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ABSTRACT

This document contains information regarding the implementation of the Performance-Based Occupational Math Requirements Assessment (OMRA), which was designed to determine the math requirements for occupations that require training of less than a baccalaureate degree, and the research supporting the development of OMRA. The first section presents the OMRA instrument and directions on how to implement it. The OMRA Coordinator Manual contains directions to be followed by the person in charge of conducting the assessment. A glossary of terms is provided. The OMRA instrument includes the OMRA Inventory for recording the required math operations and the OMRA Applications Supplement for recording sample job applications for which each operation is useful. The second section contains a report on the process used to develop OMRA and the related research supporting its validity. A literature review discusses two general approaches for determining occupation-related math requirements: occupational analysis of job or training requirements, and standardized testing. The review then describes three basic forms of occupational analysis (the chosen approach): analyses of specific occupations to yield math skills requirements, analyses of occupational math skills based on training program requirements, and identification of generic skills required across occupations. A description of the development process used to create OMRA follows. A final pilot test is discussed that tested OMRA with a technical occupation requiring a larger amount of math and another less technical occupation requiring less math. Appendixes include a list of 35 references and 4 sample math competency lists. (YLB)

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National Center for Research in Vocational Education

University of California, Berkeley

PERFORMANCE-BASED OCCUPATIONAL MATH REQUIREMENTS ASSESSMENT (OMRA)

Implementation and Supporting Research

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PERFORMANCE-BASED OCCUPATIONAL MATH REQUIREMENTS ASSESSMENT (OMRA)

Implementation and Supporting Research

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FOREWORD

This document contains two sections:

1. Implementation of the Performance-Based Occupational Math Requirements Assessment (OMRA)

2. Research Supporting the Development of OMRA

The research was conducted to develop procedures which can be used to determine the math requirements of occupations; therefore, the first section of this document was written to present those procedures for direct application. It contains the OMRA Coordinator Manual for applying OMRA as well as the OMRA Instrument in a form that can be duplicated.

The second section of this document contains a report on the process used to develop OMRA and the related research supporting its validity. It is written as a standard research report.

This document represents one half of the effort of the National Center for Research in Vocational Education Project number II.7, "Computerized Adaptive Assessment of Basic Skills." The second half will be published separately in a document entitled *Software System for Computerized Assessment of Mathematics Basic Skills*. The project, headed by Drs. David J. Weiss and David J. Pucel of the University of Minnesota, was designed to develop methods for determining the occupational math requirements of jobs and to determine the math skills possessed by individuals who may wish to enter those jobs. These tools can be used to assist in the development of vocational-technical education programs and training programs in business and industry and to assess, as a basis for math skills remediation, the extent to which individuals possess the math skills required to succeed in a particular occupation.

The first half of the project, headed by Dr. David J. Pucel, developed OMRA as an instrument for assessing the occupational math requirements of occupations. It is founded on performance-based instructional design principles. Performance-based instructional design is an integrated system for developing and evaluating instruction, and its aim is to ensure the performance capability of learners (Pucel, 1989, p. 16). A first stage in the development of such instruction is to identify through occupational or content analysis the content to be taught. The primary focus of such analysis is to identify what people will be expected to do (p. 34). OMRA was designed to analyze the math needed for people to perform in an occupation.

The second half of the project, headed by Dr. David J. Weiss, developed a computer-administered adaptive test battery for assessing the extent to which individuals possess the vocationally relevant math skills identified with OMRA. The test battery was designed to test individuals entering vocational-technical schools (or other job preparation programs) in order to identify deficiencies in the basic math skills required for a job. The test uses state of the art computerized adaptive testing procedures to ensure both high precision measurements and maximum efficiency.

IMPLEMENTATION OF THE PERFORMANCE-BASED OCCUPATIONAL MATH REQUIREMENTS ASSESSMENT (OMRA)

This section presents the Performance-Based Occupational Math Requirements Assessment (OMRA) and directions on how to implement it. OMRA is an assessment designed to determine the math requirements for occupations that require training of less than a baccalaureate degree. OMRA has two parts:

1. The OMRA Coordinator Manual which contains directions to be followed by the person in charge of conducting the assessment. It is located on page 3.

2. The OMRA Instrument to be used by math and occupational experts to determine the math requirements of a particular occupation. The assessment includes the OMRA Inventory, the OMRA Applications Supplement, and directions. It is located on page 15.

Those interested in reviewing the assessment procedures and the resources required to conduct the assessment should read the Coordinator Manual. It describes the procedure for using OMRA. OMRA is copyrighted but may be duplicated if it is duplicated in its entirety and is given complete bibliographic citation. Those interested in the research base which supports OMRA should read the second section of this document, "Research Supporting the Development of OMRA."

PERFORMANCE-BASED

OCCUPATIONAL MATH REQUIREMENTS ASSESSMENT (OMRA)

Coordinator Manual

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PERFORMANCE-BASED OCCUPATIONAL MATH REQUIREMENTS ASSESSMENT (OMRA)

OMRA COORDINATOR MANUAL

Introduction

Purpose

The Occupational Math Requirements Assessment (OMRA) is designed to determine the mathematics operations (skills) required for success in an occupation. The results of OMRA can be used as a basis for curriculum development and/or for judging an individual's occupational math preparation. OMRA was designed for use with occupations requiring less than baccalaureate degree preparation; therefore, the range of mathematics operations presented includes skills typically used in such occupations. It was also designed as a tool for local curriculum and training program development. Consequently, results are not necessarily generalizable beyond a local setting. If more generalizable results are desired, the sampling procedures must be expanded to include a broader sample of job-related materials and a broader base of experts.

OMRA includes the OMRA Inventory (for recording the required math operations) and the OMRA Applications Supplement (for recording sample job applications for which each operation is used). These applications are useful in developing contexts for occupationally relevant math instruction. [Note: A glossary of terms is presented at the end of the Coordinator Manual.]

OMRA Uses

OMRA can be used to do the following:

1. Determine the math operations required in an occupation.
2. Determine, as a basis for curriculum development, job applications which require the math operations.

Resources Required

1. Project coordinator (the person who will manage the assessment)

2. Occupational practitioners (individuals who actually engage in or supervise an occupation and can furnish samples of on-the-job materials which contain applications requiring math)

3. An occupational expert (e.g., an occupational instructor)

4. A math expert (e.g., a math instructor)

5. Sample job-related materials which include applications requiring math

Process for Coordinating the Assessment

1. Define the occupation to be analyzed.

2. Identify occupational experts and math experts.

3. Identify occupational practitioners (e.g., members of advisory committees).

4. Obtain from occupational practitioners samples of job-related materials that include applications requiring math. (These materials will later be compiled and become the job-related material source used by occupational experts and math experts when completing their part of OMRA.)

5. Provide the occupational experts and math experts with job-related materials and OMRA—including the OMRA Inventory, OMRA Applications Supplement, and directions. [Note: The OMRA Inventory contained in the OMRA Directions has been printed as three separate pages for easy duplication of this manual. However, it is recommended that the three pages be placed side by side and duplicated on one 11" by 17" sheet for distribution.]

6. After receiving the results for each of the expert teams, develop a prioritized list of math operations required for the occupation.

7. Assemble the list of sample job applications which require math.

Defining the Occupation To Be Analyzed

In order to conduct the analysis, the occupation which will be the focus of the analysis must be clearly defined. An occupational title which clearly communicates the occupation to be analyzed (e.g., machinist, secretary, electronics technician) and a description of the occupation are required. If the occupation has been in existence for some time, a beginning point for obtaining both the title and a description is the *Dictionary of Occupational Titles* (*DOT*). This *DOT* definition may need to be modified to suit local needs. If the occupation is newly emerging and a formal definition has not been developed, it is recommended that a *DOT*-like definition be developed by interviewing people employed in the occupation.

Identifying Occupational and Math Experts

One or more teams—each of which includes an occupational expert proficient in the occupation to be analyzed and a math expert who has had experience with students preparing for the occupation—should be assembled. The more teams that are assembled, the more valid the analysis will be. Three teams are recommended so that differences among teams' analyses can later be reviewed.

[Note: If the procedure is to be used with vocational education programs, the following process is recommended for identifying the occupational and math experts and the occupational practitioners. First, identify instructors of vocational programs which prepare people for the occupation to be analyzed. Ask the instructors to recommend members of their advisory committees who have access to materials actually used on the job. Those advisory committee members can then provide the materials or can ask others in their organizations to do so. The occupational instructors can also recommend math experts.]

Identifying Occupational Practitioners

Each of the occupational experts should be asked to recommend two or more people who have direct contact with job-related materials used by people in the occupation (e.g., members of their advisory committees). People selected should include those individuals who actually engage in or supervise an occupation and who can furnish samples of on-the-job math requirements.

Obtaining Samples of Job-Related Materials

OMRA is designed for use with samples of job-related materials which include job applications requiring math. Job-related math materials include any materials that contain references to the use of math and which are used by a worker on the job. They include, but are not limited to, materials containing charts, manuals, job aids, and tables used on the job. They can also include verbal references to job activities requiring math.

The examples may contain actual math calculations (number calculations), or they may verbally call for a job application which requires math. For example, a carpenter may be required to calculate the board feet needed to cover a hardwood floor. The job manual on the installation of the hardwood floor may just assume a carpenter can do such a calculation and may merely indicate "order the hardwood flooring." The actual calculations might be performed with a calculator or written on a piece of board. Such an application requires math and, therefore, needs to be included in the assessment. The accuracy of the math assessment generated by OMRA is enhanced when the job-related math materials are up-to-date and when they accurately represent the entire range of occupational skills.

The materials can be gathered entirely by mail or through a combination of mail and interviews. The following procedure is suggested.

1. Call or write to each practitioner selected. Invite her or him to participate in the project. The invitation should include (1) an explanation of the intent of the project, (2) an explanation of why a sample covering the *range* of job-related materials requiring math calculations is important, (3) an explanation of which types of materials and/or examples of math applications should be provided, (4) two samples of related math materials as examples, and (5) a telephone number which

they can call to have questions answered. (Even if the initial invitation is by phone, a follow-up letter summarizing the information should be sent.)

2. Collect the related math materials and examples.

   Option 1: Ask the occupational practitioners to send you copies of the job-related math materials within one week.

   Option 2: Arrange an interview with each practitioner after one week and collect the job-related math materials. (Interviews provide an opportunity to speak with each practitioner to obtain further clarification of the materials and to ensure that the full range of occupationally relevant math materials has been collected.)

3. From the materials collected, collate the packet of job-related materials to be included in the analysis. All teams performing an analysis must receive the same packet of materials. Select materials which sample the full range of materials that are used in the specific occupation. If the materials collected do not represent a full range, obtain additional materials.

4. Assign a number to each of the pieces of material for use as a common reference by participating experts.

Administering OMRA to Teams of Occupational and Math Experts

Contact the teams of occupational and math experts and inform them that you will be sending them a packet of materials including a sample of job-related materials and OMRA. Ask them to analyze the job-related materials and to return their results within one week. If a fee will be paid for their participation, clearly indicate what the fee will be and when it will be paid. (Even if the initial invitation is by phone, include a follow-up letter summarizing the information when you send the assessment packet.)

The packet should include the following:

1. A cover letter

2. The job-related materials

3. OMRA (including the OMRA Inventory and OMRA Applications Supplement)

4. A stamped envelope with return address

All teams should receive exactly the same packet unless special contractual arrangements have been made and are indicated in the cover letter.

Developing a Prioritized List of Math Operations

After the results have been gathered from all expert teams, do the following:

1. Total the ratings in each of the cells within each separate tally block for each team (e.g., four cells with 1, 3, 2, and 1 total 7).

2. Add the number for a given operation for all teams. Tally blocks which were crossed with an X, indicating 12 or more applications, should be considered to have a total of 36 (12 × 3).

3. Develop a prioritized list of math operations used in the occupation. Do this by placing the operation which was selected by all teams and which has the largest total first, the one used by all teams and has the next largest total second, and so on. After all of the operations selected by all teams have been placed in order, then place those selected by the next largest number of teams in order. This procedure gives those operations selected by all teams higher priority than those selected by fewer teams. (See Table C-1 for a sample prioritized list.)

Assembling the List of Sample Job Applications

The lists of applications obtained from the different teams should be synthesized and placed in order by operation number. (See Table C-2 for a sample of a synthesized list of applications.)

