strategies. An ANOVA showed the experimental section performed less well than the daytime comparison class and as well as the evening section.	
23.	Toet, J. A. (1991). A comparative study of two instructional modalities on the achievement level of underprepared community college students. *Dissertation Abstracts International, 52* (12), 4191A. (UMI No. 9215165)	Toet studied a randomly selected sample of students who had been placed into remedial reading, English, or mathematics at a community college.	Using the TABE, she compared achievement between students who completed assignments based on textbook use versus students who work in a CAI laboratory. The group taking basic mathematics showed a statistically significant cognitive gain. Those studying beginning algebra were retained longer at a statistically significant level of .05. There was no significant retention difference for the basic mathematics group.	

	Study Name	Description of Intervention and Population Measured	Outcome Measure and Effects Found	Further Conclusions/ Implications
24.	Wilson, O. D. (1987). An automated diagnostic test and tutorial package for basic skills of mathematics in post secondary vocational education of Kentucky: Construction and validation. *Dissertation Abstracts International*, *49* (01), 0055A. (UMI No. 8804685)	Describes a diagnostic and tutorial program that was conducted at a vocational school in Kentucky. The researchers designed a diagnostic test for pre- and posttesting, which they normed against the TABE at the 8.75 grade equivalent.	The results of the experiment showed a significant effect in favor of the experimental group.	