Table C-1
Sample of Secretary—Occupational Math
(Ordered by Frequency Ratings Across Teams)

Cell No.		Grp 1	Grp 2	Grp 3	Avg. Freq.	Priority
	Three Teams Selected the Operation					
1- 3	Add Whole Numbers	30	14	32	25.3	1
3- 5	Multiply a Decimal by a Decimal	26	10	24	20.0	2
3- 1	Add Decimals	20	20	17	19.0	3
4- 5	Take the Percent	15	11	12	12.7	4
3- 2	Subtract Decimals	15	6	11	10.7	5
1- 5	Multiply Whole Numbers	19	3	5	9.0	6
1- 4	Subtract Whole Numbers	20	3	3	8.7	7
3- 6	Divide a Decimal by a Decimal	4	5	3	4.0	8
1- 8	Add Signed Numbers	2	2	7	3.7	9
4- 6	Determine the Percent	4	5	1	3.3	10
	Two Teams Selected the Operation					
4- 2	Convert Percents to Decimals	14	0	14	9.3	11
4- 4	Convert Decimals to Percents	7	7	0	4.7	12
1- 7	Round Off	3	2	0	1.7	13
	One Team Selected the Operation					
5- 3	Conversion	20	0	0	6.7	14
1- 6	Divide Whole Numbers	0	2	0	0.7	15
1- 1	Convert Words to Arabic Numbers	1	0	0	0.3	16
1- 2	Convert Arabic Numbers to Words	0	1	0	0.3	17

Table C-2
Sample of Electronics Applications

	Operation Code	Description of Application	Source #.p. #
1	1-3 Add Whole Numbers	Calculate Base Current of BJT	2.170
		Calculate Current in a Two Branch Circuit	1.158
		Calculate for a Voltage across a Component when Two Supplies Are Used	1.241
		Calculate Input Impedance of an Amplifier	2.213
		Expense Report Calculations	3.15
		Fill Out Requisitions & Invoices	3.51
		Pay Calculations	3.67
		Work Order Calculations	3.73
2	1-4 Subtract Whole Numbers	Calculate Drain Current of a Junction Field Effect Transistor	2.392
		Reduce Total Resistance of Parallel Circuit	1.119

GLOSSARY

Job Application

A task or job activity that requires the application of math.

DOT

Dictionary of Occupational Titles (U.S. Department of Labor, Employment, and Training, 1991).

Job-Related Materials

Written materials containing math applications routinely used by workers in an occupation (e.g., technical manuals, graphs, worksheets, verbal references to math activities).

Math Category

A major division of math such as integers, fractions, decimals, percents, algebra, or geometry. Category names appear at the head of each section in the OMRA Inventory.

Math Expert

A person formally trained in mathematics who has command of the structure and skills of mathematics (e.g., a mathematics instructor).

Occupational Description

The occupational description as presented in the *Dictionary of Occupational Titles* (*DOT*) indicating what a worker in a given job is expected to do.

Occupational Expert

A person who has mastered the skills of the occupation to be analyzed (e.g., an occupational instructor or a person who actually works in the occupation).

Occupational Mathematics Requirements Assessment (OMRA) Applications List

The listing of math operations and associated job applications which provide contexts in which math is used within an occupation.

Occupational Mathematics Requirements Assessment (OMRA) Applications Supplement

The section of OMRA used for recording sample job applications of various math operations.

Occupational Mathematics Requirements Assessment (OMRA) Inventory

The section of OMRA which contains a taxonomy for classifying the math operations used in an occupation.

Occupational Practitioner

A person who actually engages in or supervises an occupation and can furnish samples of on-the-job materials which contain applications requiring math.

Operation

The most elemental manipulation of numbers and symbols in math. Each cell of the OMRA Inventory represents a math operation. The operations are arranged from simple to complex.

Tally Block

The shaded, twelve-section cell following each math operation on the OMRA Inventory. The cell is used to indicate the estimated monthly frequency of use for each job application.

PERFORMANCE-BASED

OCCUPATIONAL MATH REQUIREMENTS ASSESSMENT (OMRA)

OMRA Instrument

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PERFORMANCE-BASED
OCCUPATIONAL MATH REQUIREMENTS ASSESSMENT
(OMRA)

Introduction

The OMRA is designed to be completed by an analysis team composed of an occupational expert and a math expert knowledgeable about the occupation to be analyzed. The analysis will yield (1) a list of math operations required for performing successfully in the occupation and (2) a list of job applications requiring the math operations (a list which can be used as a context within which to teach the math operations). Follow the directions to complete the OMRA Inventory and the OMRA Applications Supplement.

Determining Math Operations Associated with Job Applications

1. Review the contents of the attached OMRA Inventory.

    - Categories of math are presented in bold letters.
    - Each numbered cell within a category contains a type of math operation.
    - Math operations in each category are arranged from simple to complex.

2. Review each of the job-related math materials included in the packet.

    - Review each page of each document.
    - Locate math applications in the materials. The math applications may actually be indicated by numerical calculations (2 + 2); they may be indicated verbally (e.g., "calculate the number of board feet necessary"); or they may be implied (e.g., "order the lumber needed"). Therefore, each page must be reviewed carefully for math calculations.

Sample job application: An aviation electronics manual requires the calculation of resistor wattage for selecting a replacement resistor. The application is as follows:

Calculate the wattage of a resistor. This is done using the following formula:

$$W = \frac{E^2}{R}$$

Example substitutions: $W = \frac{40 \times 40}{680}$

3. Analyze each job application in terms of the type of math operations it contains (e.g., addition of whole numbers, division of fractions, conversion of a decimal to a fraction). Many applications will require more than one math operation. If an application uses two or more operations, note each separately.

   Example: $\frac{40 \times 40}{680}$ uses "Multiply Whole Numbers" and "Divide Whole Numbers."

   Care must be taken to classify only the individual math operations used with a job application. For example, if an application contains an algebraic formula but the person does not have to manipulate the formula and only does simple addition and multiplication, the operations are entered under addition and multiplication and not under algebra. The operation would only be entered as an algebraic operation if a person has to reconfigure the formula using rules of algebra.

   Example: $W = \frac{E^2}{R}$ can be reconfigured to $E^2 = W \times R$.

4. After identifying each math operation, do the following.

   - Locate that operation by name or by example on the OMRA Inventory.
   - Rate the average number of times you would estimate a person would do the operation per month for that particular application.

     1 = 1 to 5 times per month
     2 = 6 to 10 times per month
     3 = 11 or more times per month

- Place that rating in one of the small boxes in the shaded "tally block" to the right of that operation. Each box is used to record the rating for one operation.

  Example: If an electronics technician is required to multiply whole numbers (e.g., 40 × 40 = 1600) about eight times per month when calculating resistor wattage, enter a 2 in one of the "Multiply Whole Numbers" boxes.

  Multiply Whole Numbers

2			

5. As you find an application that requires math, also record that job application on the OMRA Applications Supplement for curriculum development. (See the sample at the end of the OMRA Instrument.)

   - List each math application by name (e.g., "calculate resistor wattage") on the attached OMRA Applications Supplement Sheet.

   - List the operation code (e.g., 1-5) from the OMRA Inventory for each operation which is used in the application.

   - Indicate the job-related material source for each application by source number and page number (e.g., 1.23 indicates page 23 of source 1).

6. Complete steps 3 through 5 for each job application you find that requires math in the job-related materials. If more than twelve applications are identified that require a particular operation, place an X over the entire tally block to indicate that the operation is used very often. After doing so, you no longer need to tally additional applications of that operation.

7. Operations that are identified from the job-related materials but that do not appear in the OMRA Inventory should be recorded on the back of the inventory.

Integers

Words to Arabic Numbers — 1-1
Two hundred eighty = 280

Arabic Numbers to Words — 1-2
152 = *One hundred fifty two*

Add Whole Numbers — 1-3
$830 + 94 + 12 = 936$

Subtract Whole Numbers — 1-4
$364 - 158 = 206$

Multiply Whole Numbers — 1-5
$303 \times 97 = 29{,}391$

Divide Whole Numbers — 1-6
$2024 \div 92 = 22$

Round Off — 1-7
To the nearest ten, hundred, etc.
e.g., 162 → 160; 260 → 300

Add Signed Numbers — 1-8
$-40\ (+)\ -16 = -56$

Subtract Signed Numbers — 1-9
$+18\ (-)\ -43 = +61$

Multiply Signed Numbers — 1-10
$+6\ (\times)\ -8 = -48$

Divide Signed Numbers — 1-11
$-420 \div +42 = -10$

Fractions

Order Fractions — 2-1
Arrange in ascending order
$\frac{1}{8}, \frac{3}{8}, \frac{1}{2}, \frac{10}{16}, \frac{70}{80}$

Add Fractions — 2-2
$\frac{3}{11} + \frac{4}{11} + \frac{9}{11} = \frac{16}{11}$

Subtract Fractions — 2-3
$\frac{7}{16} - \frac{6}{16} = \frac{1}{16}$

Multiply Fractions — 2-4
$\frac{1}{3} \times \frac{1}{2} = \frac{1}{6}$

Divide Fractions — 2-5
$\frac{4}{9} \div \frac{2}{3} = \frac{2}{3}$

Least Common Denominator — 2-6
$\frac{1}{2}, \frac{1}{8}, \frac{1}{16}$ *Answer* = 16

Reduce Fractions — 2-7
$\frac{12}{16} = \frac{3}{4}$

Write as a Mixed Number — 2-8
(an improper fraction)
$\frac{11}{8} = 1\frac{3}{8}$

Add Mixed Numbers — 2-9
$6\frac{9}{16} + 4\frac{1}{2} = 11\frac{1}{16}$

Subtract Mixed Numbers — 2-10
$12\frac{3}{8} - 9\frac{15}{16} = 2\frac{7}{16}$

Multiply Mixed Numbers — 2-11
$5\frac{9}{16} \times 2\frac{3}{8} = 13\frac{27}{128}$

Divide Mixed Numbers — 2-12
$\dfrac{3\frac{1}{8}}{\frac{5}{16}} = 10$

Fraction of a Whole Number — 2-13
$\frac{2}{3}$ *of* 27 = 18

OCCUPATIONAL MATHEMATICS REQUIREMENTS ASSESSMENT INVENTORY

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Decimals

Add Decimals — 3- 1

$$\begin{array}{r} .724 \\ +\ .101 \\ \hline .825 \end{array}$$

Subtract Decimals — 3- 2

$$\begin{array}{r} .729 \\ -\ .397 \\ \hline .332 \end{array}$$

Decimal to a Fraction — 3- 3

$.833 = \frac{833}{1000}$

Fraction to a Decimal — 3- 4

$\frac{5}{16} = .3125$

Multiply a Decimal by a Decimal — 3- 5

$$\begin{array}{r} 0.077 \\ \times\ 0.023 \\ \hline 0.001771 \end{array}$$

Divide a Decimal by a Decimal — 3- 6

$0.311\,\overline{)0.933} = 3.0$

Percents

Convert Percents to Fractions — 4- 1

$25\% = \frac{8}{32}$

Convert Percents to Decimals — 4- 2

$3\frac{1}{2}\% = .035$

Convert Fractions to Percents — 4- 3

$\frac{11}{32} = 34.375\%$

Convert Decimals to Percents — 4- 4

$.32 = 32\%$

Take the Percent — 4- 5

10% of 45 = __

Answer: 4.5

Determine the Percent — 4- 6

__ of 48 = 12

Answer: 25%

Ratios

Ratio in Lowest Terms: — 5- 1

12 : 3

Answer: 4 : 1

Solve the Proportion: — 5- 2

22:6 = 14:4

Answer: 21

Conversion of Units — 5- 3

$3\ ins. \times \frac{1\ ft.}{12\ ins.} = 0.25\ ft.$

Algebra

Add Monomials — 4- 1

$7xy + 9xy = 16xy$

Subtract Monomials — 4- 2

$(5x-2y) - (8x+12y) = -3x-14y$

Multiply Monomials — 4- 3

$(x^4)(x^7) = x^{11}$

$(x^{\frac{1}{3}})(x^{\frac{1}{4}}) = x^{\frac{7}{12}}$

Divide Monomials — 4- 4

$6xy^2 \div 2xy = 3y$

$x^{\frac{3}{4}} \div x^{\frac{1}{2}} = x^{\frac{1}{4}}$

Transpose Formulas: Solve for r. — 4- 5

$t = \frac{d}{r}$ Answer: $r = \frac{d}{t}$

$P = IR^2$ Answer: $R = \sqrt{\frac{P}{I}}$

Solve Equations for x. — 6- 6

$x - 6 = 0$

Answer: $x = 6$

Solve Equations with Fractions for x. — 6- 7

$\frac{5x}{3} = 20$

Answer: $x = 12$

Solve Equations: Graphically. — 4- 8

$3x - 4y = 5$

$5x + y = 16$

Answer: $x = 3;\ y = 1$

Solve Equations: Algebraically. — 6- 9

$5x - 6y = 2$

$3x - 7y = 9$

Answer: $x = \frac{-40}{17};\ y = \frac{-39}{17}$

Find the Root — 6-10

$\sqrt{169} = 13$

$\sqrt{x^6} = x^3$

Factor Quadratic Equation — 6-11

$x^2 - 5x + 6 = 0$

Answer: $x = 2;\ x = 3$

Quadratic Equation - Complete the Square. — 6-12

$x^2 - 6x - 7 = 0$

Answer: $x = 7;\ x = -1$

Quadratic Equation - Use Quadratic Formula. — 4-13

$3x^2 + 7x + 2 = 0$

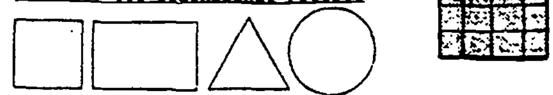
Answer: $x = -\frac{1}{3};\ x = -2$

Quadratic Formula

$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

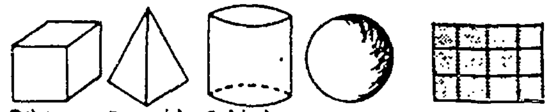
Geometry

Identify Two Dimensional Figures



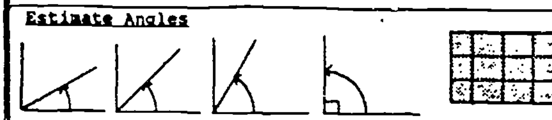
Square Rectangle Triangle Circle 7- 1

Identify Three Dimensional Figures



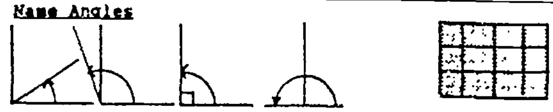
Cube or Rectangular Solid Pyramid Cylinder Sphere 7- 2

Estimate Angles



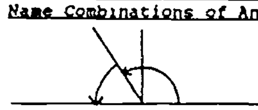
30° 45° 60° 90° 7- 3

Name Angles

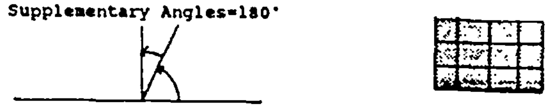


Acute Obtuse Right Straight 7- 4

Name Combinations of Angles

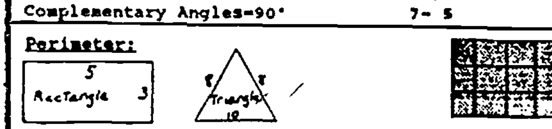


Supplementary Angles=180°



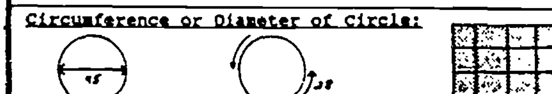
Complementary Angles=90° 7- 5

Perimeter:



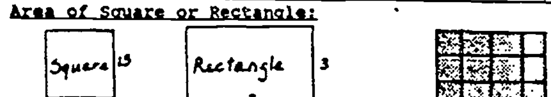
Ans=16 units Ans=26 units 7- 6

Circumference or Diameter of Circle:



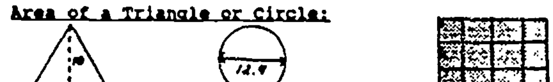
c=141.30 units d=8.92 units 7- 7

Area of Square or Rectangle:



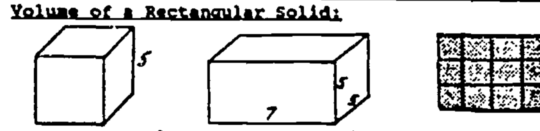
Ans=169 units² Ans=15 units² 7- 8

Area of a Triangle or Circle:



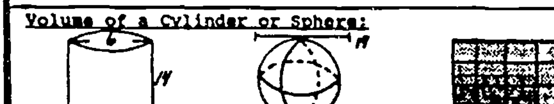
Ans=40 units² Ans=120.7 units² 7- 9

Volume of a Rectangular Solid:



Ans=125 units³ Ans=175 units³ 7-10

Volume of a Cylinder or Sphere:



Ans=395.6 units³ Ans=1436 units³ 7-11

OMRA Applications Supplement Sheet

Name ______________________ Occupation ______________________

	Description of Application	Operation Code	Source#.p#
e.g.	Calculate resistor wattage	1-5, 1-6	1.23, 4.5
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

OMRA Applications Supplement Sheet

Name ____________________ Occupation ____________________

	Description of Application	Operation Code	Source#.p#
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			
32			
33			
34			
35			
36			
37			
38			
39			
40			
41			

RESEARCH SUPPORTING THE DEVELOPMENT OF THE PERFORMANCE-BASED OCCUPATIONAL MATH REQUIREMENTS ASSESSMENT (OMRA)

INTRODUCTION

The Problem

According to the U.S. Department of Education (1983), about one-half of the young people in inner cities across the United States have reading and math skills below the ninth-grade level, which is considered to be the minimum literacy level needed for many entry-level jobs. In a research report supported by the U.S. Department of Education, Lewis and Fraser (1984) concluded that high school students are not establishing a solid foundation in the communication and computational skills that underlie all further educational and occupational efforts. Yet a recent publication entitled *Workforce 2000* indicates that "very few jobs will be created for those who cannot read, follow directions and use mathematics" (Johnston & Packer, 1987, p. xiii).

This lack of basic skills is of great concern. It presents a major problem for programs designed to prepare people for jobs. Public policy often requires that publicly funded job preparation programs have open-door admission policies that do not deny people access to training based on their basic skill levels. It assumes that public and private job training institutions will assist people to develop basic skills as part of job preparation programs if those skills are important to success on the job. It further judges the success of such programs based on the extent to which trainees are successful in the future.

With some programs, such as those funded under the Job Training Partnership Act (JTPA), federal law goes as far as to require both the identification of the basic skills requirements of jobs trained for through JTPA and the remediation of basic skills deficiencies. However, interviews with state level JTPA officials in Minnesota indicate that no formal procedures have been developed and recommended to JTPA program providers.

With the lack of adequate procedures for identifying the math requirements of jobs and the math skills of individuals in relation to those requirements, remediation becomes difficult. Therefore, people often leave vocational-technical training or other training programs without having deficiencies remediated; consequently, the problem is passed on to employers. Employers, in turn, are increasingly recognizing the need to upgrade the basic skills of employees in light of changing workforce requirements. As they attempt to address the math remediation problem, they are also faced with the same questions as educators: "What math is required on the job?" and "How can we assess whether or not individuals have those math skills?" This project was designed to develop systems useful in answering these two questions. This particular report addresses the first of the two questions.

Approach

A key concern in developing a system for assessing the math requirements of jobs as a basis for instruction is determining the unit of analysis for math competence. How fine should the competencies be broken down? Should one define courses needed—such as general math, algebra, trigonometry? Should one specify addition, subtraction, ratios? Or should one specify single digit addition, double digit addition, single number multiplication, double number multiplication?

The review of the literature suggested that most jobs require only a subset of all mathematical skills and that the identification of that specific subset can facilitate more efficient and effective education of people who will perform a job (Anderson & Peterson, 1983; Fitzgerald, 1983; Mark, 1984). Efficiency is realized by providing math education only for those skills needed. Effectiveness is realized by using the relevance of the math skills to the occupation as a motivator as well as by having meaningful examples of applications during instruction. The teaching of people within the context of an occupation is also seen to facilitate transferability of skills to the job since people can be taught in situations like those they will actually experience on the job (Cooney, 1981; Shelby & Johnson, 1988).

The review also suggested that attempts at providing math remediation based on typical math textbooks and materials which teach math as a set of abstract skills are minimally effective in remediating individuals preparing for employment. They lack the concrete application of math to learner goals and often require the learners to learn math skills seen as irrelevant to their goals (Shelby & Johnson, 1988; *Tests of Adult Basic Education*, 1987). People often drop out of such remediation programs and forsake their occupational preparation (Cooney, 1981).

Consequently, once people leave high school and enter job preparation or employment, it appears that basic skills remediation needs to focus on the requirements of the jobs for which learners are preparing. Such a functional approach is often criticized by some who believe such an approach does students a disservice. They argue that students at all levels need a broad education in math to allow them to more flexibly apply math in future situations. There is no doubt that if all people could or would learn the full range of math skills, they would be more flexible in situations requiring math throughout their lives. However, most adults who have left formal schooling and who are returning for additional training or updating cannot afford the time or cost of education which is not functional, and many find that they are only interested in learning math if it has a concrete relationship with their goals. This concrete relationship provides the motivation for spending the time and effort needed to develop necessary math skills. Often, these people could have learned math in high school had they been motivated.

The premise of the need for math skills requirements having a concrete relationship to occupational requirements is supported by the fact that many remediation programs that attempt to teach adults math using the same techniques used in high school general education programs are unsuccessful. Drop-out rates are very high, and employers report that what is learned often cannot be transferred to the job. A key in the remediation of basic math skills for adults seems to be that remediation must be focused and relevant, not general and abstract.

With this in mind, it was clear that any attempt at identifying the math requirements of occupations could not be done at the level of courses such as geometry, algebra, basic math, and trigonometry. Math requirements identified in relation to courses require people to study and master large amounts of math that have no perceived relevance and, therefore, lack an important ingredient in motivating adults. Also, such courses tend to have established protocols for delivery which concentrate on the hierarchy of math skills as determined by mathematicians rather than on the functional usage of math in job environments.

Therefore, the review suggested that a technique was needed that would allow for the identification of specific math skills associated with occupations so that those skills could be used to judge the extent to which individuals had the skills required of a given job and so that they could be used to develop instruction for people preparing for a job.

REVIEW OF THE LITERATURE

The review of the literature was conducted to identify how others have determined occupational math requirements. The review included literature on adults, postsecondary vocational education students, current employees in business and industry, JTPA participants, and senior high students. It concentrated on approaches that have been taken in the past to identify math requirements of occupations, specific occupational analysis approach methods, examples of how analyses have impacted the development of math instructional programs, and implications for the development of the methodology which is the result of this study.

Two general approaches for determining occupation-related math requirements emerged from the literature. The two general approaches, also identified by Sticht and Mikulecky (1984), were (1) occupational analysis of job or training requirements and the math associated with fulfilling those requirements and (2) standardized testing and establishing norms for occupations.

Occupational Analysis Approach

The first approach, occupational analysis, is used primarily by educators and trainers who are interested in determining the basic skills needed by a person on the job as a basis for the development of a training program. The goal is to determine the requirements of a job and to prepare people to meet those requirements.

The occupational analysis approach has most often used expert judgment (Baker, 1980) and group consensus techniques (Anderson & Peterson, 1983) to arrive at a list of math skills required for a given job. Experts are expected to explicitly or implicitly generate a list of occupational skills. If they explicitly develop a list, the list is recorded in writing (Anderson & Peterson, 1983; Horne, 1979; U.S. Department of Labor, 1972). If they implicitly develop a list, the experts are asked to think about the job skills required as they identify math requirements for a job (Greenan, 1983, 1984; Hull & Sechler, 1987; Moe, Rush & Storlie, 1980). If an explicit list is developed, it is developed before the analysis begins. Then, using the list, the occupational skills are reviewed in terms of math requirements. Since it is recognized that most occupational experts are not experts in math and that most math experts are not experts in the occupations, both sets of expertise are often represented in the group of experts (Miller & Vogelzang, 1983; Shelby & Johnson, 1988; Stanier, 1983). Various groups of experts often generate disparate lists of math skills. Each group creates its list around a math classification system uniquely agreed upon by the members of that particular group. The justification for the lack of replicability seems to be based on the assumption that the list will only be used in relation to the particular training program being developed (Greenan, 1984). When a more comprehensive review of math skills or a more reliable list is required, taxonomies of math skills are developed and then the occupational skills are reviewed in terms of those taxonomies (Anderson & Peterson, 1983; Bernstein & Mussell, 1984; Cooney, 1981; Kawula & Smith, 1975; Martin, 1983). The taxonomies provide a common reference and a classification of math skills which can be used by different groups of experts. Taxonomies found in the literature vary greatly in comprehensiveness and con ent. Some focus on mathematical concepts—addition, subtraction, and fractions (Felton, 1981; Holtz & Holtz, 1979); some focus on applications (e.g., calculation) as well as concepts (Anderson & Peterson, 1983; Shelby & Johnson, 1988); some focus on concepts, applications, and types and units of measure—for example, measurement of length in inches (*Adult Competency Education Kit*, 1977a, 1977b; Martin, 1983; Smith, 1979; U.S. Department of Labor, 1973). The wide variety of taxonomy foci appears to have come about as a result of the varied purposes which users have had.

The primary methodological difficulties of the occupational analysis approaches used in the past center around the ways in which the occupational skills and associated math skills are identified (e.g., assembled group opinion, formal analysis) and the taxonomy (or lack of a taxonomy) of math skills used as a basis for analyzing math requirements.

The two primary uses for lists of math skills associated with specific occupations are (1) as a basis for creating math curriculum and (2) as a basis for comparing the math skills of individuals with those required on the job in order to identify remediation needs.

Standardized Testing Approach

The second approach, standardized testing, is generally used to determine the global math requirements of a job as a basis for assessing the extent to which individuals have met those requirements without concern for identifying the specific math skills in which people are deficient. This approach often yields a grade level score or cut-off scores on test subscales. It is often used to screen people in terms of their ability to succeed in training or on the job with little or no concern for providing training to meet the requirements of the job.

Math requirements are identified by administering standardized tests to job incumbents or people preparing for jobs and then deriving test norms against which test scores of individuals can be compared. Standardized testing is typically used to assess an individual's skill level in reference to a norm group. There are two basic types of standardized tests related to math: (1) those tests which have been developed to measure student potential or aptitude (e.g., General Aptitude Test Battery [GATB] [U.S. Department of Labor, 1970]) and (2) basic skills achievement tests (e.g., *Adult Basic Learning Examination* [*ABLE*] [Karlsen & Gardner, 1986] and *Tests of Adult Basic Education* [*TABE*] [1987]).

The primary methodological difficulties of the standardized testing approach are (1) obtaining a sample representative of people successful on the job (Cain & Green, 1983; Webb, Shavelson, & Morello, 1981) and (2) having the test norms and scores provide sufficient information to direct remediation. The tests and norms most often produce summative indices of math ability or math aptitude. At times, subscale scores are also developed and normed (Emmit & Argento, 1980; U.S. Department of Labor, 1973), a process which provides more detailed information. However, these tests rarely provide sufficient information to direct curriculum development for specific math skills used in a particular occupation.

Occupational Analysis Approach Methods

Based on the goals of this study, it was decided that the occupational analysis approach for determining the math requirements of occupations would be the basis for developing the project's methodology. Therefore, a more intensive review of methodologies for implementing such an approach was conducted. Three basic forms of occupation-based analysis were identified. The first involves the analysis of specific jobs and job skills in terms of specific math skills required for a particular job. The second is a proxy of the occupational analysis approach. It involves the analysis of math skills required in an occupational training program which prepares people for a particular job. The third attempts to identify generic math skills required in one or more broad occupations. All three of these approaches were reviewed in detail and the results are presented below. The review is organized alphabetically by author except in those cases when two or more citations relate to the same assessment methodology and treating them together is more effective.

Analyses of Specific Occupations To Yield Math Skills Requirements

The following studies, which analyzed math requirements in terms of specific jobs, were found to have a number of characteristics in common:

1. the analysis of math skills is done in relation to activities (tasks) performed on the job,
2. a technique is presented for identifying the job activities requiring math,
3. a technique and rationale are presented for classifying math skills in an explicit or implicit taxonomy,
4. a technique is presented for recording the math skill requirements based on the taxonomy associated with the job.

The studies varied widely in how they approached each of these characteristics. Since the review was conducted to identify specific procedural methods for implementing an improved occupational analysis approach, it was decided to provide detailed information on each of the approaches rather than to try to generalize further among the procedures. The uniqueness of the combinations of procedures used in each instance was important because in many cases it is the specific combination of techniques that is important rather than some generalization over many types of techniques across many studies. Some techniques in combination with other techniques make sense; however, in combination with still other techniques, they do not make sense. Copies of existing explicitly math taxonomies developed to assist in determining the math requirements of occupations are presented in appendices A through D.

The *Adult Competency Education (ACE) Kit: Part B* (1977a) uses a job analyst to define the discrete tasks required on the job and the math skills associated with those tasks. The job analyst interviews job incumbents and analyzes printed materials relevant to the job. A math usage matrix which lists math functions (e.g., use of whole numbers, fractions, and decimals) with frequency of use is developed. Specific job tasks which utilize the math skills are listed to show how the specific math skills are used. The math skills taxonomy used is an adaptation of the Kawula and Smith (1975) "Generic Skills" list developed in Canada. The *Adult Competency Education Kit: Part C* (1977b) includes a matrix of sixty-eight jobs and four hundred basic skills associated with those jobs. (See Appendix A for the ACE Kit Math Competency List).

Fitzgerald (1983) developed a project entitled "Mathematics in Employment 16-18." It focused on math in the context of occupations. Employee interviews were conducted to identify the tasks which required math. The tasks were then analyzed in relation to the math used. The math categories used were arithmetic, fractions, algebra, trigonometry, geometry, modern mathematics, statistics, and wage calculations. Observations were made of the types of math used by individuals within job classifications. The study found that "most individuals observed required only a specific narrow range of all [mathematical] skills found in their occupational group" (p. 15). For example, some clerks worked with material requiring some math skills, and some worked with material requiring other math skills. The study also found that the use of mathematics in the workplace ranged widely from occupation to occupation. Fitzgerald indicated that the necessary math competence for most jobs appeared to be developed from daily use of the required skills and that technological innovation has eliminated the need for many complicated math skills (e.g., workers read job aids to find answers rather than doing the calculations themselves).

The U.S. Training and Employment Service has developed a systematic approach for job analysis which is reported in the *Handbook for Analyzing Jobs* (U.S. Department of Labor, 1972). Jobs are analyzed using the following terms:

1. Worker functions (what the worker does in relation to data, people, and things)

2. Work fields (the methodologies and techniques employed)

3. MTEWA (the machines, tools, equipment, and work aids used)

4. Worker traits (traits—including mathematical abilities—required of the worker)

Mathematical ability is considered a worker trait which people bring to the job. The *Handbook* recommends gathering data by direct observation of workers and by interviewing workers, supervisors, and others who might have information about the job (p. 11). In some cases, existing job descriptions are used in conjunction with interviews of administrative and technical workers. The level of mathematical skill development required for a particular job is categorized on the General Educational Development (GED) Scale. The mathematical scale is broken down into six levels: "The description of the various levels of language and mathematical development are based on the curriculum being taught at specified grade levels in schools throughout the United States" (p. 209). Each level has descriptors of the types of math operations included at that level. The descriptors include the type of math (e.g., geometry or algebra) and specific applications (e.g., calculating area and volume or calculating variables and formulas).

Webb et al. (1981) examined the reliability of the U.S. Department of Labor's (DOL) GED occupational ratings. The study used written job descriptions (rather than observations) as a basis for rating a series of jobs on the three component GED scales. Sources of variation in GED ratings among raters, occasions on which the jobs were rated, and centers at which the jobs were rated were examined using "generalizability theory analysis." The conclusions were that "the average of about four raters' ratings is needed to obtain a reliable measure of the three components [of the GED]. Only one occasion and geographic center are needed" (p. 191). Findings also "suggest that jobs can be distinguished more on their demands for language than on their demands for mathematics and reasoning" (p. 189).

Cain and Green (1983) also studied the reliability of the levels of GED scale for twenty of the most frequently used *DOT* ratings of occupational characteristics. They indicate that the reliability of the established GED math levels is lower than that for the other two scales. In testing the generalizability of the use of GED levels with service versus manufacturing occupations, the authors found that there was greater rater error when attempting to analyze GED math levels in service occupations.

Moe et al. (1980) conducted a study of the literacy requirements of industrial maintenance mechanics. The study focused on reading, writing, oral language, and mathematics. Three job sites were studied. A sample of the literacy tasks performed on the job was obtained from each site. Supervisors identified the basic mathematics skills required on the job and estimated the amount of time workers committed to tasks involving math. Supervisors described mathematics requirements using general descriptors such as addition of whole numbers, measurement skills, knowledge of the decimal system, and geometry. The mathematics skills required of maintenance mechanics varied considerably from one site to another. This may have been due, however, to the lack of structured data gathering. It was not clear how the data was gathered. In addition, the estimated amount of work time devoted to math skills from site to site ranged from less than one hour to twenty hours per week.

Anderson and Peterson (1983) used the DACUM (Developing a Curriculum) occupational analysis procedure to identify the basic job skills necessary for an entry-level salesperson. First, the essential duties and tasks required to perform the occupation were identified using a panel of local managers and expert workers. Then the basic skills (including math) needed to perform each task were identified. The first step in linking basic skills to the identified tasks was to locate basic skill taxonomies in the educational literature. Those selected were from the *Universal Skills Survey* developed by Prep Incorporated, 1982 (cited in Anderson & Peterson, 1983). The taxonomies included reading, writing, listening, speaking, and mathematics. The math taxonomy listed sixteen applications of math (e.g., calculation, use of a calculator, measurement, use of geometry). The experts were then asked to review each of the occupational tasks and identify the basic skills necessary to perform the task. The frequency of use for each of the basic skills categories was counted and used to calculate the percentage of time spent on a specific basic skill (e.g., 13% of a retail salesperson's time was spent on mathematics). A list of specific mathematics teaching activities for teaching math in the context of sales was developed.

Analyses of Occupational Math Skills Based on Training Program Requirements

Bernstein and Mussell (1984) developed a competency-based curriculum for electronics at Northern Arizona University. The authors identified a list of electronics competencies necessary to do selected electrical jobs. Although they labeled the competencies "tasks," they were actually electronics topics. They suggested that there is a range of jobs in electronics and that the continuum from the lowest to the highest level of jobs is related to mathematical rigor. Using a mathematics continuum chart from "Math and Your Career" (Martin, 1983) (see Appendix B), they analyzed electronics competencies in terms of math abilities required. They further broke the math continuum into subtopics. The major categories in the math continuum were General Mathematics, Algebra I, Algebra II, Geometry, Algebra III, Trigonometry, Calculus I, and Calculus II. Electronics competencies were then indexed against the mathematical topics using a matrix for each specific electronics job. For each of the jobs (e.g., electronic assembler), a matrix was developed which listed electronics tasks along one axis and mathematics skills along the other. The matrices were reviewed first by secondary and community college electronics instructors and then by industrial representatives both of whom addressed issues of ordering and content for both the job tasks and math skills.

Cooney (1981) described a project entitled "Linking Math, Reading, and Writing Skills to Jobs," conducted for the Employment Training Division of San Mateo County, California. The project was designed to develop a program which would teach Comprehensive Education and Training Act (CETA) clients basic skills that they needed for employment. A key element in this project was the development of a taxonomy of instructional objectives related to the basic skills of math, reading, and writing. They modified a taxonomy of generic skills developed by the Department of Manpower and Immigration, Prince Albert, Saskatchewan (Kawula & Smith, 1975). The fifty-five page taxonomy of more than four hundred basic skills (including math) was used with training program personnel to check-off the basic skills instructional objectives that pertained to their program. There was no attempt to gather job task information. The taxonomy was also used to develop tests which assess the ability of clients in the skills associated with the instructional objectives. Instruction was then focused on those instructional objectives (pertinent to a given training program) which clients had not mastered.

Miller and Vogelzang (1983) conducted structured interviews with groups of educators—vocational agricultural teachers, math teachers, principals, and parents—and documented the need to provide mathematics instruction for persons studying in high school agricultural programs. Thirteen mathematics concepts from previous studies involving mathematics and vocations, textbooks, and related literature concepts were identified. The thirteen concepts were volume, converting units of measure, using whole numbers, ratios and proportions, percentages, metric units of measure, English units of measure, averages (simple statistics), fractions, decimals, area, simple algebra, and graphs and tables.

Generic Skills Required Across Occupations

Greenan (1983) conducted a study to determine the skill areas and subskills that are generalizable within and across secondary-level vocational programs. He defined basic skills as generalizable skills and suggested that generalizable skills are necessary for success in vocational programs and occupations. One of the generalizable skills areas was math. A list of basic skills was developed from an analysis of existing studies in which basic skills were listed. The draft list was reviewed by the project advisory committee, survey research personnel at the University of Illinois, employers with workers involved in several different occupations, and workers in occupations relevant to the study. Based on the review, a list of skills potentially related to success in secondary vocational training programs was generated. The final survey instrument contained twenty-eight mathematics skills. Four hundred eighty-nine Illinois secondary level vocational teachers from five vocational program areas rated the skills according to degree of importance to program success. Findings were focused in an effort to enhance instructional support and remedial services in secondary schools.

Hull and Sechler (1987) conducted a study to determine the literacy needs (including math needs) of the American labor force. Data was collected from a literature survey, site visits to nine industry training programs, and a technical panel of experts. The study developed a basic skills list based on earlier studies and then asked trainers to evaluate the skills in terms of their best estimate of what employees generally "need to know." The skills included reading, writing, speaking, listening, and mathematics. Some companies also indicated a need for reasoning, problem-solving, and decision-making skills. The study developed a list of "42 fundamental capabilities needed by many employees in the workplace" (p. 27). It did not attempt to determine the specific math skills needed in specific occupations.

Smith (1979) conducted a large study financed by the Canadian Commission of Employment and Immigration entitled "Generic Skills: Keys to Job Performance." Workers were surveyed in forty-nine occupations, and supervisors were surveyed in twenty-eight occupations. The goal was to identify generic skills which would be common for the occupational groups. The generic skills identified were communications, mathematics, science, and reasoning. A taxonomy of the possible classifications within each skill area was developed by analyzing educational and training curricula, reports of occupational analyses, the *Canadian Classification and Dictionary of Occupations*, literature, and staff knowledge of the occupations. Once the taxonomies were developed, they were formulated into interview schedules and used with workers and supervisors to determine which skills are actually used in each occupation. Data obtained from workers and supervisors in the same settings was correlated. The study concluded that "It appears that skill data may reliably be obtained from either workers or the workers' immediate supervisors" (p. 6). The study identified twenty-four generic core math skills which seem to be needed in most occupations and twenty-one noncore math skills which are needed in some of the occupations studied. The lists of core skills and noncore skills are presented in the Generic Mathematics Competency List in Appendix C.

Occupational Math Instructional Program Development

Felton (1981) described a systematic process for developing an adult basic skills program in the private sector. An Adult Basic Education (ABE) curriculum was defined to include "the sequential skills, materials, and methods used in a program teaching reading, writing, arithmetic, and survival skills to adults" (p. 3). A trade-related curriculum was defined as a curriculum that focuses these skills on the work environment associated with a particular trade. Felton used the following general steps in the skills identification process:

1. Describe each job classification in the company unit.

2. Identify the jobs requiring math skills.

3. Identify workers who perform jobs requiring math skills and who might be possible candidates for a basic skills program (those with less than a high school education and/or those hired without prerequisite basic skills).

4. Obtain math-related forms or paper work used in the performance of targeted jobs.

5. Develop a company-wide listing of identified math skills.

6. Provide fundamental math training to identified individuals.

7. Provide specific training (in the math skills used on the job) to individuals after mastery of fundamentals (i.e., addition, subtraction, multiplication, and division of whole numbers, fractions, and decimals).

Shelby and Johnson (1988) reported on a curriculum development project designed to produce learning materials which integrated math and vocational education at the secondary level. The activity took place at the Canadian Valley Area Vocational Technical School in Oklahoma. Twenty-five math competencies were identified. They ranged from competencies such as fractions, decimals, percentages and English/metric measurement to data graphing (see Canadian Valley Math Competency List in Appendix D). In order to identify the math concepts used in the various vocational programs, a math competency-vocational program matrix was developed jointly by vocational-technical instructors and math teachers. This activity required that math instructors—with input from vocational instructors—develop math curriculum on practical uses of mathematics in the world of work. Vocational teachers explained the math competencies which they perceived as necessary for successful completion of vocational programs and assisted math curriculum developers in understanding technical and math questions and workable instructional strategies related to "real life" problems. The final products of the project were learning activity packets for mathematics which represent an effort at vocational and academic integration.

The Smith (1979) study has implications for program development, even though its primary purpose was to identify generic math skills needed in most occupations. The study found the following:

1. "Elementary arithmetic computational and measurement skills are common every day requirements for most workers" (p. 11).

2. "Workers are expected to verify the accuracy of their measurements and their calculations" (p. 11).

3. Employers are providing aids such as calculators, charts, and tables.

4. "Employers are not particularly interested in the language of mathematics" (p. 11).

5. "Mathematics at work is always measurement related" (p. 11).

6. "Many workers are involved with geometric figures, mensuration and drawings or sketches" (p. 11).

7. "Although the technologists require some elementary algebraic and trigonometric abilities, these skills are rarely required by most workers" (p. 11).

8. Algebraic calculations are generally presented as applied formulas which require only simple arithmetic.

9. "Mathematical competencies are not generally greater requirements in the foremen/supervisory positions and are probably NOT a significant reason why some workers are selected and promoted to supervisory status" (p. 11).

Stanier (1983) reported a successful methodology used for linking the teaching of mathematics and the application of mathematics to occupations developed by the Dacorum Education and Training Forum. The procedure was designed to make the math curriculum more relevant and included the following steps:

1. Teachers and curriculum planners visit a firm in order to understand and evaluate the use of mathematics on the job.

2. They produce math worksheets based on occupational applications.

3. The worksheets are reviewed by people from the firm before being used.

4. If possible, industry personnel visit the instructional setting to validate the math instruction as useful in the workplace.

This methodology was characterized as allowing teachers, who provide the curriculum perspective, to link with employers to select appropriate mathematics concepts and to enhance the relevance of those concepts to occupations.

Implications for Development of New Methodology

This literature review was conducted to gather information on the methodologies that have been used to identify the mathematics skills requirements associated with occupations. It was also conducted to gain insight into what type of analysis would provide meaningful direction to the development of math remediation programs associated with job skills preparation. Two general approaches to the identification of math skills requirements were identified in the literature: (1) the standardized testing approach and (2) the occupational analysis approach.

The standardized testing approach was found to be unsatisfactory. It is generally used in assessing the extent to which individuals have met the global math requirements of an occupation. A math test which covers a wide range of math skills is administered to a group of people in a particular occupation. The distribution of scores of members of the group are then used to develop a norm. That norm is then used to compare the scores of people who wish to enter the job or to begin training for the job. This approach is typically not concerned with identifying the specific math skills in which people are deficient. It is often used to screen people in terms of their ability to succeed in training or on the job and does not provide sufficient information for designing training to meet the requirements of the job or for assessing the specific basic skills deficiencies of individuals.

The review also revealed that the specific math skills that are required to perform on a given job vary from job to job. Therefore, a diagnosis of the math skills required for one job cannot be generalized to other jobs. Generalizability requires an occupational analysis of the job.

The review also revealed that broad categories of skills can not adequately define the specific math skills required in an occupation. Individuals in an occupation use very specific math skills and not necessarily large blocks of skills such as geometry or algebra. More often they apply only a few of the more specific skills within such large blocks. Therefore, the occupational analysis approach to identifying specific math skills associated with samples of specific job skills seems to be the most precise approach for identifying the math requirements of an occupation. Attempts at identifying generic or core math skills appear to be reasonable if training is to be general and if the specific occupation the trainee will enter cannot be determined. However, just as general math requirements in the form of traditional math courses are not appropriate, generic skills also do not make much sense in specific job training.

Occupational analysis procedures most often use expert judgment and group consensus techniques in generating a list of math skills required for a given occupation. Procedures vary greatly in terms of how the skills are identified. Most procedures begin by assembling a group of experts who are expected to explicitly or implicitly possess or generate a list of job skills for the occupation to be analyzed. Since the math skills identified for a given occupation are dependent upon the expert's perception of the occupational skills, the identification of and an agreement on the occupational skills become important. If experts use varying occupational skills as a reference point, they are likely to arrive at different lists of math skills.

In many cases, the process for producing a consensus list of occupational skills is more lengthy than the process for determining the math skills associated with those occupational skills. Current procedures often require substantial time, expertise, and money in order to generate a consensus list.

The procedures currently used to identify the math skills requirements associated with occupational skills have problems similar to those described above. Experts are usually called upon to determine the math required to perform occupational skills. Again, those experts have either an explicit or an implicit list of math skills in terms of which they analyze the occupational skills. If the list is not explicit, the various experts tend to analyze the occupational skills from different reference points. This makes achieving reasonable agreement among experts difficult because their bases for analysis are different. This problem has most often been addressed by having a group of experts agree upon a taxonomy of math skills that they will use during analysis. Sometimes a new taxonomy is developed, and sometimes an existing taxonomy is adopted. The appendices of this report present a number of different taxonomies found in the literature.

The taxonomies found in the literature vary greatly in comprehensiveness and content. Some focus on mathematical concepts (e.g., addition, subtraction, and fractions); some focus on applications (e.g., calculation) as well as concepts; and some focus on concepts, applications, and types and units of measure (e.g., measuring length in inches). Few have a theoretical rationale that is based on a continuum of math skills attainment. Most are lists of math skills based on the way math is currently presented in textbooks. Often, these lists specify math topics (e.g., decimals) rather than specific math skills (e.g., addition of decimals) and pay little attention to cumulative development of math skills. What is needed is a taxonomy of math skills that has a theoretical framework that is organized in terms of math skill development and that can be used to determine an individual's level of math skill development.

The process of actually judging which math skills are required for a person to function relative to required occupational skills also needs attention. There are a variety of approaches currently being used. At times, math experts review the occupational skills and make judgments as to which math skills are required. At other times, occupational experts make the judgments. It is becoming apparent that most occupational experts are not experts in math, that most math experts are not experts in occupations, and that both sets of expertise are needed to conduct an adequate analysis. Systematic procedures are needed which experts can use to apply math taxonomies to representative occupation skills during the analysis process.

Consequently, procedures developed by the "Computerized Adaptive Assessment of Basic Skills" project must address the following:

1. the development of a quick and valid method for generating a consensus list of occupational skills which can serve as a basis for determining math skill requirements;

2. the development of a math skills taxonomy which has a theoretical framework, organized in terms of math skill development, and which can be used (1) to analyze the math requirements of a particular occupation and (2) to determine the level of an individual's math skills development;

3. the development of efficient and systematic procedures which experts can use to apply math taxonomies to representative occupational skills in developing a list of math skills requirements.

DEVELOPMENT OF THE ASSESSMENT PROCEDURES

Design Parameters

Based on the review of the literature, a set of design parameters was created for developing new procedures for determining the math requirements of an occupation. It was decided that the procedure should

1. be performance based (i.e., yield the math requirements needed to perform on jobs prepared for through vocational education),

2. include major categories and math operations organized around functional usage dimensions rather than theoretical mathematics dimensions,

3. contain accessible verbal descriptions and examples of each math operation,

4. contain simple directions,

5. yield information useful in developing curricula,

6. be usable by staff in a typical vocational school or training environment, and

7. provide information against which an individual's math skills can be compared in determining possible deficits (which, in turn, become the basis for remediation).

The assessment system required the development of four components:

1. a taxonomy which represents the range of math skills used in occupations trained for in vocational education (less than baccalaureate degree),

2. a procedure for defining the occupation to be analyzed and for obtaining a sample of occupational skills which require math,

3. a procedure for determining and recording the math skills required in occupations,

4. a set of user directions.

The resulting instrumentation for assessing the math requirements of occupations is called the Performance-Based Occupational Math Requirements Assessment (OMRA). OMRA came to include two parts:

1. the OMRA Coordinator Manual, which contains directions to be followed by the person in charge of conducting the assessment; and

2. the OMRA Instrument, which is used by math and occupational experts to determine the math requirements of a particular occupation and which includes the OMRA Inventory, the OMRA Applications Supplement, and directions.

Both the OMRA Coordinator Manual and OMRA Instrument are included at the beginning of this publication.)

A description of the developmental process used to create the OMRA and its parts is presented next.

Math Skills Taxonomy Development

The development process started with the development of a taxonomy of math skills. (See the OMRA Inventory in the first section of this document for a copy of the final taxonomy.) The taxonomies of math skills used with previous studies were reviewed in detail (*Adult Competency Education Kit,* 1977a, 1977b; Martin, 1983; Shelby & Johnson, 1988; Smith, 1979 [see appendices A through D]). None of the existing lists were judged adequate. Most of the lists were laundry lists of math and/or measurement concepts or of math principles used in occupations. They often contained nonmath items such as "use a calculator." Often the lists were organized around the way math is typically taught in schools (i.e., as discrete courses such as general mathematics and algebra). The lists did not represent hierarchies of math concepts based on functional usage. The taxonomies rarely had examples of the math operations which could be recognized by nonmath experts. Most often the math was defined verbally, a format which required an in-depth knowledge of math to interpret.

The lack of conceptual consistency and the inability to find and record math concepts quickly by both occupational and math experts led to the decision to develop a new taxonomy. After numerous false starts, it was decided that the taxonomy should be presented in the form of a matrix. The matrix would be organized by category of math (e.g., whole number operations) and complexity of math concepts within categories (e.g., addition before division). Each math concept would be presented both as a math operation in a form recognizable to people who practice in occupations and as a written definition of the operations understandable to math experts. The major categories of math were presented in order of increasing complexity from left to right. The math operations within categories were presented in increasing conceptual complexity from top to bottom (see the OMRA Inventory, p. 15). The math operations were organized based on functional usage and not on the school courses in which they are typically taught. The format was designed to allow the user to first classify the type of math and then to look down the column to identify the level of complexity by example and/or verbal definition.

Limits on the Range of Math To Be Included

Limits on the range of math to be included in the OMRA Inventory had to be set. The OMRA Inventory was to be structured in terms of functional complexity (based on difficulty or inclusiveness of math operations). Two major questions were asked: Which categories of math, if any, could we assume all or most students would already know? The answer would help set the lower limit. Likewise, at which level should the top limit be set (e.g., Boolean algebra, calculus)? It was determined that the postsecondary target population would possess lower order number skills (e.g., counting, verbalizing numbers); therefore, the lower limit was set above lower order number skills. The range began with integer number operations. The upper limit was set at a point such that the math above it would be applicable to only a few occupations. It was assumed that highly specialized math skills could be (and often are) taught within occupational programs as the occupational skills are taught or in specialized courses. The upper limit stopped at advanced algebra and advanced geometry operations.

Math categories were originally identified by reviewing other math hierarchies and textbooks, avoiding a consensus that was not based on school math courses. The topics included in the matrix—arranged from simple to complex—were integers, fractions, decimals, percentages, ratios, algebra, and geometry. Trigonometry, calculus, Boolean algebra, and other specialized math skills were not included, based on the results of previous research that indicated that these types of math are rarely used by workers (Smith, 1979) and based on conversations with math teachers in technical colleges.

Limits also had to be set on the variety of specific math operation examples that would be included within each math category (e.g., within the integers category, should only addition be indicated? or should single digit addition, double digit addition, triple digit addition, and so on be included?). Each math category, theoretically, contains an infinite number of potential examples of increasingly more difficult operations. The problem was to select enough examples to be representative of major levels of difficulty—but not so many that they become a burden. The decision was made to include as many examples of operations as possible and to bring the OMRA Inventory to an advisory committee for assistance in possibly limiting the examples.

Item Development

Within each category, examples of math operations that are representative of the type of math used by people in occupations trained for in vocational education were developed. That is, as one moves down a column of the OMRA Inventory, each succeeding operation was designed to build on the operation directly above it and to increase in complexity. Each operation was represented by a verbal description (e.g., divide signed numbers) and an example of a calculation; therefore, the user could either identify the operation by its name or by an example of it.

Defining the Occupation To Be Analyzed and Sampling Occupational Skills

Defining the Occupation To Be Analyzed

When analyzing the math requirements of an occupation, it is important to clearly define the occupation to be analyzed. Unless this is done, the people participating in the analysis are likely to have very different images of the occupation being analyzed. Such differences can lead to widely varying results among experts because each is analyzing a different occupation. It was decided to use *DOT* (U.S. Department of Labor, 1991) as the basis for defining the occupations to be analyzed. The user could also make modifications to the definition if the occupational training program had a more specific focus.

Identifying Occupational Skills

The decision to conduct analyses of math skills requirements in relation to specific occupations required the adoption (or development) of a technique for identifying occupational skills requiring math. The technique needed to be usable by people who actually deliver vocational training and needed to result in occupational information that could be analyzed reliably in arriving at math skills requirements. Usability could not be limited to only highly skilled occupational analysis experts or to experts in theoretical mathematics. In order for the technique to provide results with validity and reliability, it was important that the user not have to be highly subjective in identifying the skills.

The literature had revealed two common techniques for identifying the occupational skills that required math. The first was to conduct a task or behavioral analysis to determine the occupational skills to be included in a training program. Once the occupational skills are determined, the math skills required are typically inferred. The second technique was to obtain copies of actual materials which people use on the job and to review those materials for math applications.

The second technique was adopted and adapted for use in this study because it has three major advantages. First, it does not require a full occupational analysis. It only requires people knowledgeable about the occupation to identify sample materials requiring math calculations that are representative of the range of math required in the occupation. This saves the great deal of time required for conducting a complete in-depth occupational analysis. Second, it minimizes the need to infer the math requirements because actual materials containing examples of math requirements are the basis for the analysis. They are published in job-related materials. Third, the technique also provides a vehicle for recording the occupational tasks or applications which required the math skills. Documenting those applications during analysis becomes the basis for teaching the necessary math skills in the future. It was hypothesized that if different groups of people use the same sample of occupational materials and a common taxonomy of math skills, they would arrive at similar math requirements, thereby providing both valid and reliable results.

Gathering Job-Related Materials

The procedures for obtaining job-related materials are critical to implementing OMRA since the accuracy of the math requirements assessment is dependent upon the extent to which the materials represent the occupation. Job-related math materials were defined to include any materials that contain references to the use of math. These materials are used by a worker while performing on the job and contain examples of occupational applications requiring math. They include, but are not limited to, materials containing charts, manuals, job aids, and tables used on the job. They can also include verbal references to job activities requiring math.

First attempts at gathering the materials were designed to gather materials from instructors of vocational programs. It was quickly realized, however, that the instructors rarely had samples of materials actually used on the job. Almost all of the materials they could provide were curriculum materials and textbooks; therefore, a procedure was developed for gathering information directly from work sites.

Since the project was designed to identify the math skills to be included in postsecondary vocational education programs and since each program is expected to have an advisory committee, vocational program advisory committee members were utilized.

Committee members were assumed to represent the occupations for which a program is designed to prepare students.

If OMRA were going to be used with vocational programs, it was recommended that instructors of vocational programs which prepare people for the occupation to be analyzed be identified. The instructors were then to recommend members of their advisory committees who had access to materials actually used on the job. Those advisory committee members were then given a set of criteria for selecting sample job-related materials. The materials received were then reviewed by the coordinator to determine whether the range of math skills required in the occupation appeared to be represented. When the range was not represented, additional materials could be sought.

Originally, the procedure called for identifying those materials in which math was actually demonstrated (e.g., in which calculations were shown). However, a problem soon arose. In some occupations, math is applied without actually being explicit in the materials used on the job. For example, a carpenter usually does not record calculations while on the job. The carpenter may be required to calculate the board feet of material needed to cover a hardwood floor, but the job manual on the installation of the hardwood floor simply assumes that a carpenter can do such a calculation and merely indicates "order the hardwood flooring." The actual calculations might be performed with a calculator or written on a piece of board. Therefore, the materials assembled for analysis needed to include not only those that contained actual calculations, but materials that required math skills which were not indicated with actual calculations.

Analyzing Occupational Skills To Determine and Record the Math Applications and Math Skills Requirements

A technique which would yield a list of job applications and the math operations required to perform them was needed to analyze the job-related occupational skills requiring math. The literature indicated that it was not reasonable to assume that an occupational expert had the necessary knowledge of math nor that a math expert had the knowledge of the occupation needed to analyze the math requirements of an occupation. Consequently, it was decided that a team consisting of an occupational expert and a math expert should review the materials.

The team was to review the job-related materials for job applications which required math. The job applications were recorded on the OMRA Applications Supplement (included with the OMRA Instrument). They were then analyzed in terms of math operations using the OMRA Inventory. Each required math operation was identified. Then the number of times that operation would be performed with that application per month was recorded in one of the cells next to the math operation. Since some math operations are performed frequently in an occupation with many job applications, it was decided that only the first twelve job applications requiring a particular math operation would be documented. This provides ample evidence that the math operation is a math requirement of the occupation. It also provides a range of job applications as possible contexts within which to teach the operation.

User Directions

After the procedures were developed, two sets of user directions were created. One set, the OMRA Coordinator Manual, was for the person who coordinates the assessment. The second set of directions was for the occupational and math experts who use the OMRA Inventory and the OMRA Applications Supplement to actually review job-related materials. The directions were designed to allow people in a typical vocational school environment to implement the procedures. The Coordinator Manual includes the following steps:

1. Define the occupation to be analyzed.
2. Identify occupational and math experts.
3. Identify occupational practitioners (e.g., members of advisory committees).
4. Obtain samples of job-related materials containing math applications.
5. Provide the occupational and math experts with the job-related materials and OMRA.
6. After the team members have completed their activities, develop a prioritized list of math operations required for the occupation.
7. Assemble the list of sample job applications requiring math.

Team member directions contained in the OMRA Instrument included the following steps:

1. Review the contents of OMRA.

2. Review each of the job-related materials included in the packet for job applications requiring math.

3. Analyze each math job application in terms of the type of math operations it contains (e.g., addition of whole numbers, division of fractions, and conversion of a decimal to a fraction). Many applications require more than one math operation. If an application contains two or more operations, note each separately. For example, [40 ¥ 40] / 680 involves both multiplying and dividing whole numbers.

4. Record each application on the OMRA Applications Supplement.

5. Record the operations associated with an application and their frequency of use on the OMRA Inventory.

Initial Pilot Testing

After the OMRA materials were developed, they were pilot tested with a group of five graduate students at the University of Minnesota. Each had a technical background and had studied math through at least geometry and algebra. The content selected was from auto mechanics and aviation mechanics manuals used on the job. All five people were asked to review the same sample of materials. Each reviewed the same materials separately and completed OMRA. Later, the group was assembled and suggestions were elicited for improvements.

Advisory Committee Consultation

The materials that were developed and their associated rationales were presented to the project advisory committee in October of 1989. The committee was composed of the six experts listed in Table 1. Each member was selected for a particular area of expertise and perspective.

Table 1

Advisory Committee

Role	Name and Position
Technical math educator	Dr. Michael Morgan, Director of Math, Science, and Electronics Chemeketa Community College Salem, Oregon
Mathematics department	Dr. Theodore Vessey Professor and Chairman College of Liberal Arts St. Olaf College St. Olaf, Minnesota
Technical college math	Mr. Richard Wagenknecht Instructor St. Paul Technical College St. Paul, Minnesota
Math evaluator	Dr. Joan Garfield Associate Professor General College University of Minnesota Minneapolis, Minnesota
Math teacher educator	Dr. Franklin Roberts Assistant Professor Department of Curriculum and Instructional Systems University of Minnesota Minneapolis, Minnesota
Occupational assessment expert	Dr. Rene Dawis Professor Department of Psychology University of Minnesota Minneapolis, Minnesota

The advisory committee members were sent a description of the intent of the project and were asked to review the draft OMRA. The directions were reviewed for clarity and for their ability to produce valid results. The OMRA Inventory was reviewed for its inclusiveness of the math operations performed in occupations trained for in vocational education and for the level of detail included in the categorizations. The OMRA Inventory and the OMRA Applications Supplement were also reviewed for their usefulness in recording the math applications of an occupation. The committee members were given two weeks to review the materials and gathered at the University of Minnesota for an all day meeting to discuss their reactions. During the meeting, the results of the first pilot were shared with the committee.

The committee was first asked whether the range of math operations contained on the OMRA Inventory represented the range typically used in occupations which required less than a baccalaureate degree and which are trained for in vocational education. Members indicated that the correct range was presented. There was some debate about whether to include trigonometric operations or calculus. It was agreed that these are rarely used in the range of occupations that was under discussion.

The committee did raise concerns about the number of levels which were presented within each of the math categories. Members indicated that the examples within categories were broken down into steps that were very fine and that represented mathematical, but not necessarily practical differences. The committee was helpful in determining the meaningful differences, and the operations contained in each category were clustered into fewer operations. They did significant editing of the algebra section and suggested that the geometry section needed major editing because many levels were not used in occupational training.

Based on input from the advisory committee, the materials were revised. Directions were rewritten; categories within the OMRA Inventory were simplified, combined, and rearranged; and the OMRA Applications Supplement was further developed.

FINAL PILOT TESTING

Design Parameters

The pilot was designed to test the OMRA procedures with two occupational areas—one technical occupation requiring a larger amount of math and one less technical occupation requiring less math. The purposes of the pilot were to

1. determine consistency of results between teams and

2. obtain feedback on the usability of the procedures.

Pilot Administration

The occupations selected were general secretary and electronics technician. General secretary job-related materials were obtained from secretaries responsible for budgets at the University of Minnesota. Electronics materials were collected by asking occupational instructors for recommendations of people on their advisory committees who had firsthand knowledge of what people in those occupations do. Those selected were first contacted by phone to obtain their cooperation and to inform them that we would be asking for examples of materials which contained applications of math. Interviews were held with each participant to collect actual samples of occupational materials which required math. No attempt was made to gather an exhaustive set of materials. The purpose of the pilot was to test the procedure, not to generate definitive lists of required math skills for the occupations selected.

Six review teams were assembled: three teams of secretary reviewers and three teams of electronics reviewers. Each team was composed of an instructor who taught in the occupational area and a math instructor from a Minnesota Technical College. No person was on more than one team.

Each of the three secretary teams was presented with the same set of occupational materials, as were the three electronics teams. Each team was asked to read the OMRA directions carefully and to complete the OMRA Inventory and the OMRA Applications Supplement. Teams were also asked to complete a feedback sheet on OMRA.

Data Analysis

Once the OMRA Inventory and Applications Supplement were received from the six teams, the data was analyzed. Team results were compared to examine the inter-group consistency.

Second, for each occupation, operations indicated by only one team were reviewed to determine if there appeared to be any systematic bias. This was done by reviewing the actual job-related materials to verify that math was required.

Third, for each occupation, a revised list containing only those operations which were selected by more than one group (or which were selected by one group and verified against the job-related materials) was developed.

Fourth, a prioritized list of math operations for each occupation was created. The list could be used in determining the relative importance of each math operation in a math curriculum designed to prepare people for an occupation. The list could also be used as the basis for determining if people tested with the Computerized Adaptive Test (developed as the second part of this project) met the math requirements of an occupation.

Prioritizing was done by first determining how many teams selected the operation. Then each operation's relative importance was determined based on estimated frequency of use. The total number of times each team felt that a particular operation would be used during a given month was calculated. This was done by adding the frequencies of use for all applications indicated in the cells in the tally block to the right of that operation. For example, if four applications of an operation were found by a team, four cells would have been completed in the tally block for that operation. If the frequency of usage for the first application during a month was five, the second two, the third seven, and the fourth ten—the total estimated usage of that operation per month would be twenty-four. Teams were told to account for only the first twelve applications. After accounting for twelve, they could just place a check across the total tally block to indicate more than twelve applications of that operation were found. Such applications were treated as having an infinite frequency of usage for analysis purposes. Once the total frequency of usage per month was calculated for each operation for each team, an average frequency across all three teams for a given occupation was calculated. The prioritized list for an occupation was then created—based, first, on the number of teams indicating the operation was required in the occupation and, second, on the average frequency of use calculated across the teams. This resulted in a list with all operations agreed on by all three teams being first on the list. Those operations agreed to by all three teams were further ordered, largest average estimated frequency of use per month first. Next, came those operations on which two groups agreed, and so on.

Fifth, a list of job applications for each operation was developed from the OMRA Applications Supplements. A composite list was generated from the data of the three teams. Redundancies among the lists were removed. This list could be used to provide instructional contexts for teaching the various math operations.

Results

Usability of OMRA

Team member reactions regarding the usability and usefulness of OMRA were gathered through a reaction questionnaire. The general consensus was that the directions were clear. Some concern was expressed about estimating the frequency of usage of operations. Some teams felt that estimating the absolute number of times an operation was used per month was very difficult. They recommended developing frequency categories from which they could choose (see the discussion of the three-part scale below).

The people in electronics felt that the range of math skills represented was not sufficient. This led to an interesting question about how to determine the math requirements. None of the on-the-job sources of job-related materials yielded materials that required math beyond the range in the OMRA Inventory. The advisory committee also suggested that the range was sufficient. In addition, the literature suggested that math beyond some basic algebra and geometry is not necessary. However, the electronics instructors felt the range should include the math that is covered in their texts but that may not actually be used on the job.

All of the teams felt they could quickly identify applications requiring math in the job-related materials. There were mixed reactions from the teams as to the value of such a list of applications. Most felt it would be valuable. Many expressed concern that the actual list developed was not sufficient, even though they were asked to judge the procedure and not the specific list and were told that the materials presented to them were not meant to be comprehensive. One team felt that the needs of industry should not be the basis for judging what should be taught. They felt that deciding what should be taught was the role of the instructors.

All of the teams felt they would be able to assemble the job-related materials required for such an analysis if they were asked to do so. Five of the six teams felt that the OMRA procedure would yield an adequate sample of the types of math needed in an occupation. Five of the six teams felt they would use OMRA to identify basic math skills. The overall judgments of the six teams who applied OMRA indicated that it was understandable, usable, and provided the intended results. They felt they could implement the procedure.

Based on feedback from the users, the procedure for estimating the monthly frequency of use of an operation was changed. OMRA users are now asked to rate the frequency of usage on a three point scale: 1 = 1 to 5 times per month, 2 = 6 to 10 times per month, 3 = 11 or more times per month.

General Secretary Results

A total of seventeen of the sixty-three math operations included on the OMRA Inventory were listed by at least one of the three teams as being required for a general secretary (see Table 2). Ten were listed by the three groups, three by two groups, and four by only one group. Two additional entries were written in by team members: "accounting concepts" and "determine the amount." Neither of these were math operations. Both were applications of math operations. All of the operations selected by only one group could be found in the job-related materials.

The secretarial teams listed thirty-four different applications of the seventeen operations. The results are presented in Table 3. The sources and page numbers are not listed because clear directions were not presented on how to record them. Therefore, the different teams used different approaches and the results could not be consolidated.

Table 2

Secretary—Occupational Math

(Ordered by Frequency Ratings Across Teams)

Cell No.		Grp 1	Grp 2	Grp 3	Avg. Freq.	Priority
	Three Teams Selected the Operation					
1- 3	Add Whole Numbers	30	14	32	25.3	1
3- 5	Multiply a Decimal by a Decimal	26	10	24	20.0	2
3- 1	Add Decimals	20	20	17	19.0	3
4- 5	Take the Percent	15	11	12	12.7	4
3- 2	Subtract Decimals	15	6	11	10.7	5
1- 5	Multiply Whole Numbers	19	3	5	9.0	6
1- 4	Subtract Whole Numbers	20	3	3	8.7	7
3- 6	Divide a Decimal by a Decimal	4	5	3	4.0	8
1- 8	Add Signed Numbers	2	2	7	3.7	9
4- 6	Determine the Percent	4	5	1	3.3	10
	Two Teams Selected the Operation					
4- 2	Convert Percents to Decimals	14	0	14	9.3	11
4- 4	Convert Decimals to Percents	7	7	0	4.7	12
1- 7	Round Off	3	2	0	1.7	13
	One Team Selected the Operation					
5- 3	Conversion	20	0	0	6.7	14
1- 6	Divide Whole Numbers	0	2	0	0.7	15
1- 1	Convert Words to Arabic Numbers	1	0	0	0.3	16
1- 2	Convert Arabic Numbers to Words	0	1	0	0.3	17

Table 3
Summary of Secretarial OMRA Applications

	Operation Code	Description of Application	Source #.p. #
1	1-1	Memo	No sources listed for pilot (teams used different methods for recording)
2	1-2	Prepare Deposit	
3	1-3	Calculate Death and Autopsy Statistics Calculate Purchase Order Calculate Travel Expenses Compute Grades Compute Travel Authorization Figure Payroll Project Report Summary Record Voucher	
4	1-4	Calculate Death and Autopsy Statistics Calculate Grades Figure Payroll Travel Authorization	
5	1-5	Calculate Death and Autopsy Statistics Compute Travel Authorization Figure Payroll Program plus Invoice	
6	1-6	Calculate Death and Autopsy Statistics Calculate Payroll Distribution Compute Grades	
7	1-7	Calculate Payroll Distribution	
8	1-8	Project Report Summary Reconciliation Report	
9	3-1	Calculate Dues - Subscription Fees Calculate FAX Charges Calculate Invoice Calculate Payroll Calculate Phone Charges Calculate Purchase Order Calculate Salary Calculate Sick Leave	

Table 3 (cont.)

	Operation Code	Description of Application	Source #.p. #
9	3-1 (cont.)	Cash Receipt Voucher Cell Regulation Complete Journal Voucher Complete Requisition Compute Budget Transfer Compute Travel Authorization Inventory Control Order Supplies Payment of Honorarium Prepare Deposit Reconcile Budget Reconciliation Report Reimbursement	
10	3-2	Calculate Salary Fringe Benefit Check Inventory Control Invoice UMAP/100 MOA Order Supplies	
11	3-5	Calculate Fringe Benefits Calculate Payroll Distribution Calculate Phone Charges Calculate Purchase Order Calculate Salary Combined Requisition and Invoice Complete Journal Voucher Compute Travel Expense Voucher Contract Release P.O. Memo of Agreement Payment of Honorarium Reconciliation Report Record Voucher	
12	3-6	Calculate Payroll Calculate Payroll Distribution Formulas on Excel Spreadsheet	
13	4-2	% Distribution of Hours and Effort Calculate Fringe Benefits Calculate Payroll Calculate Purchase Order Combined Requisition and Invoice Formulas on Excel Spreadsheet Reconciliation Report	

Table 3 (cont.)

	Operation Code	Description of Application	Source #.p. #
14	4-3	Compute Grades	
15	4-4	Calculate Death and Autopsy Statistics Calculate Grades Calculate Payroll Distribution Calculate Salary and Fringe Benefit Formulas Formulas on Excel Spreadsheet Nelson's Office Supply Percent Distribution	
16	4-5	Combined Requisition and Invoice Figure Payroll Fringe Benefit Check Order Supplies Percent Distribution Reimbursement	
17	4-6	Calculate Death and Autopsy Statistics Calculate Grades Formulas on Excel Spreadsheet Fringe Benefit Check Nelson's Office Supply Payroll Distribution Effort and Hours	
18	5-3	Record of Vacation and Sick Leave	
19	8-1	Calculate Salary and Fringe Benefit Formulas Journal Voucher	

Electronics Results

A total of fifty-five of the sixty-three math operations were initially listed by at least one electronics team. Twenty-eight were selected by only one group and were examined in relation to the job-related materials used in the pilot. Seventeen operations selected by only one group were removed because, upon examination of the job-related materials, they could not be found. For example, one team indicated that all of the operations pertaining to fractions were needed. Upon review of the materials, fractions were not included. Consequently, only thirty-eight operations were actually found to be represented in the sample materials.

Of the final thirty-eight verified math operations listed by at least one team, fifteen were selected by all three groups, twelve by two groups, and eleven by only one group (see Table 4). Six additional operations were added by team members: Boolean algebra, exponential values, base-N operations, base conversion, binary math, scientific notation, and construction and reading of graphs. Again, upon review of the job-related materials, none of these math operations could be found. Upon follow-up conversations, it was determined that the team members who had made these suggestions felt they should be taught because they are contained in electronics textbooks and are always taught to people preparing for electronics technician positions.

The electronics teams listed forty-five different applications of the thirty-eight operations. The results are presented in Table 5. The sources and page numbers are not listed because clear directions were not presented on how to record them and the teams used various approaches in recording the information, so the information could not be consolidated.

Table 4
Electronics—Occupational Math
(Ordered by Frequency Ratings Across Teams)

Cell No.		Grp 1	Grp 2	Grp 3	Avg. Freq.	Priority
	Three Teams Selected the Operation					
1-3	Add Whole Numbers	240	12	149	133.7	1
1-5	Multiply Whole Numbers	240	12	131	127.7	2
3-1	Add Decimals	240	12	120	124.0	3
1-6	Divide Whole Numbers	230	12	112	118.0	4
1-4	Subtract Whole Numbers	240	12	40	97.3	5
3-2	Subtract Decimals	240	12	20	90.7	6
3-5	Multiply a Decimal by a Decimal	140	12	81	77.7	7

Table 4 (cont.)

Cell No.		Grp 1	Grp 2	Grp 3	Avg. Freq.	Priority
3-4	Convert a Fraction to a Decimal	0	12	21	11.0	23
4-4	Convert Decimals to Percents	20	10	0	10.0	24
4-2	Convert Percents to Decimals	20	7	0	9.0	25
4-5	Take the Percent	150	12	63	75.0	8
6-7	Solve Equations with Fractions: Solve for x	160	12	3	58.3	9
6-6	Solve Linear Equations: Solve for x	150	12	3	55.0	10
5-2	Solve the Proportions	140	12	4	52.0	11
4-6	Determine the Percent	110	10	4	41.3	12
3-6	Divide a Decimal by a Decimal	80	12	24	38.7	13
5-3	Conversion	10	12	80	34.0	14
5-1	Express the Ratio in Terms	60	12	4	25.3	15

Two Teams Selected the Operation

Cell No.		Grp 1	Grp 2	Grp 3	Avg. Freq.	Priority
1-7	Round Off	240	12	0	84.0	16
6-5	Transpose Formulas: Solve for r	180	12	0	64.0	17
1-8	Add Signed Numbers	90	6	0	32.0	18
1-9	Subtract Signed Numbers	80	6	0	28.7	19
1-10	Multiply Signed Numbers	80	4	0	28.0	20
6-10	Find the Root	70	12	0	27.3	21

Table 4 (cont.)

Cell No.		Grp 1	Grp 2	Grp 3	Avg. Freq.	Priority
1-11	Divide Signed Numbers	40	4	0	14.7	22
4-1	Convert Percents to Fractions	20	1	0	7.0	26
4-3	Convert Fractions to Percents	20	1	0	7.0	27
	One Team Selected the Operation					
3-3	Convert a Decimal to a Fraction	0	0	40	13.3	28
6-8	Solve Systems of Equations: Graphically	0	12	0	4.0	29
6-9	Solve Systems of Equations: Algebraically	0	12	0	4.0	30
1-1	Convert Words to Arabic Numbers	0	4	0	1.3	31
1-2	Convert Arabic Numbers to Words	0	4	0	1.3	32
6-4	Divide Monomials	0	4	0	1.3	33
6-3	Multiply Monomials	0	3	0	1.0	34
6-1	Add Monomials	0	2	0	0.7	35
6-2	Subtract Monomials	0	2	0	0.7	36
2-1	Order Fractions	0	1	0	0.3	37
2-11	Multiply Mixed Numbers	0	0	1	0.3	38

Table 5

Summary of Electronics OMRA Applications

	Operation Code	Description of Application	Source #.p. #
1	1-3	Calculate Base Current of BJT Calculate Current in a Two Branch Current Calculate for a Voltage Across a Component When Two Supplies Are Used Calculate Input Impedance of an Amplifier Calculate Resistor Wattage Calculate Series and Parallel Inductance Calculate Series and Parallel Resistance Calculate Voltage Slopes Convert #s to Different Bases Expense Report Calculations Fill Out Requisitions and Invoices Pay Calculations Use Kirchoff's Current and Voltage Law Work Order Calculations	No sources listed for pilot (teams used different methods for recording)
2	1-4	Calculate Drain Current of a Junction Field Effect Transistor Calculate Series and Parallel Capacitors Calculate Series and Parallel Inductance Calculate Series and Parallel Resistance Calculate Voltage Collector to Emitter of BJT Calculate Voltage Slopes Reduce Total Resistance of Parallel Circuit	
3	1-5	Calculate Area of Wire Calculate Base Current of BJT Calculate Collector Current of BJT Calculate Current in a Two Branch Circuit Calculate Drain Current of a Junction Field Effect Transistor	

Table 5 (cont.)

	Operation Code	Description of Application	Source #.p. #
3	1-5 (cont.)	Calculate for a Voltage Across a Component When Two Supplies Are Used Calculate Input Impedence of an Amplifier Calculate Power Dissipation of a Transistor Calculate Series and Parallel Capacitors Calculate Series and Parallel Inductance Calculate Voltage Collector to Emitter of BJT Calculate Voltage Drops Expense Report Calculations Fill Out Requisitions and Invoices Pay Calculations Pricing Components Transformer Calculations Use Ohm's Law Work Order Calculations	
5	1-8	Calculate for a Voltage Across a Component When Two Supplies Are Used	
6	1-9	Calculate for a Voltage Across a Component When Two Supplies Are Used	
7	1-11	Calculate for a Voltage Across a Component When Two Supplies Are Used	
8	2-11	Price Components	
9	3-1	Calculate Input Impedance of an Amplifier Expense Report Calculations Fill Out Field Service Reports Fill Out Requisitions and Invoices Fill Out Time Sheets Pay Calculations Work Order Calculations	

Table 5 (cont.)

	Operation Code	Description of Application	Source #.p. #
10	3-2	Calculate Base Current of BJT Calculate Capacitance - Inductance Calculate Current in a Series ckt with a Diode Calculate Drain Current of a Junction Field Effect Transistor Calculate Voltage Collector to Emitter of BJT Calculate Zener Diode Power Fill Out Requisitions and Invoices Work Order Calculations	
11	3-4	Calculate Current Resistance Price Components	
12	3-5	Calculate Capacitance - Inductance Calculate Collector Current of BJT Calculate DC Content of a Half-Wave Rectified Signal Calculate Drain Current of a Junction Field Effect Transistor Calculate Input Impedance of an Amplifier Calculate Power Dissipation of a Transistor Calculate Voltage Collector to Emitter of BJT Calculate Zener Diode Power Expense Report Calculations Fill Out Field Service Reports Fill Out Requisitions and Invoices Pay Calculations Pricing Components Work Order Calculations	
13	3-6	Calculate Base Current of BJT Calculate Capacitance - Inductance Calculate Current in a Series ckt with a Diode Calculate DC Content of a Half-Wave Rectified Signal Calculate Drain Current of a Junction Field Effect Transistor Calculate Frequency and Time of Cycles	

Table 5 (cont.)

	Operation Code	Description of Application	Source #.p. #
13	3-6 (cont.)	Calculate Voltage Gain Price Components	
14	4-5	Fill Out Field Service Reports Fill Out Requisitions and Invoices Work Order Calculations	
15	4-6	Price Components	
16	5-1	Calculate Voltage and Current Ratios Calculate Voltage Drops Across Capacitors Price Components	
17	5-2	Calculate Voltage and Current Ratios Calculate Voltage Drops Across Capacitors Price Components Transformer Calculations	
18	5-3	Calculate Resistor Wattage Deciphering Specs. Fill Out Time Sheets	
19	6-5	Calculate Current in a Two Branch Circuit Calculate Voltage Across Component Calculate Voltage Drops Reduce Total Resistance of Parallel Circuit	
20	8-1	Calculate Resistor Wattage Calculate Stored Energy in a Capacitor Convert #s to Different Bases Truth Table Logic	
21	8-2	Perform Binary Calculation Perform Base Conversion Deciphering ASCII Codes	
22	8-3	Using Nomographs	
23	8-5	Logical Reasoning	

SUMMARY AND CONCLUSIONS

Summary

The lack of adequate math skills for performing on a job has been viewed as a serious barrier to job success. "What types of math skills are required on a particular job?" and "How can we determine if people have those skills?" become important questions with respect to this issue. These questions were addressed by the Computerized Adaptive Assessment of Basic Skills project. This document is the result of the first part of that project. The results of the second part are published separately in a document entitled "Software System for Computerized Assessment of Mathematics Basic Skills." The project, headed by Drs. David J. Weiss and David J. Pucel of the University of Minnesota, was designed to develop methods for determining the occupational math requirements of jobs and for determining the math skills possessed by individuals who may wish to enter those jobs. The tools developed as part of this project can be used to assist in the development of vocational-technical education programs and training programs in business and industry and to assess, as a basis for math skills remediation, the extent to which individuals possess the math skills required for succeeding in a particular occupation.

The first half of the project, headed by Dr. David J. Pucel, developed the Occupational Math Requirements Assessment (OMRA) for assessing occupational math requirements. OMRA is based on principles of performance-based instructional design, which is an integrated system for developing and evaluating instruction. Its aim is to ensure the performance capability of learners (Pucel, 1989). A first stage in the development of such instruction is to identify through occupational or content analysis the content to be taught. The primary focus of such analysis is to identify what people will be expected to do (p. 34). OMRA was designed to analyze the math needed for people to perform in an occupation.

The second half of the project, headed by Dr. David J. Weiss, developed a computer-administered adaptive test battery for assessing the extent to which individuals possess the relevant math skills included in OMRA. The test battery was designed to test individuals entering vocational-technical schools (or other job preparation) in order to identify deficiencies in the basic math skills required for a job as identified using OMRA.

The test uses state-of-the-art computerized adaptive testing procedures to ensure measurements of both high precision and maximum efficiency.

When there is a lack of adequate procedures for identifying the math requirements of jobs and for evaluating the math skills of individuals in relation to those requirements, remediation becomes difficult. Because of this, people often enter employment programs with deficiencies. Employers, in turn, are increasingly recognizing the need to upgrade the basic skills of employees in light of changing workforce requirements. As they attempt to address the math remediation problem, they are also faced with the same questions as educators: "What math is required on the job?" and "How can we assess if individuals have those math skills?" This project was designed to develop systems useful in answering those two questions. The present report addresses the first of the two questions, "What math is required on the job?"

Conclusions and OMRA Modifications

The following are the conclusions and some modifications of OMRA, based on the pilot studies:

1. ***OMRA is usable by occupational instructors and math instructors.***
   Instructors indicated that they were able to follow the directions for and to complete the procedure presented by the OMRA Inventory and the OMRA Applications Supplement. The results of the pilots confirmed the instructors' perceptions.

2. ***OMRA is capable of providing an inventory of the actual math requirements of an occupation.***
   The information provided by both the secretarial teams and the electronics teams was used to generate a prioritized list of math requirements for the occupations using OMRA procedures. (The reader should be aware that the lists developed to test the procedures were developed from a readily available sample of job-related materials. No attempt was made to ensure that the materials represented the total range of possible math applications; therefore, the lists should not be viewed as accurately representing the math skills required of secretaries or electronics technicians.)

3. ***The range of math presented in the OMRA Inventory does cover the basic math requirements of the occupations sampled.***

   This was verified by the project advisory committee and by the fact that all of the math actually contained in the job-related materials did appear on the inventory. Some concern was raised by electronics instructors that electronics technicians would need more math, but there was no evidence to support this in the literature or as a result of the study.

4. ***Occupational instructors were very sensitive to the range of math-related materials that they were asked to review.***

   Although it was clearly stated in the pilot that the materials provided were exemplary, a number of instructors were uncomfortable with the fact that the materials did not represent a full sample of their occupations.

5. ***The amount of the math required to perform successfully on a given job is relatively small.***

   The job-related materials for the secretarial pilot were obtained from secretaries responsible for budgets at the University of Minnesota. The pilot revealed that only seventeen of the sixty-seven math operations listed on the inventory were required. Almost all of them dealt with operations requiring decimal numbers. Three individuals who worked in different firms employing electronics technicians provided sample job-related materials. Only thirty-eight of the sixty-seven math operations contained in OMRA were actually used within the sample materials. As expected, the range of math required for electronic technicians was larger than that for secretaries.

6. ***It is difficult for instructors to limit the range of math taught to that required of an occupation.***

   The electronics instructors were uncomfortable with the fact that the range of math indicated in OMRA did not reflect that of their textbooks. They also felt higher-order math not included on OMRA was necessary in order to learn and understand the occupation. They consistently included math requirements that could not be found in the sample materials. Some also indicated that the math requirements should not be set by industry needs. They felt that instructors knew best.

7. ***OMRA is capable of generating lists of exemplary on-the-job applications of math which can serve as contexts for teaching math.***

   Both the secretarial and the electronics teams felt they could easily identify job applications requiring math within the job-related materials. The majority also felt that these applications would be helpful in providing occupational contexts within which to teach math.

8. ***It was difficult to estimate the absolute frequency of the use of operations per month.***

   A number of teams felt uncomfortable with estimating the absolute number of times an operation was used within an application per month. Therefore, the procedure for indicating the frequency of use of an operation was changed. A rating scale was developed which allows team members to indicate three frequency ranges rather than absolute frequencies.

9. ***It was not possible to generate accurate indications of the sources of each job applications identified in job-related material by the teams.***

   The original OMRA asked each individual team to indicate the source number and page number within each source for each job application on the OMRA Applications Summary. The data that came back could not be summarized because it was not possible to determine how each team referred to a given source. Therefore, the Coordinator Manual was changed to ask the coordinator to number each of the sources before distributing them. This will allow all of the teams to have a common way of referring to each source.

10. ***A prioritized list of math operations and on-the-job applications for an occupation can be generated using the procedures indicated in the OMRA Coordinator Manual.***

    The procedures were used in both the secretarial pilot and the electronics pilot to generate the materials without difficulty.

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APPENDIX A
ACE Kit Math Competency List

Whole Numbers
- 1A. Read, Write, and Count
- 1B. Add and Subtract
- 1C. Multiply and Divide
- 1D. Combination of Function Problems
- 1E. Round Off

Fractions
- 2A. Read and Write
- 2B. Add and Subtract
- 2C. Multiply and Divide
- 2D. Combination of Function Problems

Decimals
- 3A. Read, Write, and Count
- 3B. Add and Subtract
- 3C. Multiply and Divide
- 3D. Round Off
- 3E. Dollars and Cents
- 3F. Combination and Function Problems

Percent
- 4A. Read and Write
- 4B. Percentage Calculation
- 4C. Word Problems

Mixed Operations
- 5A. Equivalents
- 5B. Problems with Mixed Functions with Varied Types of Numbers
- 5C. Ratio
- 5D. Proportion
- 5E. Distance, Time, Rate

Measure, Estimate, Calculate
- 6A. Areas
- 6B. Perimeters
- 6C. Volumes
- 6D. Capacity
- 6E. Weight
- 6F. Distance
- 6G. Time
- 6H. Costs
- 6I. Conversion, English Units

Algebra
- 7A. Symbols and Terminology
- 7B. Directed Numbers
- 7C. Formula Solution
- 7D. One-Variable Open

ACE Kit Math Competency List (cont.)

Sentences

- 7E. Progressions and Series
- 7F. Exponents and Polynomials
- 7G. Special Products

Factoring

- 7H. Radicals, Rational and Irrational Numbers, and Quadratic Equation
- 7I. Graphs
- 7J. Sentences in Two Variables
- 7K. Matrices
- 7L. Permutations and Combinations
- 7M. Probabilities
- 7N. Number Bases
- 7O. Set Theory
- 7P. Group Theory

Measure

- 8A. Read Graduated Scales

Metric Measure

- 9A. Distance
- 9B. Distance Conversion
- 9C. Weight
- 9D. Weight Conversion
- 9E. Capacity
- 9F. Capacity Conversion
- 9G. Temperature Conversion

Drawing and Graphs

- 10A. Read Graphs
- 10B. Draw Graphs

Geometric Figures

- 11A. Forms and Figures
- 11B. Angles
- 11C. Draw/Sketch

Drawings and Graphs

- 12A. Read Scale Drawings
- 12B. Draw to Scale
- 12C. Measure From Scale Drawings
- 12D. Read Assembly Drawings
- 12E. Read Schematic Drawings
- 12F. Shop Drawings

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APPENDIX B

Math and Your Career Competency List

General Mathematics
- Whole Numbers
- Fractions
- Decimals
- Estimation
- Quick Computation
- Rounding
- Averaging
- Other Number Bases
- Ratio/Proportion
- Per Cent
- Statistics
- Statistical Graphing
- English Measurement
- Metric Measurement
- Area/Perimeter
- Volume
- Angle Measurement
- Geometric Concepts
- Pythagorean Theorem
- Square Root
- Exponents
- Scientific Notation
- Probability
- Negative Numbers
- Set Theory
- Ancient Numeration

Algebra I
- Linear Equations
- Linear Inequalities
- Formulas
- Polynomials (Operations)
- Factoring Polynomials
- Rational Expressions
- Co-ordinate Graphing
- Systems of Equations
- Simplifying Radicals
- Quadratic Equations

Geometry
- Induction, Deduction, Logic
- Angles/Perpendiculars
- Parallel Lines/Planes
- Congruent Triangles
- Similar Polygons
- Circles
- Constructions/Loci
- Distance in Plane
- Transformations

Algebra II - Trigonometry
- Linear/Quadratic Functions
- Trigonometric Functions
- Trig. Identities, etc.
- Complex Numbers
- 2nd Degree Equations in 2 Variables
- Systems in 3 Variables
- Exponents/Logarithms
- Polynomial Equations
- Sequences/Series
- Permutations/Combinations
- Vectors
- Matrices/Determinants

Other
- Use of the Calculator
- Computer Operations
- Computer Programming
- Higher Mathematics

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APPENDIX C
Generic Mathematics Competency List

Arithmetic

- Whole Numbers
- Fractions
- Decimals
- Percent
- Ratio/Proportion
- Mixed Operations
- Measure: Time
  - Weight
  - Distance
  - Capacity

Geometric Figures

- Calculate: Perimeter
  - Area
  - Volume
- Draw/Sketch
- Read: Scale Drawings
  - Assembly Drawings
  - Schematic Drawings
  - Graphs
- Draw: Graphs
  - Scale Drawings

Intermediate Mathematics

- Solve Given Formulae
  1. Variable Algebra
     Algebra Powers/Roots
  2. Variable Algebra
     Quadratics
     Logarithms
     Trigonometry

Generic Mathematics Competency List (cont.)

CORE CLUSTERS

Mathematics

1. Read, write, and count whole numbers.
2. Add and subtract whole numbers.
3. Multiply and divide whole numbers.
4. Solve word problems with whole numbers.
5. Round off whole numbers.
6. Read and write fractions.
7. Add and subtract fractions.
8. Multiply and divide fractions.
9. Solve word problems with fractions.
10. Compute dollars and cents.
11. Read, write, and round off decimals.
12. Multiply and divide decimals.
13. Add and subtract decimals.
14. Solve word problems with decimals.
15. Read and write percents.
16. Compute percentage.
17. Determine equivalents.
18. Know order of operations.
19. Solve word problems (mixed operations).
20. Do quick calculations.
21. Compute averages.
22. Read graduated scales.
23. Perform operations with time.
24. Operate calculator.

NONCORE SKILLS

Mathematics

25. Compute ratios.
26. Compute proportions.
27. Compute rate.
28. Compute principal.
29. Measure weight.
30. Measure distance.
31. Measure capacity.
32. Know geometric forms and figures.
33. Computation on angles.
34. Draw/sketch geometric forms and figures.
35. Compute perimeters.
36. Compute areas.
37. Compute volumes.
38. Read graphs.
39. Read scale drawings.
40. Read assembly drawings.
41. Read schematic drawings.
42. Draw graphs.
43. Measure from scale drawings.
44. Draw to scale.
45. Solve algebraic formulas.

Smith, A. D. W. (1979). *Generic skills. Keys to job performance.* Ottawa, Ontario: Canadian Commission of Employment and Immigration. (ERIC Document Reproduction Service No. ED 220 578)

APPENDIX D
Canadian Valley Math Competency List

Calculators
Fractions, Decimals, Percents
Basic Arithmetic Operations
Data
Graphs, Charts, Tables
Estimating Solutions
Problem Solving
English/Metric Measurement
Lines & Angles
2 Dimensional Shapes
3 Dimensional Shapes
Ratios & Proportions
Scale Drawings
Signed Numbers & Vectors
Scientific Notations
Precision, Accuracy, Tolerance
Uses of Powers & Roots
Formulas for Applied Problems
Applied Linear Equations
Applied Non Linear Equations
Graphing Data
Working with Statistics
Working with Probabilities
Right Triangle Relationships
Trigonometric Functions

Shelby, S., & Johnson, J. (1988). Tying it all together. *Vocational Education Journal, 63*(2), 27-29.